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Maintenance Mentor

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NOTICES

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FOR THE COMMANDER

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Maintenance Mentor (MXM) is a research effort conducted by a joint AFRL/HESR and Northrop Grumman Information Technology team to identify the basic, high-level requirements necessary for improving flightline diagnostic capabilities. The effort was initially focused on identifying specific informational and visual requirements and needs of the maintainer for a specific avionics diagnostics task on a specific aircraft. Soon after its start, however, redirection of the project began to move it from a single task approach to one of documenting the basic flightline troubleshooting and maintenance process and identifying the requirements that, if satisfied, could significantly enhance the maintainers' efficiency and effectiveness in turning aircraft mission-capable much faster than is currently possible. With the redirection of the project, the initial predisposition to emphasize a single weapon system approach that might later be broadened evolved into a higher-level, multi-weapon system view. This program was felt to be particularly timely since statistics clearly show that most aircraft fix rates have not markedly improved in recent years and many have declined. Although this is certainly a multi-faceted problem, it is apparent that one element of the solution is that the maintainer's ability to troubleshoot and diagnose problems requires enhancement. The MXM research is aimed at helping bring that about.

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PREFACE

The research documented in this technical report for the Maintenance Mentor program sponsored by the Air Force Research Laboratory, Human Effectiveness Directorate, Logistics Readiness Branch, Wright-Patterson AFB, OH. Northrop Grumman Information Technology performed the work under Delivery Order #24 of the Technology for Readiness and Sustainment (TRS) contract F33615-99-D-6001. Capt. David A. Lemery (AFRL/HESR) was the program manager for the effort.

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1 Executive Summary

1.1 Introduction

Maintenance Mentor (MXM) is a research effort conducted by a joint AFRL/HESR and Northrop Grumman Information Technology team (referred to throughout this report simply as "the team" or "the research team") to identify the basic, high-level requirements necessary for a follow-on research and development program aimed at improving flightline diagnostic capabilities. The effort was initially focused on identifying specific informational and visual requirements and needs of the maintainer for a specific avionics diagnostics task on a specific aircraft. Soon after its start, however, redirection of the project began to move it from a single task approach to one of documenting the basic flightline troubleshooting and maintenance process and identifying the requirements that, if satisfied, could significantly enhance the maintainers' efficiency and effectiveness in turning aircraft mission-capable much faster than is currently possible. With the redirection of the project, the initial predisposition to emphasize a single weapon system approach that might later be broadened evolved into a higher-level, multi-weapon system view. This program was felt to be particularly timely since statistics clearly show that most aircraft fix rates have not markedly improved in recent years and many have declined. Although this is certainly a multi-faceted problem, it is apparent that one element of the solution is that the maintainer's ability to troubleshoot and diagnose problems requires enhancement. The MXM research is aimed at helping bring that about.

1.2 System Identification

One of the very early phases of the MXM effort was System Identification. Simply stated, System Identification was a basic process through which the team sought to identify a target weapon system (aircraft) and a target subsystem upon which to focus their research. Because of re-direction of the project, it was decided that selections for target weapons systems and subsystems would be conducted in parallel to provide maximum flexibility despite the direction the program later took.

It was decided that the A-10, B-1, B-52, F-15, F-16, KC-135, C-130, C-5 and C-17 weapon systems would be considered. For a number of reasons detailed in the report, low density, high demand systems (i.e., F-117, B-2, Rivet Joint, AWACS, Joint Stars, Special Operations) and pure training systems such as the T-1, T-37, and T-38 were not considered. Likewise, developmental systems such as the F/A-22, F-35, and CV-22 were not considered in the assessment.

AFRL/HESR set out to gather the maintenance data that would be analyzed to support System Identification. They successfully collected most of the Air Combat Command (ACC) data that was needed but getting Air Mobility Command (AMC) proved more difficult and resulted in only some basic information becoming available. In the interest of time, the team decided to move forward without going after additional information.

The team devised some basic guidelines to provide structure for the decision process. Those guidelines are listed below:

- High Maintenance Man-hour Consumer
- Probability of Data Availability
- Probability of Access for Data Gathering/Knowledge Acquisition
- Potential for SPO Support
- Ease of Interfacing with the Aircraft
- Potential for Major Command (MAJCOM) Support
- Longevity/Potential Payback
- Other Programs On-going

Scores ranging from 1 to 5 were assessed by the team to denote the relative ease (1) or the (5) difficulty in dealing with the area covered by the appropriate guideline. Under "High Maintenance Man-hour Consumer," for example, if an aircraft was considered to be a very high consumer of maintenance time according to the various statistics and inputs the team had available to them a score of 5 was assessed. A very low consumer received a 1, while scores between the two extremes were assessed based on the information available. Although a numeric score was not given for "Other Programs On-going," if the team was aware of other programs that might conflict with the MXM effort or compete with it or a potential 6.3 follow-on program for support that fact was noted.

The F-15, F-16, KC-135, C-130, and C-5 were the top five weapons systems based on the scores attained. The team decided to focus on the F-15 and/or F-16 and the C-130 and/or KC-135.

Subsystem selection was done in much the same way as the weapon system selection. ACC data on the A-10, B-1, B-52, F-15, F-16, and EC/HC-130 data was used and assessments were made of the primary subsystems listed below in each of those aircraft.

- Fuel
- Hydraulic

- Propulsion
- Landing Gear
- Flight Controls
- Radar
- Electronic Countermeasures
- Electrical

Each of the subsystems on the aircraft in question was evaluated using the guidelines listed below.

- Top Five Man-hour Consumer
- Ease of Troubleshooting
- Relevance to the MXM Project
- Potential Integration Challenges
- Potential Improvement for Maintainers

As in weapon system selection scores ranging from 1 through 5 were assessed with the exception of "Top Five Man-hour Consumer." In this case, if the subsystem had been one of the top five maintenance man-hour consumers over the past year a score of 5 was awarded. If it had not been, a score of 1 was given. This is the only category in which no intermediate scores were used and it was also the only category in which the score was purely objective.

Table 2 in the report shows that flight controls, propulsion, fuel, landing gear, and electrical garnered the highest scores. Flight controls was the subsystem on which the team ultimately decided to center the MXM research. That decision was made not only because flight controls attained the highest overall score across all weapons systems and was also a high scorer in the F-15, F-16 and C-130 target weapon systems, but for a number of other reasons as well, all of which are spelled out in the report.

1.3 Requirements Definition

This project phase, consisting of three interrelated tasks, addressed maintainers' flightline work in light of required data and information. These three tasks - *Knowledge Acquisition (KA), Cognitive Task Analysis (CTA),* and *Information Resources Analysis (IRA)* - were conducted with a scope of reference modified from that originally planned. Starting at the kickoff, AFRL/HESR raised the issue of expanding the scope of research to address multiple aircraft so as to obtain results more generally applicable and informative than details on one aircraft and one weapon system. After discussions among all parties, the MXM team agreed on a new scope based on three criteria: First, the scope of system/subsystem concern would be a general class of apparatus applicable to a wide variety of operational USAF aircraft. Second, this scope of concern was agreed to be flight controls. A reasonable range of operational USAF aircraft would be reviewed with respect to flight control maintenance issues. Third, the MXM team agreed to achieve this breadth of range by reviewing both small aircraft (i.e., fighters) and large aircraft (airlift aircraft in this case).

Knowledge Acquisition (KA) is the process of obtaining task-related knowledge from subject matter experts (SMEs) and other information resources. In this case, the team sought data on the cognitive and informational aspects of maintenance functions for the population of aircraft surveyed. The KA plan was tailored to emphasize topics common across the set of aircraft and maintainers. To achieve this breadth the team conducted detailed data gathering and interviews with a set of maintainer SMEs reflecting a reasonable sample of different aircraft and aircraft types.

Planning the KA effort required considerable thought and discussion. Site access was a problem due to Operation Enduring Freedom (OEF), Operation Iraqi Freedom (OIF), and ongoing Homeland Defense commitments. It was concluded the most constructive and feasible course of action would be a two-phase KA itinerary. The first phase would address fighter aircraft. Nellis AFB, Nevada was identified as a lucrative KA site for a variety of fighter aircraft including A-10s, F-15Cs, F-15Es, and F-16C/Ds, as well as the F/A-22 and RQ-1. The second phase would address an airlift aircraft. It was decided that a visit to Charleston AFB, SC for KA on the C-17 was the best feasible option. A four-person KA team executed this itinerary during April 2003.

The multi-aircraft scope required adjustments to the KA tactics. The most commonly used on-site KA tactics include structured interviews with SMEs, observations of target tasks being accomplished, and task simulations. The shift to a more general scope induced several new or newly-prioritized criteria for choosing the specific KA tactics. Emphasis was placed on maximizing on-site time while minimizing digressions into data too fine-grained for the scope of the effort. In addition, the team had to maximize the "generalizability" of the data acquired on task processes, information requirements, and the tools and support aids employed in the maintenance work.

Proactive SME review of 'straw man' materials (as contrasted with passive free-form questioning) was given priority in order to accelerate model formation for process and information needs. The target SME population was expanded to include technical support and other relevant personnel to get a better overview of the maintenance environment. A KA plan was then developed to serve as a structured guide for the team.

The KA plan used a four phase "cascade" approach to exploring maintenance process and associated task elements. First, a general model of the maintenance process flow (from problem notification through to returning the aircraft to duty) was elicited, refined, and validated with subsequent SMEs. Second, this model was leveraged as the framework for eliciting and collating comments on procedures, practices, and problems related to each. Third, this model (and the data on procedural matters) was then used as the framework for polling SMEs on what data or information they needed or expected to employ at each stage of the process path and with regard to the procedural issues. In the fourth phase of this exploration, the team visited selected support sections to review flight control tools and instruments and to gather data on the tools and their usage.

A meeting room was made available to the KA team at both sites, and all SME interviews were conducted there in accordance with an agenda prepared by host unit representatives. Each scheduled session typically afforded at least 90 minutes with each SME group. Sessions began with the team introducing themselves, the MXM project, and the session objectives. A lead interviewer facilitated each session, with the other team members participating as circumstances warranted. The set of key issues assembled prior to the KA visits was used as the basis for the interviews. Significant points arising in earlier interviews were fed forward as talking points in subsequent sessions.

The team began the first phase exploration of the maintenance process path by presenting a straw man sequence of steps for a representative flight control maintenance process. The SMEs were then asked for their opinions and invited to make any comments or corrections they thought would make it more accurate. Once this review and modification cycle was completed, the revised model (depicted in Figure 1 in the report) was reviewed and validated by subsequent SME groups. The model was effectively validated with the first session on the first day, which allowed it to be leveraged for the other KA goals at a very early point. The final process path model breaks out into eight primary steps or phases as follows:

- Problem identification/reporting
- Front-end unit coordination (to get the aircraft into the maintenance process)
- Maintenance setup/preparation
- Troubleshooting cycle (subsuming testing, diagnosis, prognosis, repair actions, and testing/evaluation to the point the work is deemed complete)
- Solution reporting/documentation

- Solution validation/verification and process completion decision
- Maintenance stand-down/cleanup
- Back-end unit coordination (to get the aircraft back to duty)

The process path represents the entire end-to-end progression for a typical maintenance cycle, the completion and documentation of which is captured in aggregate performance statistics. The KA team discovered a substantial proportion of apparent flight control discrepancies that were resolved without going through this process path or being documented. This means that maintainer time and effort is expended on diagnosis and problem solving that is not reflected in the maintenance statistics. This issue arose in the very first KA session, and it was added as a talking point for subsequent interviews. Up to 50% of the flight control discrepancies in some aircraft were said to fall into this "no fix" category owing to several factors. For example, this situation was sometimes attributed to "switchology" (incorrect control, switch, or knob settings) or to resetting some component of the flight control (sub)system or an associated (sub)system. In other cases, reported flight control discrepancies could not be duplicated or could be readily explained by incorrect pilot actions.

Rapidly arriving at a consensus process path model allowed the team to correlate information requirements with process path steps early in the KA effort. The approach was to step the SMEs through the acknowledged process path map and probe at each step for the key issues they needed to resolve to accomplish that step. Section 4.1.6 of the report includes a summary listing of the most commonly cited information requirements for each step in the flight control maintenance process path.

Several issues and concerns regarding current flight control maintenance information resources arose during the interview sessions. The maintainer SMEs consistently made reference to problems with operational reference aids (e.g., manuals, checklists, TOs). For example, the SMEs cited differences between pilot checklists and maintenance TOs as sources of some of the "no fix" situations mentioned earlier. The team paid particular attention to the availability, utility, and sufficiency of diagnostic decision aids. Although much time was spent probing for data on deficiencies in the diagnostic aids, the SMEs offered relatively few complaints on the aids themselves. In general, they emphasized the advantages of having aids that are employed along with built-in test (BIT) code data, which greatly expedites diagnosis. Both paper fault isolation guides (FIs) and available electronic diagnostic aids have been found to contain deficiencies, gaps, and even some errors. The lack of feedback and the slow revision process for TOs and FIs were recurrently cited as problems.

Interestingly, those maintainer groups with equivalent access to both paper and electronic fault diagnosis aids indicated a general preference for the paper materials. This preference derived in part from the problems unique to the electronic aids. Because electronic aids require laptops (or similar devices) on which to run applications, access to the aid depends on availability and serviceability of these platforms. Maintenance work is often two-handed work. This means that maintainers must set a laptop somewhere and then go back and forth between manual actions on the aircraft and manual interactions with the laptop. At the very least, much head turning is required to address both the aircraft and the laptop. This divides attention and consumes time.

The legibility of laptop-based aids varies with circumstances and often diminishes usability. For example, severe glare off the display screen under certain lighting conditions, especially direct sunlight, makes it unreadable. Another problem is the usage of small fonts making it difficult to read text information or diagram captions. Reading such small fonts requires the user to get close to the display (further increasing the probability he/she cannot use the aid while working directly on the aircraft). The procedural and interface structure of the laptop-based diagnostic aids is such that it can be slower to navigate through the fault tree on the laptop than using a reference card. In other words, the laptop-based aids may prove to be cumbersome logically as well as physically. Version discrepancies among software-based reference and diagnostic aids are also a persistent irritant.

These types of problems explain the SMEs' lack of optimism for electronic documentation aiding. Most documentation is still done by hand with paper, such as AFTO Form 781A entries, logbook entries, and notes on clipboards. This documentation is generated in the course of the maintenance process in the actual maintenance setting. As a result, using a computer for these documentation functions is subject to the same usability problems noted for computer-based diagnostic aids. When asked if they saw any potential for improved support by computerizing incidental documentation, the SMEs consistently answered in the negative.

The SMEs were also asked about their tools and instruments. Surprising, the frequency and criticality of such problems surpassed those reported for the diagnostic guides. Maintainers do not have much confidence in some of their test equipment. Much of this equipment is old and/or dysfunctional, and some of the newer equipment is less usable or robust than the older alternatives.

A surprising equipment issue was the extent to which connectors and connections (as contrasted with the components being connected) cause headaches for maintainers. Many problems center on connections between aerospace ground equipment (AGE), such as hydraulic mules, and the aircraft. In addition, problems with cables and connectors can affect test readings and mislead troubleshooters (at the cost of time and effort). For example, the TT-205 tester connection set ("hose kit") is the most common obstacle to using the tester, and the lack of compatible connectors is a major reason why the TT-205 is not used on the F-16.

The notion of "expertise" is important in undertaking task-specific cognitive and information requirement analyses. It is important to identify what features are associated with attributed expertise in a given task. The SMEs provided several features characteristic of expert maintainer performance.

It was learned that a variety of distinctions between experts and novices not only affect the quality and course of the maintenance process, but also affect the readiness with which other parties accept their diagnoses. Novices tend to scrupulously follow the procedures step-by-step and rely exclusively on the technical order (TO) and BIT as the entirety of their diagnostic approach (as opposed to digging into the fault via exploratory troubleshooting). Experts are more proficient about relating symptoms to states or features of the physical aircraft than novices—a capability repeatedly described as reflecting experts' better knowledge of how the aircraft and its constituent subsystems actually work. Maintainers, technical support staff, and trainers agreed that novices are more reluctant to initiate free form exploratory troubleshooting when the available diagnostic procedures fail to pinpoint the fault. This makes novices quicker and more amenable to stopping the maintenance process and "making the call" (invoking external technical support) once the cookbook procedure bogs down.

This naturally leads to the subject of training. The team made a point to interview trainers, and training was cited repeatedly in the other SME sessions. Much of the discussion on training improvements mirrored the types of points made with respect to perceived differences between novice and expert maintainer capabilities.

In each interview session, SMEs were asked what type(s) of data or information would most improve their ability to perform flight control maintenance. Throughout all the interview sessions, the #1 item on the SME "wish list" was better information on what was happening in flight when a flight control issue occurred.

The #2 recommendation from the SMEs was better capability to simulate in-flight conditions on the ground. Yet another information need concerns knowledge that is available, but not effectively captured and disseminated. In spite of the generally voluminous "official" data found in the TOs, there is much relevant and useful information that can only be obtained from maintenance experience with a particular aircraft. Such information includes tips, tricks of the trade, and illustrative "lore" derived from experience. The SMEs uniformly cited the value of the unit logbooks as information resources; however, there are no effective channels for general discussion and note-sharing (e.g., chat rooms; bulletin boards, ListServ forums).

The KA visits to Nellis and Charleston went very well, and the team obtained considerable data in a relatively short length of time. The attention to generating a KA plan in advance of the trips allowed the team to coordinate its effort and to make maximum use of on-site time. The "cascade approach" to incrementally fleshing out team understanding of flight control maintenance atop the initial process path map allowed the team to remain focused throughout the KA effort. Attention to gathering data on auxiliary units of the maintenance organization (i.e., test stations and support sections) enabled the team to understand the core maintenance process in a wider context. The data presented above represents only a portion of what was obtained. However, even if this were all that was gathered on the two KA trips, the outcome would still have to be considered a solid success.

Cognitive Task Analysis (CTA) concerns the examination and critical analysis of a work activity or process with regard to the cognitive aspects of work. Basically, this means analyzing the "mental work" associated with a given task in the same way that older methodologies analyzed that task's "physical work." A task's "cognitive aspects" commonly include:

- The perceptual acquisition of data in the course of a task
- The data and information elements critical to conducting the given task
- Mental models a worker employs for the task process itself and the subject matter he/she must address during the task
- The decisions that must be made to complete the task
- The critical dimensions of decisions made in the task (e.g., critical data, time to decide, confounding factors, mode of inference, means for testing alternatives)
- The degree of "cognitive workload" or "cognitive burden" entailed in performing the task
- Cognitive and informational factors which can induce errors and other degradations in task performance (e.g., data deficiencies, data overload)

The MXM effort was geared to explore the relationships between maintainer information processes and their maintenance tasks. The majority of the points cited in the section on KA relate to data, information resources, and process. Applying all this information to the maintenance task requires stating what it is about task performance one is seeking to analyze. In the course of the KA work the team obtained summary statistics on USAF maintenance performance. A set of tabular compilations of such data (for fighter aircraft) is offered in Appendix I. A more concise summary table of performance statistics for four categories of fighter aircraft covered in the KA work is given in Table 6.

There are a number of points in this data. In absolute terms, 4- and 8-hour fix rate performance has degraded for all aircraft over the 10-year period. With the exception of the A-10, performance results fall short of established standards for the 10-year period as a whole. There was no clear pattern to the summary outcomes with respect to average performance (relative to standard) over the 10-year period.

Because these particular statistics are framed with regard to time, it is reasonable to characterize the evaluation context as temporal. The fact that the 4-hour rate performance has degraded more than the 8-hour rate performance is consistent with a situation in which the maintenance process is taking longer and longer to effectively complete. Time to completion is the one general criterion that can be interpreted to subsume negative effects resulting from a variety of possible sources, such as errors and grappling with ambiguity. Given its generality and its prominence in the available data, it is therefore reasonable to adopt temporal maintenance process performance as the general dimension for framing the analysis of the maintenance process.

The crux of the CTA effort was to identify a model or schema for coherently laying out the flight control maintenance process path. The model or framework judged most amenable to MXM purposes was the *OODA Loop* of Col. John R. Boyd (Boyd, 1987). The OODA Loop is a cyclical interrelating process path leading from perception of situational data through decision making and on to resultant action. An OODA Loop affords a scope of referential context identical to that of MXM (maintainers perceiving data and making decisions for ongoing maintenance actions). This permits one to proceed without decomposing the subject process into multiple and potentially irreconcilable sub-models.

The mapping of the maintenance process path onto an OODA representation is presented in the form of 11 tables in Section 4.2.5. Each of the tables provides a cursory enumeration of elements associated with each of the four OODA steps. For the "Observe" step, these will be elements (e.g., data, situations) that must be perceived. For the "Orient" step, these will be elements for which maintainers must achieve situational awareness. For the "Decide" step, these will be the issues or topics for which decisions must be made. Finally, for the "Act" step, these will be the typical actions (or courses of action) deriving from that phase's "Decide" step. As applicable, the tables also include a listing of the potential "leaps" (process path jumps other than simply moving forward to the next step) that might occur.

In addition, an inventory of the most significant cognitive performance issues identified from the SME sessions was compiled, and several pages in Section 4.2.6 are dedicated to a detailed discussion of them. Those issues include: complexity in the flight control maintenance decision space; criticality of up-front information; criticality of simulating or reproducing the perceived problem; fault sources unaccounted for in available diagnostic aid representations; progressive deskilling in the maintainer population; and value of experiential knowledge.

Information Requirements Analysis (IRA) is the examination and analysis of a work activity or process with regard to the information set required to perform a task, the set of data and information available during the task, the differences between these two sets, and the implications of these differences on task support.

One of the most salient characteristics of the maintenance process is that it is collaborative; that is, it involves multiple players jointly working to diagnose and repair the reported fault. It is not the case that all possible players participate in all reported cases. Some sources of data and expert knowledge participate only if invoked by the front line maintainers. This constitutes a discretionary 'reachback' for relevant information as circumstances warrant. Although the precise details vary from aircraft to aircraft, the SMEs outlined three representative steps in a progression of information reachback. The first is to on-base technical support personnel, such as Air Force Engineering and Technical Service (AFETS) personnel and forward-deployed contractors. The second is to remote (off-base) technical expertise accessible via telecommunications (e.g., hot line). The third is to technical expertise accessible by calling on personnel at the relevant depot. Each of these reachback assets possesses technical data resources exceeding the scope and/or depth of those available on the flightline. The general form of this reachback progression is illustrated in Figure 3.

With regard to maintenance performance, the key point is that each information reachback action serves as a drag on the maintainer's ability to resolve the reported maintenance problem within a given timeframe. Reachback degrades temporal performance metrics for a number of reasons. For one thing, setting aside the maintenance activity to call in outside help may involve practical actions (e.g., parking, putting away tools, etc.) that either consume time or mandate time consumption for getting back on task. Time is consumed in making effective contact with the next reachback resource and in relating the maintenance problem and the action taken so far to the reachback resource. Where personal contact on-site is needed, there will be time consumed in coordinating such consultations and there may be redundant time consumption for briefing the technical support staff once they arrive.

The primary information needs identified for flight control maintenance are:

- Detailed and comprehensive description of the perceived problem as it was encountered during flight (the SMEs' #1 wish list item)
- Access to experiential knowledge to fill in the gaps in the formal information base
- Capture and dissemination of experiential knowledge to help bring less experienced maintainers up to more expert levels of performance
- Dissemination of experiential knowledge across maintenance units to minimize the need to "reinvent the wheel" in developing tips and tricks of the trade
- Attention to real-world operational context in training materials and courses
- Better background technical knowledge for incoming trainees
- Better knowledge of an aircraft's inner workings to provide less experienced maintainers with a foundation for analyzing the data their reference and diagnostic aids provide them

The SME groups clearly and uniformly cited better situation awareness on in-flight fault context as their #1 desired improvement. Modern military aircraft are complex systems. As a result, the decision space for diagnosis is complex. Any and all clues available up front allow the maintainer(s) to more expeditiously vector in on a likely diagnosis and proceed toward resolution or repair. The most straightforward approach to maximizing such up-front SA is to capture and record as much in-flight data as possible. The maintainers who seemed most content with their current or prospective in-flight data access were those working with the C-17, RQ-1, and the F/A-22—all of whom enjoy significant access to in-flight data.

Multiple SMEs involved with the older fighters touted the utility of data "snapshots" (pilot-triggered recordings of selected system data). For example, the A-10 SMEs claimed their snapshot access was a big help in analyzing reported problems, and the F-15E maintainers were happy that a snapshot capability was finally being made available on their aircraft. Many of the snapshot capabilities have to be actively triggered by the pilot, who may be preoccupied at the point a flight control anomaly occurs. The ultimate solution is, of course, to dynamically record as full a record of in-flight data as the available hardware permits. Though not cheap in absolute terms, it would seem proportionally cost-effective to consider adding a more comprehensive onboard data capture and recording capability to these older aircraft.

One alternative aiding strategy might be to evaluate the relative incidence of candidate fault conditions and provide a statistical basis for "playing the odds" when initially hypothesizing what a given fault may be. However, good information up front is more likely to improve overall process path performance than advice on the odds of it turning out to be this or that based on prior cases. In any case the prospects for compiling sufficiently accurate statistical data are diminished so long as the present proportion of discrepancies continue to go unreported.

Everyone felt a need for better capture and dissemination of experiential knowledge, but just as uniformly noted that there are few if any mechanisms in place for capturing such knowledge and even fewer channels for disseminating it. There are two straightforward innovation paths that would reasonably address this deficiency:

- Improve capture and collation of logbook entries
- Provide effective channels for disseminating access to capture experiential knowledge

The prospects for addressing novice deficiencies in background knowledge fall outside this project's purview. Because the general and aircraft-specific technical knowledge deficiencies are clearly subjects to be addressed with training, they lie outside the scope of the central focus of this research—the maintenance process itself.

1.4 Technology Search

A general search was performed to determine what tools were available or in production that might potentially suit the stated needs of flightline maintainers. The initial 1360 "hits," most of which were eliminated almost immediately, were ultimately reduced to 29 that were included even if there was a remote possibility of a match. A technical review identified five that appeared to meet some requirements; however, it should be noted that the information obtained was gathered from marketing material. The requirements against which the technologies in this research were validated are high level and thus extremely general. On the other hand, Commercial-Off-The-Shelf (COTS) products are generally designed to meet a specific need within a specific set of business processes and a standard operational environment. The focus of these products is typically quite narrow and well defined.

MXM covers a very broad scope of requirements and the solution must function within a set of unique processes and run on a variety of machines with interaction to many outside sources. It must do all this reliably in a wide range of operational environments where even minor "glitches" may often be out of the question. It is unlikely that any COTS product will meet the MXM requirement. Thus, the research team recommended that a custom development effort be initiated.

To provide high level system requirements needed to facilitate a broad search for potential tools the MXM Team hosted a Decision Criteria Development Workshop 30-31 July 2003.
In that two-day period the team facilitated the attendee group through a structured process that resulted in the development of five decision models (see Table 25) that identify the basic high level requirements for a potential MXM solution system. A set of associated requirements and criteria were developed for each model. Table 31 depicts the combined prioritized requirements. It should be emphasized that these are quite general, but could be a starting point from which a specific set of definitized requirements could ultimately be developed, and in turn a system could be built.

2 Introduction

2.1 Scope

This effort was focused on performing research to aid AFRL/HESR in identifying the basic, high-level requirements necessary for a follow-on research and development program aimed at improving flightline diagnostic capabilities. The project was initially aimed at identifying specific informational and visual requirements and needs of the maintainer for a specific avionics diagnostics task. Shortly after it began, however, AFRL/HESR redirected the effort to emphasize a much broader, higher-level approach. Focus shifted from a single task approach to one of documenting the basic flightline troubleshooting and maintenance process and identifying the requirements that, if satisfied, could significantly enhance the maintainers' efficiency and effectiveness in turning aircraft mission-capable much faster than is currently possible. With the redirection of the project, the initial predisposition to emphasize a single weapon system approach that might later be broadened evolved into a higher-level, multi-weapon system view. There was little doubt that this much broader look at the problem would provide the baseline information for a follow-on program that would have wider applicability and probably garner more widespread support in the maintainer community than any single task or single system approach.

2.2 Background

With the Aerospace Expeditionary Force (AEF) concept now a basic tenet of Air Force doctrine, units are expected to deploy far more quickly and go to far more austere locations than was the case only a few years ago. In addition, those units are expected to deploy with only the basic maintenance support necessary to initiate operations upon arrival. Given this reality, the need for the maintainers who deploy under these conditions to be as capable and effective as possible is taking on a whole new significance.

Despite the fact that USAF aircraft are typically more reliable and easier to work on than their predecessors, maintainers are still faced with considerable challenges. Aging aircraft, longer supply lines, Two-level Maintenance, declining manning, austere budgets, consistently high operations tempo, and a long list of other challenges have combined in recent years to make it difficult for maintainers to meet the demands placed upon them. If one assumes that these conditions are a blueprint for the future, and every indication suggests they are, then it stands to reason that the maintainer's job will only get more difficult unless something substantive is done to enhance their capability to produce mission-capable aircraft.

The F/A-22 Program promises major improvements in the ability of its maintainers to keep that aircraft flying and the autonomic logistics system for the F-35 will include additional capability enhancements. That is certainly good news, but neither of those aircraft will be available in numbers for a decade or more. At the same time, over half of the aircraft that will comprise the Air Force fifteen years hence are on the flightlines today. That fact cannot be ignored.

As will be discussed later in this report, statistics clearly show that despite longer hours on the flightline for the maintainers and some budget relief that has improved the spare parts situation somewhat, most aircraft fix rates have not markedly improved in recent years and many have declined. Although this is certainly a multi-faceted problem, it is apparent that one element of the solution is that the maintainer's ability to troubleshoot and diagnose problems requires enhancement. The Maintenance Mentor (MXM) research is aimed at helping bring that about.

3 System Identification

Because previous AFRL/HESR programs such as Integrated Maintenance Information System (IMIS) and Predictive Failures and Advanced Diagnostics (PFAD) were essentially built around the F-16 and/or its radar, the notion that the MXM research would also be focused on the F-16 and its radar was essentially a given. However, with the broader, higher-level look the project had taken on this approach had to be modified. To ensure maximum flexibility as the project moved forward, the team decided that parallel selections of target weapons systems and subsystems would be conducted. AFRL/HESR then set out to gather the maintenance data that would be analyzed to identify potential weapon systems and subsystems upon which to focus the research. Although most of the necessary data for Air Combat Command (ACC) weapons systems was ultimately acquired, problems were experienced in gathering Air Mobility Command (AMC) aircraft data that resulted in only some basic information being available. In the interest of time, the decision was made to move forward with weapon system selections without going after additional information.

3.1 Weapon System Selection

As a baseline from which to move forward, the team devised a set of basic guidelines to provide some structure for the weapon system decision process. Those guidelines are listed below:

- High Maintenance Man-hour Consumer
- Probability of Data Availability
- Probability of Access for Data Gathering/Knowledge Acquisition (KA)
- Potential for SPO Support
- Ease of Interfacing with the Aircraft
- Potential for Major Command (MAJCOM) Support
- Longevity/Potential Payback
- Other Programs On-going

No attempt was made to prioritize the guidelines and none was necessarily considered more or less important than the others. Although that could probably have been done and, in addition, other guidelines might have been devised, it was determined that available research time could be better spent on other facets of the effort.

3.1.1 High Maintenance Man-hour Consumer

From the beginning the team decided that the research would be focused as much as possible on weapon systems that consumed significant maintenance man-hours because those are the ones that typically provide maintainers the most challenges and generate the most headaches for both their leaders and the headquarters for whom they work. It was obvious that no program would be supported if it were not attacking a recognized problem and the team felt that man-hour consumption was a key indicator of potential problems. A score of 1 denotes a weapon system that is not a high maintenance man-hour consumer while those that were rated a 5. A weapon system was assessed to be a high maintenance man-hour consumer according to command standards or headquarters input.

3.1.2 Probability of Data Availability

Because the success of any research effort will be affected by the ability of the research team to get required data, a subjective assessment of how likely it was that data could be acquired was included as one of the guidelines. If data for a weapon system could be acquired rather easily, that particular weapon system would receive a score of 5. If on the other hand it was unlikely that the team could get the needed data, then that weapon system was given a score of 1. Scores between 1 and 5 were assigned to denote varying degrees of potential data availability.

3.1.3 Probability of Access for Data Gathering/Knowledge Acquisition

The team then made an assessment of how likely it would be that access would be granted to units with a specific weapon system for data gathering and KA purposes. A score of 5 meant that access was highly likely, while 1 meant it was unlikely. Scores between 1 and 5 indicated a likelihood of access between the two extremes.

3.1.4 Potential for SPO Support

This was an assessment of how supportive of a follow-on MXM 6.3 effort a particular weapon system program office (SPO) might be. SPO support could prove to be vital to success of any future effort so the team felt it should be considered up front. A high probability of support rated a score of 5 with scores down through 1 indicating less and less likelihood of active support.

3.1.5 Ease of Interfacing with the Aircraft

It was apparent to the team that the 6.3 follow-on effort for which the MXM research would be the groundwork would require drawing information from an aircraft at some point. The ease with which this could be done was assessed by scores ranging from 1 (very difficult) to 5 (very easy).

3.1.6 Potential for MAJCOM Support

As in the other guidelines, this was the team's professional assessment of the likelihood of active MAJCOM support for the MXM research and a follow-on effort. High potential for active support rated a score of 5 while low potential was rated 1, with varying degrees of potential in between.

3.1.7 Longevity/Potential Payback

If a weapon system was assessed as likely to be around for a long time and thus the payback from a MXM 6.3 effort might be very significant, that weapon system was rated a 5. A weapon system that was assessed as probably not be destined to be around long and therefore bring little payback was given a score of 1. Varying degrees of potential payback were scored between 1 and 5. Although the team realized that there might not necessarily always be a direct relationship between longevity and potential payback, it was still felt that this was something that should be considered. It should also be noted that for a follow-on 6.3 effort the area of potential payback will certainly be a pass or fail criterion and will require major detailed analysis to support it. In that follow-on effort considerably more emphasis in this area will be required than was the case here.

3.1.8 Other Programs On-going

Although a numeric score was not given, if the team was aware of other programs that might conflict with the MXM effort or compete with it or a potential 6.3 follow-on program for support that fact was noted.

3.1.9 Systems Not Considered

It should be noted that some weapon systems were purposely not included in the assessment. For a number of reasons, including significant potential access problems, small numbers of platforms, and security considerations to name only a few, the team decided not to include low density, high demand systems (i.e., F-117, B-2, Rivet Joint, AWACS, Joint Stars, Special Operations). In addition, pure training systems such as the T-1, T-37, and T-38 were not considered because much of their maintenance is done under contract to commercial sources. Given that fact, it was decided that including them in this research might present problems that could cost undue amounts of time and might generate other issues (i.e., contractual) with which the team was not prepared to deal. Likewise, developmental systems such as the F/A-22, F-35, and CV-22 were not considered in the assessment.

3.1.10 Assessment Results

Using the aforementioned guidelines, the team assessed nine weapon systems (see Table 1). Information from various sources, including logistics data provided by AFRL/HESR, experience from previous programs, inputs from MAJCOM headquarters contacts, sources in a number of flying organizations, and inputs from other professional contacts were considered. The team then gave each weapon system under consideration a subjective score based on the data available. Not surprisingly, the amount of available information varied widely among weapon systems. Certainly, more could have been gathered, but it soon became obvious that an inordinate amount of additional time would have been necessary to do so; thus, a decision was made to move ahead.

Table 1: Guidelines for Weapon System Selection

	A-10	B-1	B-52	F-15	F-16	KC-135	C-130	C-5	C-17
High Maintenance Man-hour Consumer	1	5	5	5	1	5	5	5	1
Probability of Data Availability	3	2	3	5	5	4	4	3	2
Probability of Access for Data Gathering/KA	5	2	4	5	5	5	5	2	3
Potential for SPO Support	2	1	2	3	3	3	3	2	1
Ease of Interfacing with the Aircraft	3	2	1	4	4	2	2	2	5
Potential for MAJCOM Support	2	1	2	3	3	4	3	3	2
Longevity/Potential Payback	2	4	4	3	5	4	5	5	5
Other Programs On-going		X				X	X	X	
	18	**17**	**21**	**28**	**26**	**27**	**27**	**22**	**19**

The F-15, F-16, KC-135, C-130, and C-5 were the top five weapons systems based on the scores attained. To maintain a multi-command flavor in the program the research team decided to attempt to focus on the F-15 and/or F-16 and the C-130 and/or KC-135. Not only did both score high in the assessment, but there was also the likelihood that both would be in the inventory for a long time. In addition, these weapon systems represent both ends of the technology spectrum, which supports the AFRL/HESR desire for MXM to be applicable across as much of the USAF fleet as possible.

3.2 Subsystem Selection

Although the research team intended to follow a similar process for selection of a target subsystem as that used in weapon system selection, that proved difficult to do. Logistics data on ACC aircraft was relatively easy for AFRL/HESR to acquire; however, getting similar AMC data was a much greater challenge. As a result, little substantive AMC data was ever received so the decision was made to move forward using the ACC data. A-10, B-1, B-52, F-15, F-16, and EC/HC-130 data was used. Assessments were made of the primary subsystems listed below in each of those aircraft:

- Fuel
- Hydraulic
- Propulsion
- Landing Gear
- Flight Controls
- Radar
- Electronic Countermeasures
- Electrical

3.2.1 Selection Guidelines

The team established a set of five guidelines to govern the assessment of subsystems leading to selection of the target subsystem on which the research would be focused. The guidelines are discussed individually in the following paragraphs.

3.2.1.1 Top Five Man-hour Consumer

The first guideline was whether or not the subsystem in question had consistently been one of the top five maintenance man-hour consumers over the past year. If the answer was "no," the subsystem received a score of 1. If the answer was "yes" a score of 5 was awarded. This is the only category in which no intermediate scores were used and it was also the only category in which the score was purely objective.

3.2.1.2 Ease of Troubleshooting

A score between 1 (Easy) and 5 (Tough) was used to gauge the challenges in troubleshooting each of the evaluated subsystems on each of the six aircraft types. The scores were assessed based on a combination of professional knowledge and experience of the team and inputs gathered from discussions with maintainers in both ACC headquarters and field units. Although formal interviews, a survey, or some other more scientific method of gaining these inputs would have been preferred, this method was chosen to save time. As it turned out, the inputs from these various sources were quite consistent and agreed very closely with information gained later in the KA phase of the research.

3.2.1.3 Relevance to the MXM Project

The scores in this category were solely the professional opinion of the team based on what was known about the project and its goals at the time. Scores were from 1 to 5, with 1 meaning there was not much relevance and 5 meaning there was significant relevance.

3.2.1.4 Potential Integration Challenges

In this area, the team attempted to assess the challenges that might have to be overcome in integrating a potential MXM solution into the subsystem and aircraft in question. Scores were assessed based on team member background and experience as well as inputs gathered from conversations with SPO representatives and maintainers on the ACC staff. Scores ranged from 1 to 5. If the conclusion was that there would potentially be huge challenges, a score of 1 was awarded. A score of 5 was given if the challenges were likely to be manageable. Scores between 1 and 5 denoted varying degrees of challenge between the two extremes.

3.2.1.5 Potential Improvement for Maintainers

In this category, the team attempted to assess the potential benefit to the line maintainers if a MXM solution could be leveraged to improve troubleshooting on the aircraft and system in question. Scores again ranged from 1 to 5. If little benefit would likely accrue to the maintainer from an MXM solution a score of 1 was given. If major improvements for the maintainers were assessed to be possible a score of 5 was given, with varying degrees of potential improvement between 1 and 5 scored accordingly.

The results of the assessment are shown in Table 2 and the detailed data from which those results were derived is listed in a set of tables in Appendix J. Although some might argue about the scores and how they were derived, the team has since found widespread agreement with the results among maintainers who have seen them, specifically those interviewed during field visits and those who participated in the Decision Criteria Development Workshop during this research effort.

Table 2: Subsystem Assessment Results

	Ranking	Score	A-10	B-1	B-52	F-15	F-16	C-130
Fuel	3	86	11	18	15	13	15	14
Hydraulic	8	51	7	10	9	9	7	9
Propulsion	2	94	14	20	7	18	19	16
Landing Gear	4	84	15	11	17	17	9	15
Flight Controls	1	103	15	20	7	24	23	14
Radar	7	59	9	10	7	12	11	10
ECM	6	71	10	9	18	8	18	8
Electrical	5	82	10	19	19	8	9	17

3.2.2 Target Subsystem Selected

With the assessment results as a baseline, the team set out to determine the subsystem on which the research would be focused. Propulsion was eliminated almost immediately, primarily because there was considerable work already being done to improve engine troubleshooting and diagnostics and MXM might have been perceived to be duplicating that effort. The fuel system was eliminated because, although there is certainly improvement needed in diagnosing and troubleshooting fuel problems on nearly every aircraft, AFRL/HESR's technical focus was on an electronic system and most fuel systems do not have a significant electronic component to them. Landing gear and electrical dropped from consideration for essentially the same reasons. Electronic countermeasures (ECM) systems, with some notable exceptions, typically are not especially difficult to troubleshoot, which coupled with potential security concerns resulted in their being dropped from consideration. The remaining systems did not rate high enough in the assessment to focus further effort on them.

Ultimately, it was decided that flight controls would be the target subsystem. That decision was made not only because flight controls attained the highest score, but for a number of other reasons relating to the newly broadened scope of the effort. For one thing, most flight control systems are not pure electronic systems in that they also have mechanical and hydraulic elements. This afforded the opportunity to discern issues that may have been obscured had focus been only on an avionics unit. In addition, because flight control problems may derive from any of the associated elements, this focus guaranteed examination of a maintenance task involving a large diagnostic search space (of alternatives). At the same time nearly all flight control systems, such as those in the F-15 and the F-16, have a significant electronic component to them and should lend themselves rather easily to demonstrating a diagnostic or prognostic capability. This is especially true in the newer aircraft such as the C-17. In addition, most are difficult to troubleshoot and flight controls, even in the newer aircraft, tend to be consistently high maintenance man-hour consumers. Furthermore, flight control issues often mandate impoundment of an aircraft. This meant flight control maintenance was the class of maintenance activities most likely to both (a) represent cases dragging down aggregate performance metrics (for repair time) and (b) involve the widest range of information assets and coordination with other personnel. Given those circumstances, even moderate improvements in troubleshooting time could bring major pay back. Thus, it was decided that flight controls would be the target subsystem for this research.

4 Requirements Definition

4.1 Knowledge Acquisition

Knowledge acquisition (KA) is the label for activities and procedures directed toward obtaining task-related knowledge through interaction with original sources, particularly experts on the topic at hand. This section will briefly review the background for MXM KA efforts, the tactics for pursuing KA on this project, and the activities through which the KA phase the technical effort was conducted. This section will review the approach to gathering data on the target maintenance subject matter and provide a brief overview of the most central outcomes of the KA effort. The subsequent section on cognitive task analysis (CTA) will then review other significant outcomes and conclusions distilled from the KA activities.

4.1.1 Scope and Focus of the KA and Subsequent Efforts

The MXM project was initially focused on research into the prospects and candidate means for improving aircraft/systems maintenance activities. More specifically, MXM was intended to aid AFRL/HESR in determining the feasibility of conducting research and development toward innovations reducing aircraft downtime. The types of innovations to be emphasized were those enhancing maintainer capabilities to troubleshoot system failures through better diagnostic aids, decision aids, and advanced information visualization.

As originally envisioned and discussed, the MXM work was expected to exhibit the following features:

- The MXM team would focus on one particular aircraft and subsystem (i.e., radar on the F-16)
- The team's research efforts would concentrate on the cognitive and informational aspects of maintenance functions for the target aircraft/system alone
- The team's research efforts within this narrow scope of interest would lead to specific recommendations for improving maintenance of that particular aircraft and subsystem.

As noted earlier, the MXM project was redirected soon after it started and the scope of research interest was expanded to a broader, higher-level focus. Thus, it was decided that the MXM effort would be framed with regard to the following criteria:

- The scope of system/subsystem concern would be a general class of apparatus applicable to a wide variety of operational USAF aircraft (discussed earlier in Section 3).

- This scope of concern was agreed to be flight controls (see par. 3.2.2). A reasonable range of operational USAF aircraft would be reviewed with respect to flight control maintenance issues.
- The MXM team agreed to achieve this breadth of range by reviewing both small aircraft (i.e., fighters) and large aircraft (airlift aircraft in this case).

4.1.2 Tailoring the Knowledge Acquisition Itinerary to Fit the Project Scope and Focus

Had the research proceeded with the original (one aircraft/one subsystem) scope, the KA itinerary would have been tailored to emphasize depth with respect to the target subsystem. Such a depth-orientation would have involved detailed data gathering and interviews with a small set of expert maintainers involved with the target maintenance task. The revised project scope required that data be obtained across a reasonable sample of different aircraft and aircraft types. This in turn required an adjustment to the KA itinerary to afford reasonable coverage corresponding to the new scope (i.e., more breadth at a lesser depth of detail). Various options were reviewed with respect to travel costs, the range of maintenance knowledge that would be required, and site access. It should be noted that site access became a major consideration because of the exceptionally high operational tempo due to the continuing operations in Operation Enduring Freedom (OEF), the buildup for and initiation of Operation Iraqi Freedom (OIF), and ongoing Homeland Defense commitments. In the end, it was decided that the most constructive and feasible course of action would be a two-phase KA itinerary:

- *Phase 1: Fighter Aircraft*. It was determined that Nellis AFB, Nevada was a lucrative site for obtaining maintenance knowledge on a variety of fighter aircraft. The range of aircraft stationed at Nellis included A-10s, F-15Cs, F-15Es, and F-16C/Ds, as well as the F/A-22 and RQ-1. As a training and testing base, Nellis offered the prospect of operational conditions similar to those of bases to which access had become problematic owing to ongoing contingency operations.
- *Phase 2*: *Large Aircraft*. Significant time was spent considering options for KA on a larger aircraft. As noted earlier in Section 3.1.10, a C-130 or a KC-135 was preferred; however, considerable time and effort to arrange either of those visits proved fruitless due to heavy operational taskings in those units. In the end, it was decided that going to Charleston AFB, South Carolina to do KA on the C-17 was the best feasible option.

The actual itinerary is summarized in Table 3. A four-member MXM team traveled to each of the designated bases and conducted multiple days of KA activities.

Table 3: MXM KA Itinerary

SITE	KA Team Members	Days on-site	Aircraft Reviewed
Nellis AFB, NV	♦ John Jacobs (NGIT) ♦ Randall Whitaker (NGIT) ♦ Capt. David Lemery (AFRL) ♦ Capt. Brian Tidball (AFRL)	15 – 18 April 2003	♦ A-10 ♦ F-15C ♦ F-15E ♦ F-16C/D ♦ F/A-22 ♦ RQ-1 (Predator UAV)
Charleston AFB, SC	♦ John Jacobs (NGIT) ♦ Randall Whitaker (NGIT) ♦ Capt. David Lemery (AFRL) ♦ Capt. Brian Tidball (AFRL)	29 April – 1 May 2003	C-17

4.1.3 Tailoring the Knowledge Acquisition Tactics to Fit the Project Scope and Focus

4.1.3.1 Setting KA Criteria Appropriate to the Revised Plan

Shifting the scope of the MXM effort also meant that adaptations had to be made to the KA tactics to be employed. The most commonly used on-site KA tactics include structured interviews with subject matter experts (SMEs), observations of target tasks being accomplished, and task simulations. The shift to a more general scope induced several new or newly prioritized criteria for choosing the specific KA tactics. Some of the most important such criteria were:

- *Minimizing time consumption on-site*. The original allocations for KA travel time and funding were based on a narrow study of one subsystem of one aircraft. Detailed data collection (i.e., observations) for representative maintenance activities on the seven different aircraft being covered would have potentially required more time than was available. Thus, KA tactics were tailored against available time.
- *The trade-offs between depth and breadth in data collection*. The available time would permit drill down only so deep on each of the subject aircraft. This meant a decision had to be made on how many relevant dimensions of the flight control maintenance activities would be explored and the depth to which each would be explored. This became an involved set of trade-off evaluations.

- *Minimizing collection of data too fine-grained to be informative on the stated topic.* Details of work procedures might be peculiar to one or more of the subject aircraft, resulting in the collection of fine-grained data of little applicability at the more general level of interest that was now the focus. Similarly, details of those tools and aids peculiar to one or another aircraft would be unlikely to illuminate issues and problems pertinent to all the aircraft.
- *Maximizing the generalizability of task data and derived models with respect to as many aircraft as possible.* To deal with the expanded scope of concern, target data and knowledge of broad applicability to flight control maintenance functions across all aircraft was needed. This meant tailoring of the KA plan would be required to concentrate on maintenance processes and procedures of sufficient generality to be relevant across all the subject aircraft.
- *Maximizing the generalizability of data on the tools and aids employed in flight control maintenance.* The MXM effort was geared toward exploring the role of current and prospective maintenance support tools. However, some of the support aids (specifically diagnostic decision support aids) are specific to only one or another of the subject aircraft. It was decided to emphasize data collection on those tools most generally applicable across all aircraft. This is why special attention was given to examining the tool inventories of the units visited.
- *Administrative constraints.* Given the revised and more general scope of MXM efforts, consideration was given to how to supplement the on-site KA with other, wider-ranging forms of data collection. The use of a written questionnaire or survey was one of the alternative tactics examined in most detail. As it turned out, there are significant USAF administrative constraints on broadcasting such instruments to operational units. The overhead for overcoming these administrative constraints, added to the practical overhead costs of conducting such a survey, resulted in the decision that this tactic was not feasible within the planned timeframe.

4.1.3.2 Selecting KA Tactics Appropriate to the Revised Plan and Criteria

Once revised criteria for the KA approach were established, KA tactics (themes, questions, instruments) were developed that reflected them. The most important KA tactics devised for the MXM effort included the following:

- *A preliminary KA plan to serve as a structured guide for the KA team.* A 10-page KA plan was drafted and distributed to the team. This document outlined the rationale for KA tactics to be employed and provided a notional set of key questions and issues to serve as a guide during the KA sessions. This plan (see Appendix C) provided the basic pre-visit preparation for the KA team.
- *Emphasis on a proactive "straw man" review rather than passive elicitation.* The MXM team had access to substantial information on general maintenance issues and facts. Based on this information

base, the KA team was in a position to get a head start on outlining some general points to put in front of the SMEs (as opposed to starting from scratch and taking time to draw out such basics during the interviews). Much time can be conserved if SMEs are presented with an initial "straw man" (model, diagram) to which they can immediately react. In this case, the "cascade" approach to mapping the flight control maintenance process was aided by presenting maintenance SMEs with a set of presumed stages in the maintenance process and then asking them to arrange these elements into a representative model of that process path.

- *Surveying the tool inventories of frontline maintenance units.* A point was made to request time and access to review unit tools with a focus on those specifically employed in flight control maintenance. In preparation for the KA trips a structured questionnaire form (see Appendix E) was developed for documenting information about flight control-related tools and instruments.
- *Interviews with support and other relevant personnel.* Flightline maintainers are supported by a number of people and activities in the course of their work. Support personnel, such as Air Force Engineering and Technical Services (AFETS) and contractor technical support staff, and support functions (i.e., on-base component test station shops) were visited wherever possible. This allowed a broader perspective on maintenance operations as actually practiced, and it afforded the team additional insight regarding the means by which the frontline maintainers reach back for information as necessary.
- *Collection of additional documentary data as available.* In addition to the interview sessions and tool questionnaires, a point was made to solicit other available data such as:
  - Overall maintenance operations statistics (for the unit)
  - More specific maintenance functional statistics (overall, and especially for flight control issues)
  - Incidence statistics for flight control problems (e.g., how often, how long it takes)
  - Data on specific tools (especially those employing automation, programming, and/or resident software)
  - Inventory of information resources available to the maintenance team
  - Data on the maintenance team's supply chain and supply procedures
  - Data on any recent or pending changes/innovations in flight control maintenance
  - Pointers and/or data on better tools identified by the SMEs in the course of the interviews

4.1.3.3 "Cascade" Approach to Progressive Knowledge Elicitation

Given the scope and timeframe for the KA activities, it would be necessary to obtain maximally generalizable data (facts, models) in minimum time. The final KA plan implemented a four phase "cascade" approach to exploring maintenance process and associated information utilization. A core model of the maintenance process would be elicited and then employed as the common reference framework for collating details on critical dimensions of the maintenance task. As implemented, this cascade tactic consisted of the following components:

- First, a general model of the maintenance process flow (from problem notification through to returning the aircraft to duty) would be elicited, refined, and validated with subsequent SMEs.
- Second, this model would be used as the focal framework for eliciting comments on procedures, practices, and problems related to each.
- Third, this model (and the data on procedural matters) would be used as the framework for polling the SMEs on what data or information they needed or expected to employ at each stage of the overall work process and with regard to the procedural issues developed in the second stage.
- As the fourth phase of this exploration, the team visited selected support sections to review flight control tools and instruments and to gather data on those tools and their usage.

This four phase KA progression is laid out in Table 4. As the table indicates, the team was able to rapidly achieve consensus results on the goals of the first three phases, and reviewed flight

Table 4: Four Phase KA Strategy

PHASE 1	PHASE 2	PHASE 3	PHASE 4
Establish basic maintenance process flow	**Correlate key info requirements**	**Correlate primary data/info resources**	**Correlate tools and instruments**
Interview SMEs to derive the main steps and progression of typical process path	Probe SMEs on key issues and questions for each of the steps in the process path	Poll SMEs on identity and utility of data and information employed on these issues/questions in the process path	◆ Probe for what the SMEs employ during the process path ◆ Probe for issues and problems ◆ Solicit suggestions/ recommendations ◆ Inventory support shop tool inventory

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PHASE 1	PHASE 2	PHASE 3	PHASE 4
Establish basic maintenance process flow	**Correlate key info requirements**	**Correlate primary data/info resources**	**Correlate tools and instruments**
♦ Begun in session 1, Day 1 ♦ Consensus path model achieved in first session ♦ Model validated in all subsequent sessions	♦ Structured probing began in second session, Day 1 ♦ Key issues/questions carried over and presented for subsequent groups' review ♦ Stable/consensus set of questions and issues discernible by end of Day 2	♦ General questioning on info assets began with session 1, Day 1 ♦ Structured probing began halfway through Day 1 ♦ Specifics of info resources vary among A/C types ♦ Attention paid to human info assets (e.g., tech support)	♦ Obtained data on diagnostic and reference aids in interviews ♦ Probed on usage of tools and aids ♦ Visited support sections to inventory flight control tools (F-15C, F-15E, F-16, C-17)

control maintenance tools on four of the five aircraft types for which a dedicated support section was in operation.

4.1.4 Conducting Knowledge Acquisition On-site

At both sites, a meeting room was made available for the team's use, and all the SME interviews were conducted there. The four members of the KA team (Lemery, Tidball, Jacobs, and Whitaker) were present in all the interviews. The sessions were typically scheduled to permit at least 90 minutes with each set of SMEs. Auxiliary visits to on-base sites (i.e., support sections and test stations) were made as necessary. In addition to the interview sessions, Capt. Lemery and Capt. Tidball solicited documentary evidence (e.g., statistical summaries and maintenance reports) relating to both flight control maintenance in particular and maintenance performance overall.

All sessions were conducted in accordance with the agenda established by the on-site hosts. There was only one session (at Nellis) where a miscommunication resulted in the designated set of SMEs not being available for the scheduled interview. In this case, the SMEs were re-scheduled to participate in a later session on the same aircraft (F-15), so their inputs were not lost. Some on-site adjustments were made during the visits, allowing the team to obtain data and interview SMEs beyond what was afforded by the original agenda. For example, on-site adjustments at Nellis allowed data to be gathered on maintenance issues for the RQ-1 Predator UAV and the newly arrived F/A-22 Raptor.

Each of the interview sessions began with an introduction of the team, an overview of the MXM project, and the purpose of the session. All SMEs were asked to provide basic identification information on a sign-in sheet (Appendix D) and were advised of the team's non-attribution policy regarding the information they would be providing. A lead interviewer facilitated each session with the other team members participating as circumstances warranted.

The set of key issues assembled prior to the KA visits (Appendix C) was used as the basis for the interviews. As time went on, the focal points arising in the early interviews were fed forward as talking points for subsequent sessions. Unexpected significant claims and answers arising in each session were specifically noted. A good example of this occurred in the very first session at Nellis, where the SMEs indicated that a near-majority of flight control problems ended up being a matter of "switchology" (i.e., incorrect switch, knob, or control settings). This issue was flagged and care was taken to question SMEs in all subsequent sessions about it. In addition to the switchology issue, examples of other such "pop up" priority questions included:

- Quality (e.g., clarity, completeness, informativeness) of aircrew problem reports (AFTO Form 781A write-ups) and the procedures for such reporting
- What one type of information the maintenance team would most like to obtain at the outset of the process path
- Maintainer descriptions of the indicators of maintenance expertise
- Distinctions and differentiations between the knowledge and skills evidenced by expert/experienced maintainers and novice/newer ones
- Distinctions between the focus for flight control maintenance training and what actually happens out on the flightline
- Problems and deficiencies deriving not from LRUs but from what interconnects LRUs (e.g., wiring, connectors)
- Tradeoffs between paper and electronic decision aids
- The issues surrounding efficiency in setting up and working within an impound team
- Personally or locally developed information resources and aids
- Which categories of tools (or components required to employ said tools) ended up costing time and effort
- Coordination issues in establishing and operating an impound team
- Coordination issues in cycling LRUs back upstream (i.e., to test stations and beyond)
- Coordination issues in finally certifying a maintenance process as completed

- Degree of reliance on automated aids (i.e., portable maintenance aids (PMAs)
- Degree of reliance on local technical support staff (e.g., AFETS, contractors)

No video or audio recording was performed in the KA sessions. The products from the KA sessions consisted of individual sets of handwritten notes, transcriptions of material written on whiteboards during sessions, flip chart sheets (where used), SME-supplied photocopies and tool data, some FI cards, and data requested from on-base QA and other maintenance staff offices. The volume of data from the KA session was very large. Owing to time and budget constraints, transcription of the KA session notes was limited to those from the Nellis sessions.

4.1.5 Laying out the Course of a Representative Flight Control Maintenance Process Path

The very first session at Nellis began with a review of a straw man sequence of steps for a typical or representative flight control maintenance process generated prior to the KA trip. It included a series of pro forma steps with attention to (a) repair actions, (b) administrative coordination, and (c) decision processes relevant to the maintenance cycle. The candidate steps were drawn from preliminary readings on the maintenance process and professional experience of the research team members. A set of Post-It notes (one labeled for each step) was laid out on the interview room conference table. The steps represented by each Post-It note were given brief explanations. The initial sequence shown to the SMEs was as follows:

- Problem Identification (acknowledge and describe a flight control issue)
- Problem Reporting/Documentation (communicating and recording the fact and the type of flight control issue; "get the case started")
- Unit Coordination[1] to get the aircraft into the maintenance cycle (make arrangements for maintenance work; convene an impound team)
- Maintenance Setup/Preparation (park the aircraft; assemble tools)
- Diagnosis (probe to see what the problem is)
- Prognosis (decide prospects for solutions)
- Repair Actions/Activities (the actual work of fixing the plane)
- Supply/Requisition (in parallel to everything else; actually outside the main sequence)
- Completion Decision (decide that we're finished)
- Test/Evaluate the Solution/Repairs (make sure it now works right)

[1] The SMEs were advised that the team used the term "Unit Coordination" to mean "coordinating actions and responsibilities among relevant players."

- Certification/Validation of Solution (sign off that the plane is now fixed)
- Solution Reporting/Documentation (paperwork; records)
- Maintenance Stand-Down (clean up; put away tools, etc.)
- Unit Coordination to get the Aircraft Back into Service

SMEs were then asked for their opinions on this straw man layout of a typical or representative maintenance process path. They were invited to make any comments or corrections they thought would make it more accurate. The first set of SMEs made several comments on this initial sequence, including:

- The Completion Decision step is accomplished after, and not before, the Test/Evaluation and the Certification/Validation steps.
- It is difficult to separate the two first steps (Problem Identification and Problem Reporting/Documentation) in all cases. It is often the case that identification of the problem and reporting/documentation occur together (e.g., during the pilot debriefing).
- There is often some measure of Prognosis occurring up front with the Problem Identification and Reporting/Documentation steps. In other words, experienced maintainers often have a sense of maintenance prospects (roughly how much time; how big a job) at the point they received the initial problem description (e.g., from the pilot).
- The Test/Evaluation and the Certification/Validation steps are most commonly blended together in practice. Although distinct, these two functions are typically interleaved in the course of flight control maintenance.
- The Diagnosis and Maintenance Setup/Preparation steps do not always occur independently and/or in the order originally presented. Sometimes Diagnosis is pretty much done up front (e.g., for an obvious fault), and the Setup/Preparation is done with knowledge of what the problem is. Sometimes Diagnosis and maintenance Setup/Preparation go hand-in-hand, as when something uncovered during Diagnosis requires them to back up to do more Setup/Preparation before proceeding.
- Depending on circumstances, the course of an actual flight control maintenance process can be cyclical or iterative (as contrasted with the basic linear schema presented to the SMEs). In other words, it is not always accurate to characterize the maintenance process as a one-pass stepwise progression through the given steps.
- One exception to the linear stepwise progression occurs when it is possible and/or appropriate to "skip" or "jump" along to a later step without having to stop and do an intermediate one. An example of this would be when the solution is immediately apparent and/or readily implementable.

- ♦ A more common exception to the linear stepwise progression relates to the "troubleshooting cycle." An actual maintenance process often consists of multiple iterations through the section of the sequence from Diagnosis through Certification/Validation. This sort of cyclical process path is most evident when swap-and-test tactics are employed to address the flight control problem (i.e., change a component - test if that fixes the problem - repeat as necessary).

Once this review and modification cycle was completed, the SMEs agreed that the revised sequence was a good representative model. This revised model, illustrated in Figure 1, was subsequently reviewed and validated by all the SME groups interviewed at both Nellis and Charleston.

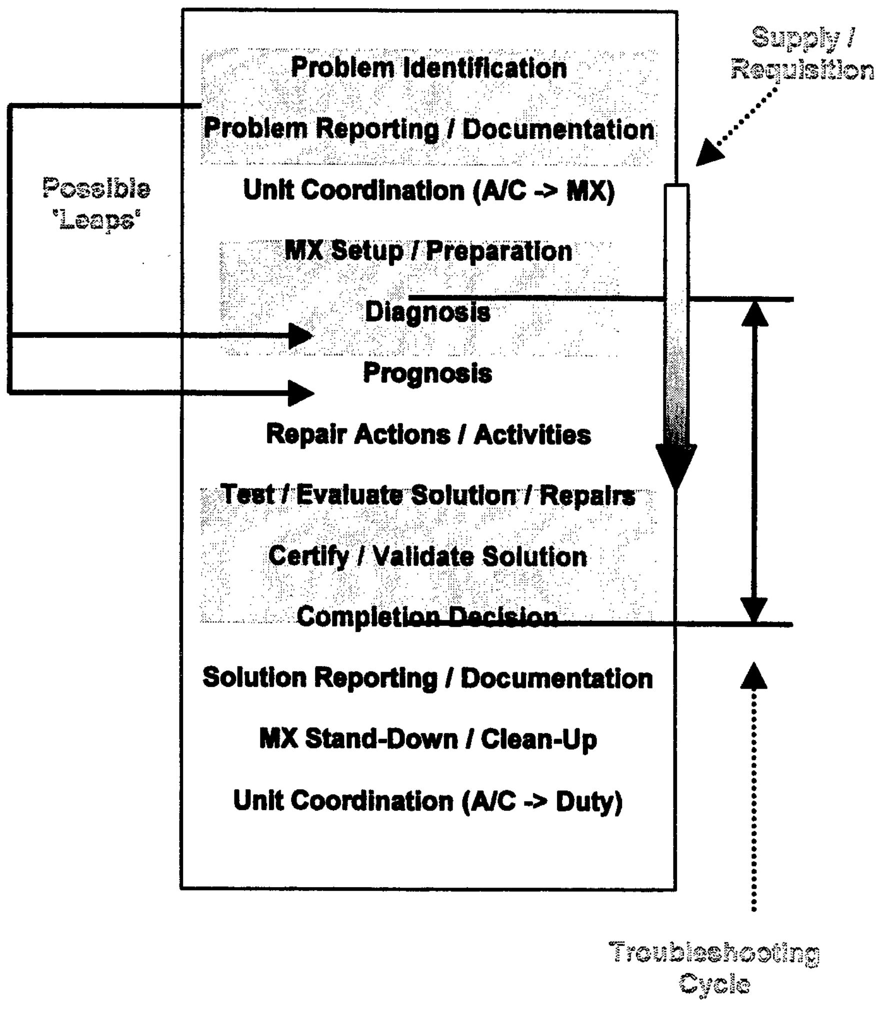

Figure 1: Consensus Layout for a Representative Maintenance Process Path

Figure 1 uses shaded boxes to group together steps, which the SMEs indicated might be blurred or interleaved together. There were three such "clusters" noted by the SMEs:

- Problem Identification - Problem Reporting/Documentation
- Maintenance Setup/Preparation - Diagnosis
- Test/Evaluate - Certify/Validate

A set of arrows indicate the "possible leaps" (forward through the process path) the SMEs indicated might occur. Two such "leaps" were consistently mentioned by the SMEs. These occur when information obtained during the Problem Identification/Reporting "cluster" leads immediately to a result (perhaps only a tentative result) for Diagnosis and/or Prognosis. The SMEs in multiple sessions at both bases noted information obtained at the point of initial reporting might "leap forward" to an immediate repair action. Insofar as this presumes a hypothesis on the nature of the problem (i.e., a diagnosis), this type of "leap" is not separately illustrated in Figure 1.

A shaded arrow on the right indicates the region of the process path during which supply/requisition activities may be proceeding in parallel. No SME in any session characterized supply/requisition as anything other than a parallel activity occurring outside the primary maintenance process path. In addition, another set of arrows is used to delimit the range of process steps incorporated into the iterative "troubleshooting cycle" which the SMEs noted as a common feature of the process. These are the steps starting with Diagnosis and continuing through the Test/Evaluate - Certify/Validate clusters. Multiple SMEs in multiple sessions noted this cycle as being particularly apparent when pursuing a "swap-and-test" approach to fixing a flight control problem.

The process model outlined in Figure 1 coalesced into near-final form on the first day of the first KA visit at Nellis. The model was subsequently presented to every other maintenance group interviewed at both Nellis and at Charleston. No later group had any significant comments or recommendations for improving the model at the given level of generality. As such, the model was effectively validated with the first session on the first day, which allowed it to be leveraged for the other KA goals at a very early point.

Allowing for the "clustering" noted or suggested by the SMEs, the final process path representation breaks out into eight primary steps or phases as follows:

- Problem identification/reporting
- Front-end unit coordination (to get the aircraft into the maintenance process)
- Maintenance setup/preparation

- Troubleshooting cycle (subsuming testing, diagnosis, prognosis, repair actions, and testing/evaluation to the point the work is deemed complete)
- Solution reporting/documentation
- Solution validation/verification and process completion decision
- Maintenance stand-down/cleanup
- Back-end unit coordination (to get the aircraft back to duty)

There were multiple reasons for settling on this eight-way breakout. First, it reflects the points of transition or natural boundary events evident in the SMEs comments about the progress of their maintenance work. Second, this decomposition matches points of transition for the changing set of specific individuals working on the problem at any given time. Third, this decomposition is the one most consistently applicable across all the SME groups interviewed. This eight-step decomposition will be referred to during the remainder of this report.

4.1.6 Identifying Information Requirements for Typical Flight Control Maintenance Process Path

The rapid delineation of a consensus model for the typical maintenance process path allowed the team to start associating information requirements with process path steps early in the KA effort. The approach was to step the SMEs through the acknowledged process path map and probe at each step for the key issues they needed to resolve to accomplish that step. In some cases, this boiled down to a set of key questions to be asked and answered. In some other cases, this yielded a set of key issues needing to be addressed (and which were not readily translated into key questions per se). The following is a summary listing of the most commonly cited information requirements for the flight control maintenance process path.

4.1.6.1 Problem Identification/Reporting

- What is the nature of the flight control malfunction?
- What are the malfunction's symptoms?
- When (at what point(s) during the flight) did these symptoms occur?
- What was the pilot doing at the time(s) the malfunction was apparent?
- What questions do the fault tree (diagnostic guide) recommend or require once we start tracing the problem using that aid?
- How did/does the malfunction affect the mission?

- In what axis or axes was the flight control problem observed or noted?
- What other indications can be cited (e.g., by the pilot) to help describe the nature of the apparent malfunction?
- What other indications can be cited (e.g., by the pilot) to help describe the operational context or flight conditions at the time the apparent malfunction was observed/noted?
- Are there any physical attributes or features of the plane that would seem to correlate with the stated problem?
- Are there any configurations of the plane or its controls that seem to correlate with the nature of the stated problem?
- Does the reported fault appear to be intrinsic to the aircraft's systems, or was it induced (by pilot actions)?
- Were there any visual observations of the plane in flight that help to contextualize the occurrence of the apparent malfunction?
- What were the flight parameters at the time(s) the apparent flight control malfunction was observed/noted (e.g., altitude, AOA, etc.)?
- What was the pilot doing (or trying to do) at the time he/she perceived an apparent flight control malfunction?[2]
- Did the apparent malfunction occur only once, or did it re-occur during the flight?
- Was there uncommanded flight control movement observed?[3]
- What was the aircraft configuration during the flight/mission during which the apparent flight control malfunction was observed?[4]
- What, if any, system or systems are obviously offline?
- Is the apparent problem obviously a procedural or configuration glitch resulting from (e.g.):
  - Improper sequencing of actions (i.e., error in procedure)
  - Errors or problems with controls/switch settings (i.e., switchology)
  - Transient control or (sub)system state which can be corrected simply by doing a "reset")
- What fault codes are associated with the apparent problem?
- Does a reset resolve the problem (to the extent it can be observed/replicated on the ground)?[5]

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[2] In contrast with the previous point, this refers to the mission- or flight-related tactics, maneuvers, etc., at the time the apparent fault occurred.
[3] Uncommanded flight control movement was repeatedly cited by multiple SMEs as a very serious indicator in flight control problems. Several SMEs (across multiple sessions) cited uncontrolled movement as a factor which would always ensure an impound.
[4] This point was explained to be focused on mission-related aircraft states (e.g., weapons load) which might contribute to explaining aberrant flight control behaviors. Examples given in this session were fuel imbalance and any other weight distribution feature which might have affected the aircraft center of gravity at the time of problem occurrence.
[5] This is not exactly redundant with the preceding allusion to "reset" in this list. In the first case, the SMEs were referring to an initial or up-front quick resolution because something specifically cued them the resolution was a matter of a reset. In this case, the SMEs were indicating a step or point at which a reset was attempted, even though they had not previously identified the apparent problem as a "quick fix via reset."

- What specific information/clues can the pilot provide that can be documented in writing up the problem report?
- How much relevant information can we get from the pilot at the point of his/her initial report?
- Are the forms (and/or other documentation of this problem) accurately filled out?
- What MFL code(s) can be identified for this problem?
- What BIT codes or other onboard data can be immediately obtained to shed more light on this reported problem?
- What candidate diagnoses suggest themselves at this point?

4.1.6.2 Unit Coordination

The unit coordination (to get the aircraft into the maintenance cycle) include:

- What maintainers need to be assigned to work this problem?
- What place/space will be used to work this problem?
- Do we have to arrange for hangar time?
- What are the pending weather conditions? (i.e., can we work the problem outside?)
- When is the aircraft scheduled to fly next?
- What do we tell the Pro Super about the aircraft's prospects for making its next scheduled flight?
- Key points in making the impoundment arrangements:
    - Assign an impound official
    - Assign and assemble the flight control impound team for this plane/problem
    - Assign or designate the Team Chief
    - Coordination with QA/QC (with additional documentation)
    - Release the aircraft for maintenance work

4.1.7 Maintenance Setup/Preparation

- Where will we park the aircraft to work this reported problem?
- How do we get the aircraft into position (i.e., parking spot) to begin work?
- What aerospace ground equipment (AGE) is on hand/accessible for this effort?
- Does additional AGE have to be obtained (e.g., from other units) before we can proceed?
- What tools and test equipment will be needed?
- What tech data (job guides, wiring diagrams, or other reference aids) will be needed?
- Do we need to obtain any of the required resources (tools, test equipment, etc) from outside our unit?

- Do the Aero Repair (AR) riggers need to inspect the aircraft at this stage?[6]

4.1.7.1 Troubleshooting Cycle

- Does the problem identification give us a head start on diagnosis?
- When can the aircraft return to duty?
- What detailed in-flight data can be accessed to shed light on the reported fault?
- Are there any pilot-triggered data "snapshots" available for inspection?
- Is any such data volatile (and hence needing to be captured immediately)?
- What clues (informative symptoms, etc.) can we glean at the outset?
- Does the aircraft offer built-in test (BIT) capabilities?
- If so, what formal maintenance codes (e.g., BIT codes) do we get when testing the aircraft?
- If not, what test(s) should we run to obtain data on the reported fault condition?
- How do we translate BIT/test results so that they map onto the structured diagnostic aids (e.g., fault trees)?
- What options/recommendations are obtained when tracing the decision aid using the input data?
- In the case of broadly defined data (e.g., BIT codes indicative of a range of possible conditions), how do we sort out the most likely culprit?
- After iterating through the decision aid's inference structure, what is the apparent diagnosis?
- Is this diagnosis consistent with what we know about the reported fault and this aircraft?
- If so, what repair or replacement actions are needed?
- If not, what should we do to backtrack to either explore other unexplored paths in the diagnostic aid's inference network, or else conduct tests to gather additional/better data on the flight control systems?
- Do we finally arrive at a positive diagnosis (perhaps after multiple attempts)?
- If not, fall back to "swapology" (swapping out components to see if a replacement fixes the fault).[7]
- Do we need to call in the AR people?

4.1.7.2 Solution Reporting/Documentation

- What do we have to do to document what we did?
- Identify and document what action or change fixed the reported problem

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[6] AR might be involved on a required or optional basis throughout the flight controls maintenance process path. For example, F-15 SMEs at Nellis noted the AR (rigging) team typically runs checks during or in parallel with the maintenance setup and preparation. At this step in the process, these checks can induce a delay. If the initial AR checks are inconclusive or conflicting, the maintenance team may have to wait for a second AR team to repeat the rigging checks and render a second opinion.

[7] The term "swapology" denotes an approach to repair via changing out components until things are OK again. This notion of repair-via-replacement came up repeatedly during the KA visits, and "swapology" ended up being a valuable piece of terminology.

- Identify and document any and all components we changed out during this maintenance process
- Assure that follow-on checks are or will be done
- Take care of information system documentation requirements (i.e., CAMS)
- Document this maintenance action in the logbook
- Complete the various forms associated with this aircraft
- Settle up with supply and complete any associated documentation of supply/requisition actions taken

4.1.7.3 Solution Validation/Verification & Completion Decision

- When can we schedule a meeting to determine and sign off on completion?
- Who needs to be in attendance?[8]
- What is the set of documentation and forms we need to process via this meeting?
- What was the course and status of the given maintenance work (as presented by the meeting participants and the relevant documentation)?
- Does the Maintenance Group Commander sign off on the repairs as presented?

4.1.7.4 Maintenance Stand-Down

The SMEs did not cite any key informational questions or issues to be addressed in standing down the maintenance process (e.g., cleaning up, putting things away, etc.).

4.1.7.5 Unit Coordination (Getting the Aircraft Back to Duty)

- What needs to be done to prepare the aircraft for its next mission (e.g., doing mission-specific reconfiguration)?
- What arrangements need to be made (e.g., towing) for returning the aircraft to duty status?

The implications of the key questions and issues solicited from across the SME groups will be discussed further in the subsequent sections on cognitive task analysis and information requirements.

4.1.8 Issue: Truncating or Avoiding the Process Path in "No-Fix" Situations

The process path illustrated in Figure 1 represents the entire end-to-end progression for a typical maintenance cycle. The completion and documentation of such a maintenance cycle is what gets captured

[8] This meeting always includes the Maintenance Group Commander (or designee), the impound official, and the impound Team Chief. Additional people (e.g., Production Superintendent, Quality Assurance representative) may participate depending on the circumstances.

in unit and aggregate performance statistics.[9] However, it would appear that such statistics underreport the level of effort expended by maintenance staff in servicing their aircraft. One of the most significant surprises encountered in the KA work was the fact that a substantial proportion of apparent flight control faults end up being resolved without going through this process path. Perhaps just as important is the fact that such incidents typically go unreported. This means maintainer time and effort is expended on diagnosis and problem solving that is not reflected in the maintenance statistics. This issue arose in the very first KA session, and was immediately added to the list of points to probe in subsequent sessions.

Among the SME groups, the following situations were cited as resulting in "no-fix" resolutions:

- *The apparent flight control problem is simply a matter of "switchology" (incorrect switch, knob, or control settings).* Currently-apparent problems can be resolved by merely reconfiguring switch settings, while past such problems can be reasonably explained away by reference to incorrect settings. Such switchology faults were the category of "no-fix" situations most commonly cited by all the SME groups.
- *The flight control problem indications disappear upon conducting a reset of the flight control (sub)system or an associated (sub)system.* Particularly for those aircraft whose flight control systems are computer controlled, the appearance of a flight control fault may reflect a computer anomaly and not a problem with the controls per se. The SMEs indicated that conducting a reset action and then rechecking the system(s) often eliminates the apparent fault.
- *The reported flight control problem cannot be observed during reasonable attempts to replicate it.* This is a particular problem with flight control anomalies, because they may only be apparent in the air and their circumstances of occurrence may not be capable of replication or simulation on the ground.
- *The reported flight control problem indications (e.g., anomalous in-flight behavior) can be readily explained by pilot actions inappropriate or out-of-range with respect to established standards or limits.* This situation was cited by multiple Nellis SME groups. They explained that the training and testing missions conducted at that base often put pilots into unfamiliar situations, and that erroneous pilot actions often accounted for apparent flight control faults.

A summary of the specific SME estimates of such "no-fix" occurrences is compiled in Table 5.

[9] The operational fighter statistics summarized in Appendix I.

Table 5: SME Estimates for "No Fix" Occurrences

Aircraft[10]	Estimates/Comments Made	Consensus
A-10 "Switchology"	◆ "No-fix" incidents are at least as frequent as incidents requiring actual maintenance work. ◆ Switchology accounts for the majority of "no-fix" flight control incidents	50 % (of all flight control problem reports turning out to be "no-fix")
F-16 "Switchology"	◆ 50 - 60% of all initial flight control problem reports ◆ 60% of all initial flight control problem reports ◆ 25 - 50% of all initial flight control problem reports	50 - 60%
F-15	The F-15 SMEs acknowledged significant proportional occurrence of "no-fix" cases as well as one root cause being "switchology"; however, they didn't estimate incidence in %-age terms.	No Quantitative Estimate Obtained[11]
C-17 "Switchology"	◆ 10% of all reported flight control problems ◆ 20% of all reported flight control problems	No Consensus Achieved
C-17 "Resets"[12]	◆ 25% or more of flight control "freezes" can be resolved by resetting communication control units (CCUs). ◆ Most mission computer (MC) problems can be resolved with a reset. ◆ Majority of problems with electronic flight instrument system (EFIS) can be resolved with reset.	No Consensus Achieved

As Table 5 illustrates, there are differences among the SME groups with respect to the types of "no-fix" conditions emphasized and the relative incidence they were willing to attribute to them. However, the fact remains that all SME groups indicated a significant proportion of initially reported flight control problems are resolved without having to enter the plane into the formal maintenance cycle as laid out in Figure 1. With cursory estimated "no-fix occurrence rates" ranging from a low of 10% (C-17) to a high of 50% (A-10; F-16), this further implies that a significant proportion of maintainer problem resolutions are not being documented.[13]

[10] No such estimates were obtained for the RQ-1 and the F/A-22. The former has no onboard cockpit, and the latter is only now arriving.
[11] The inability to obtain estimates from the F-15 SMEs may be related to the fact that the main F-15 session ended up involving a large number of participants and became relatively unwieldy. However, they were advised of the striking estimates of approximately 50% "no-fix rates" given by the A-10 and F-16 SMEs, and they did not discount or refute these estimates.
[12] Owing to the interconnectedness of multiple electronic systems on their aircraft, the C-17 SMEs indicated the majority of "no-fix" flight control cases involved resetting one or more of these associated systems (as opposed to the basic cockpit "switchology" emphasized by the other groups).
[13] Some SMEs also noted that "quick-fix" actions in response to "red balls" commonly go undocumented, especially when done at the last minute (right before takeoff). It was not clear whether such "quick fixes" are entirely subsumed under the "no-fix" categories listed above.

4.1.9 Issues and Concerns Regarding Current Flight Control Maintenance Information Resources

Having reviewed the flight control maintenance process path and the key questions/issues associated with it, attention would turn to the manner in which current information resources effectively supported the maintainers. In the following subsections an overview of the issues cited with regard to various data and information resources is provided.

4.1.9.1 Operational Reference Aids

This category refers to job guides, checklists, TOs, and other general reference information employed in the operation of a given aircraft. The SMEs consistently made reference to problems with these reference materials, particularly in the context of differences between pilot checklists and maintenance TOs. Specific points illustrated this class of issues included:

- The general availability and perceived quality of the primary reference documentation (the TOs) varies from aircraft to aircraft, with the newest aircraft being the ones with the least effective TO support.[14]
- The pilots and the maintainers are typically operating with different information resources. Pilots do not use the TOs. Conversely, pilot checklists are not used or accessed by the maintainers. Maintainers do not routinely see pilot checklists until and unless there is an issue on which they compare their notes/references. There have been specific disjunctions observed between the maintainers' and the pilots' reference materials. Most often these consist of something noted in one not being mentioned in the other. At the extreme, some of the SMEs specifically cited instances where both references addressed the same thing, but gave different data (e.g., values).[15]
- There were repeated allusions to gaps or breakdowns in the established administrative procedures for documenting and correcting deficiencies in basic reference materials. For all the aircraft addressed, there is an administrative process through which such corrections are made (via technical support units). Problems with these established processes include:
- Deficiencies and discrepancies are not always documented or not always uniformly documented and submitted into the official resolution process.
- Once reported to the depot engineering staff, maintainers have no visibility on the course of efforts to resolve such discrepancies/deficiencies.

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[14] The RQ-1 and F/A-22 SMEs at Nellis both claimed their TOs were rudimentary at best and fragmentary in both coverage and depth.

[15] To give one example, the A-10 SMEs at Nellis specifically cited a table of data appearing in both the maintainers' TOs and the pilots' references within which different specific values were listed for the same parameter(s).

- Multiple SME groups stated the biggest problem with the current TOs is not so much the gaps and deficiencies identified with them, but rather inefficiencies in the mechanisms for updating/correcting them.[16]
- Multiple SME groups (and the maintenance Group Commander at Nellis) indicated that much of the usable knowledge on flight control maintenance is not available within the TOs. Such knowledge is typically the sort of "lore" that derives from experience. This "lore" often includes information obtained at substantial cost (in time and effort), which will only cost others as much to find out for themselves.
- There is a notable lack of channels or means by which maintainers can share such experiential knowledge or "lore." Within a given maintenance unit, the logbook provides the main repository and channel for sharing such knowledge. Across units there are few if any ways to capture and share such experiential knowledge.
- It is occasionally the case that the TOs fail to provide adequate descriptive or explanatory information on a key aircraft component.
- It is occasionally the case that the TOs fail to provide adequate reference support for diagnostic procedures for one or another subsystem.[17]
- As time goes on, some TOs actually become *less* detailed than earlier ones, in the sense that they now portray components whose internals were previously detailed (e.g., via schematic diagrams) as mere "black boxes." This means that signal tracing (and hence troubleshooting) is more difficult and less informative using the current (versus the earlier) TOs.
- There are instances in which the relevant TO is simply inaccurate owing to its data being obsolete.
- In the absence of any ability to do solid troubleshooting, maintainers (especially less experienced ones) have no recourse except to resort to "swapology" (changing out components in hopes of correcting the fault).

4.1.9.2 Diagnostic Aids (General)[18]

The "Maintenance Mentor" concept is usually invoked in relation to reference aids for the troubleshooting and diagnostic functions in the maintenance process path. In accordance with this topical focus, particular

[16] Multiple SMEs across the various groups told stories of it taking forever for clear-cut updates or corrections to be reflected in the formal TOs. In some cases, the SMEs made reference to never having seen any indication that obvious revisions submitted by them personally had ever been acknowledged, much less incorporated. One SME cited a particular clear-cut correction he submitted some two years earlier, but which was still unacknowledged and unimplemented. This lack of perceived action or interest tends to de-motivate maintainers to go to the trouble of trying to improve the TOs.
[17] For example, the F-16 SMEs stated their TOs offer poor support in diagnosing problems with the ALR-56M electronic countermeasures subsystem(s).
[18] This section focuses on general issues relating to diagnostic aids. Electronic (e.g., computer-based) diagnostic aids will be more specifically discussed in a subsequent section.

attention was paid to the availability, utility, and sufficiency of diagnostic decision aids. Although much time was spent probing for data on deficiencies in the diagnostic aids employed in flight control maintenance, the SMEs offered relatively few complaints concerning the diagnostic aids themselves. Some of the most significant points made by the SMEs on general diagnostic aiding issues included:

- There are a variety of diagnostic aids available to maintainers, including the TOs themselves, fault isolation manuals (FIs), job guides, schematic diagrams, CAMS history, precedents in the unit logbook, BIT cards, and fault trees.
- Even for the more common paper aids, there are variations in the types of reference documentation available from one aircraft to another.
- Depending on the aircraft type, the maintenance unit, the maintenance environment and other circumstances, the precise mix of available paper and/or electronic diagnostic aids will vary.[19]
- For those aircraft where electronic aids are available, it can still be the case that these aids cannot actually be deployed for use.[20]
- Electronic aids require laptops (or similar devices) on which to run the aiding applications. Application of electronic aids therefore remains dependent on the availability and serviceability of these platforms from day to day.[21]
- The fault isolation guides serve as the primary "logic" being followed in diagnosing a problem. The maintainers match observed data to conditions in the FI structure, then proceed by following where in that logical layout the identified state or condition leads.
- The availability of built-in test (BIT) code data greatly expedites the diagnostic process. For one thing, BIT codes are usually more quickly obtained than (e.g.) visual or manual inspection data. For another thing, the BIT codes are mappable into a finite set of formal categories and alternatives.
- Both paper FIs and available electronic diagnostic aids have been found to contain deficiencies, gaps, and even some errors.
- The procedural cycle for reporting, revising, and reissuing FI aids is similar to that established for the TOs (as discussed earlier).
- The lack of feedback and slowness of this revision cycle noted earlier with respect to TOs applies to the FI materials as well.

[19] The maintenance aid toolkit for the newest manned aircraft surveyed (the C-17 and F/A-22) displays a marked emphasis on electronic aid deployment. The F/A-22 is the most radical example in this regard, because its maintenance concept revolves around the computerized Portable Maintenance Aid (PMA) as its sole intended maintenance aid.
[20] For example, the C-17 maintainers identified the Digital Technical Order System (DTOS) as their most valuable documentation aid. However, DTOS is deployed on a digital disc (DVD). The onboard C-17 portable computers do not have DVD-capable drives, thus making it impossible to simply carry a DTOS disc onto the aircraft for immediate use. As a result, the C-17 maintainers have to bring another laptop onto the plane.
[21] For example, the F-15 SMEs at Nellis stated that laptops are not guaranteed to be available if too many other parties are using them. In other words, availability of a laptop through the support section can make a difference in whether or not a maintenance task can proceed.

- Those maintainer groups with equivalent access to both paper and electronic fault diagnosis aids indicated a general preference for the paper materials in everyday use.[22]
- Strictly following the FIs can lead to states where the maintainers are instructed to stop and "check rig" (i.e., call in the riggers). Such stopping places are time-consuming, because the riggers are an independent team, which is not usually included in the impoundment team.
- Tips and clues derived from experience can enhance the utility of the FIs.[23]

4.1.9.3 Diagnostic Aids (Electronic)

This section will outline the major points the SME interviewees cited with respect to electronic aiding. Some of the most significant points made on electronic diagnostic aiding issues included:

- The utility of electronic diagnostic aids is largely dependent on the diagnostic software they contain.
- Issues surrounding the software itself can constrain the basic availability of the aid for maintenance use, particularly during the period when software is first made available.[24]
- Some maintainers are generally "computer averse," unfamiliar with computer usage, or less adept at using electronic versus paper aids.
- The legibility of laptop-based aids varies with circumstances and is often a cause of diminished utility. The most commonly cited such problem relates to severe glare off the display screen under certain lighting conditions, especially direct sunlight.
- Another problem with electronic aid displays was small fonts that make it difficult to read text information or diagram captions. Reading such small fonts requires the user to get very close to the display (further increasing the probability he/she cannot use the aid while working directly on the aircraft).[25]
- Maintenance work is often two-handed work. This means that maintainers must set a laptop aid somewhere and then go back and forth between their manual actions on the aircraft and their manual interactions with the laptop. At the very least, there is a lot of head turning required to address both the aircraft and the laptop. This divides attention and consumes time.
- Simply positioning the laptop can be a problem. Often a convenient surface cannot be found close to the relevant area on the aircraft where the laptop can be conveniently and safely placed.

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[22] The most commonly cited bases for this preference related to the fact that paper aids are more portable, less fragile, less demanding of digressive actions to use (a glance versus typing and mouse-clicking), and free from the usability problems associated with the laptop-based aids.
[23] For example, the Nellis Aero Repair SMEs claimed the F-15E FIs are somewhat better than those for the F-15C because they provide more detailed information, especially more tips and data derived from past experience.
[24] For example, F-15 SMEs at Nellis noted that newly arrived software tools are still unavailable for flightline use pending resolution of issues relating to validation and security.
[25] This text legibility issue was noted by multiple SME groups. It seemed to be a common issue with the C-17 maintainers and the EDNA (F-16) users.

- None of the aircraft surveyed originally made provisions for laptop placement/positioning.[26]
- Some workarounds or adaptations have been made for laptop placement.[27]
- The electronic aids are often touted as being "portable," but they are often less portable (or less convenient) than paper materials.[28]
- The procedural and interface structure of some of the laptop-based diagnostic aids is such that it can be more cumbersome to navigate through the fault tree on the laptop than using a reference card. This can make it more time-consuming to use the electronic aid than a paper equivalent.[29]
- The software used for electronic diagnostic aids is often tied to one or another operating system. This linkage results in constraints regarding what platform must be available to use the software or even whether the software can be used at all.
- Version discrepancies among software-based reference and diagnostic aids are a persistent headache. It is often the case that different personnel or units are operating with different versions, and hence with different specific data.

4.1.9.4 Maintenance Documentation Aids

In addition to their diagnostic assets, maintainers must have some means for documenting actions during the course of maintenance (e.g., requirements, procedural notes, etc.). Some of the points made by the SMEs on documentation aiding issues included:

- Most documentation is still done by hand on paper (e.g., AFTO 781A entries, logbook entries; notes on clipboards).
- Most documentation is generated in the course of the maintenance process in the actual maintenance setting.
- As a result, using a computer for these documentation functions is (or would be) subject to the same usability problems noted earlier for computer-based diagnostic aids.
- When asked if they saw any potential for improved support by computerizing incidental documentation, the SMEs consistently answered in the negative.[30] The one significant exception to this trend was the F/A-22 group.[31]

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[26] This is particularly striking on the F/A-22, for which the PMA is the maintainers' sole means for interacting with the aircraft. The PMA connection points provided (in the cockpit and each of the main wheel wells) offer no support for the PMA unit.

[27] The C-17 SMEs at Charleston noted that repeated complaints about laptop placement inside the aircraft had led to the installation of a shelf for this purpose. F/A-22 maintainers at Edwards AFB, CA custom-built a pedestal stand on which to place the PMA. This innovation is being evaluated for possible proliferation.

[28] There is no electronic aid as light (and hence portable) as the FI quick reference cards. F-16 SMEs at Nellis noted that it is just as easy to lug an entire manual out to the plane as a laptop. The problem is particularly evident with the F/A-22 PMA, a portable computer unit whose hardware is basically over a decade old. About the size of an old-fashioned reel-to-reel tape recorder, the PMA is an example of a device that is "luggable" rather than "portable".

[29] In one F-16 session at Nellis, an SME bluntly claimed he could navigate through the paper manual 5 times faster than the equivalent material on the computer-based aid. The others in the session agreed.

4.1.9.5 Historical Data on Maintenance Processes and Procedures

Multiple SMEs cited the usefulness of knowing how a particular maintenance problem, especially a very challenging one, was resolved in the past. In the case where such knowledge is extrinsic to the formal reference aids (e.g., the TOs and FIs), it is part of the experiential knowledge discussed later. However, such historical information can be similarly useful in the formal diagnostic procedures performed within the purview of the established TOs and FIs. For example, the F-16 "Falcon" unit SMEs at Nellis noted the growing importance they attribute to documenting the course of the troubleshooting activities themselves (as opposed to only the starting states and the outcomes). They claimed the particular inference chain followed in the TO/fault tree can itself prove informative as a future point of reference in subsequent similar situations. They stated that they even sometimes record what was connected/disconnected during the troubleshooting process as part of this historical trace.

4.1.10 Issues and Concerns Regarding Tools and Instruments Employed in Flight Control Maintenance

As intended in the KA plan, the SME groups were probed for issues and concerns relating to their tools and instruments. These include devices employed in capturing, testing, and manipulating aircraft parameters. These actions yield data that is then fed into or compared against the diagnostic logic available through the maintainers' personal knowledge and their diagnostic aids. Such tools and instruments may be peripheral to the cognitive or decision processes at the core of diagnosis, but they are critical to accomplishment of those processes. One cannot decide which next step to take in a fault tree until and unless the condition(s) specified in the diagnostic aid are verified (by test and data analysis). This verification cannot be done until and unless the equipment allows one to conduct whatever testing is required to obtain or check the relevant data.

It was not surprising that the SME groups consistently cited problems relating to such testing equipment. However, it was surprising that the frequency of such citations and the importance attached to them surpassed the issues and problems reported with the diagnostic guides themselves. Some of the more significant such points included the following:

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[30] One F-16 group noted this had in effect been tried before. They stated CAMS had been made available on the flightline so maintainers could enter maintenance activity data as they went along. This SME group's characterization of that experiment was "a disaster." They stated the cited usability issues were the reason for failure of that initiative.

[31] However, there are some relevant factors that must be borne in mind in considering their situation. First, their PMA support tool is specifically designed to serve as an electronic repository for notes and comments generating during its use. This means they have a capability for dynamic electronic documentation not available to the other maintainers interviewed. Second, the PMA deployment concept mandates that they use this device exclusively. As such, they do not have a choice.

- Some designated test equipment is not very useful, but the maintainers have to use it anyway.[32]
- Maintainers do not have much confidence in some of the test equipment.[33]
- Much of the test equipment is aged and/or dysfunctional.[34]
- Newer is not necessarily better in the case of some devices. Improvements in one aspect of a device's capabilities (e.g., measurement precision) are sometimes obtained only with additional problems with another aspect (e.g., its usability).[35]
- For some specialized devices there is only one on hand, meaning that they can constitute "single point of failure conditions" in being able to conduct certain maintenance tasks.[36]
- Most of the SME groups at Nellis complained of AGE being quite old and subject to malfunction. Such comments were less frequently made at Charleston, where the maintainers enjoy an inventory of newer equipment.
- Some common flight control problem components are not subject to troubleshooting because there is no equipment available for the purpose.[37]
- Some of the available aircraft test equipment cannot be used because of connection or other compatibility issues.[38]
- In some cases there are newer, more sophisticated, and/or better pieces of equipment commercially available.[39]
- Better equipment cited by the SMEs is already in use elsewhere, even within USAF and other military units.[40]

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[32] For example, the FLTS tester is the only available flight control tester available for the F-15C. Unfortunately, the F-15C SMEs indicated that even when it works properly it provides a limited range of testable parameters and the data obtained is often unreliable.

[33] For example, the AR (rigger) SMEs at Nellis stated they do not trust the results from a FLTS tester. In particular, they stated FLTS testing can "pass" a component multiple times, even though alternative tests clearly show the component to be unserviceable.

[34] For example, Nellis Aero Repair has a force tester for measuring G-force loads on flight control components; however, it is old and very unreliable. The F-16 SMEs reported their TTU-205 units are often broken or out of calibration. Although a sufficient number is available, few if any are usable when needed.

[35] A good example of this situation was cited by Nellis AR people. Their available stick rigging indicator tools have changed in recent years, but not completely for the better. The old (mechanical) devices took several minutes to install, whereas the newer (digital) ones only require about 30 seconds. However, the new digital versions are fragile, have problems with the batteries falling out, and can be expected to last only about 4 months. The old mechanical versions last for years.

[36] To give an extreme example, the Nellis Aero Repair Shop is small, and it is has a minimal inventory of test equipment and tools. In general, they have only one of each tool on hand at any given time. Moreover, some of these tools, such as a cable tensiometer, are the only ones on base. This means that if a piece of test equipment breaks or is out for recalibration Aero Repair has no testing capability. This can bring flight control work to a halt.

[37] Two good examples were cited by the F-16 and F-15 training SMEs at the Nellis FTD. Actuators were repeatedly cited as a source of diagnostic headaches on both aircraft. However, there is no diagnostic aid for troubleshooting integrated servo-actuators and no tester available for checking them on either plane.
F-16 leading edge flaps incorporate numerous mechanical subcomponents, so troubleshooting them quickly gets complicated, but there is no tester available to help with this job.

[38] For example, in one F-16 session it was noted that the only available pitot-static tester (the venerable TTU-205) cannot even be connected to the F-16, because the ones on hand do not have any F-16 compliant/compatible connectors.

[39] For example, an F-16 AFETS SME noted a commercially available tester, the ADTS 405F, that is far superior to the TT-205 for aircraft pitot-static checks.

[40] Some AF Reserve and Air National Guard units are already using the Druck 405 tester.

- Some equipment proven consistently useful is not always officially available or officially sanctioned.[41]

4.1.11 Connectors and Connections: A Persistent Issue in Both Diagnosis and Equipment Usage

One point that surfaced multiple times during the KA sessions was the extent to which connectors and connections (as contrasted with the components being connected) caused headaches for maintainers. This includes problems with connectors on the aircraft and connectors employed in setting up the test devices. Illustrative SME comments on this subject included:

- Connectors are quite often the source of fault conditions on the aircraft.[42]
- Many of the problems associated with AGE involve the connections between these devices (e.g., hydraulic mules) and the aircraft.
- Variations and glitches in cables and connectors can affect test readings and hence mislead troubleshooters (at the cost of time and effort).
- The SMEs and the support sections repeatedly cited the TT-205 connection set ("hose kit") as the most common source of problems in using the tester.[43]
- The ubiquity of connection faults in aircraft wiring is illustrated by the fact that one of the only tools found in the support sections surveyed was a wire and wire connection repair kit.
- The EDNA diagnostic tool used on the F-16 is deployed in a kit containing the basic cables. In addition, the support section stocks a connector kit with approximately 15 to 20 additional cables and connectors for linking EDNA to a given aircraft. The box containing the additional cable set is larger than the EDNA kit itself.
- Sophisticated onboard test capabilities are geared to identifying faults in discrete components, and they cannot discern when faults lie in the lines or connections among these components.
- The lack of compatible connectors is a major reason why the TT-205 is not used on the F-16.

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[41] For example, the F-16 SMEs cited breakout boxes as greatly facilitating their ability to track down signal faults in aircraft wiring. They are particularly helpful in determining which particular pin(s) relate to a problem identified in a connection or connector. The use of breakout boxes is not emphasized, there are no standard breakout boxes issued, and maintenance units often end up custom-building their own.

[42] The F-16 SMEs claimed the highest failure rates for F-16 swappable components are found among the weight on wheels (WOW) switch cannon plugs.

[43] The TT-205 hose kits are harder to get replaced than the testers themselves. The most commonly reported failure had to do with sealer rings in the hose end connectors. If one of these rings warps or degrades the hoses are unusable, making the tester unusable. Replacement hose components have to be ordered from Canada.

4.1.12 Issues Concerning Maintenance Expertise and Differences Between Experienced and Inexperienced Maintainers

The notion of "expertise" is important in undertaking task-specific cognitive and information requirements analyses. With respect to cognitive factors, it is important to identify what features are associated with attributed expertise in a given task. This sets the stage for focusing on what constitutes expert performance and aids in facilitating such performance. With respect to information requirements, it is important to both discern what "expert-level" information support is needed for proficient technicians and to account for more "novice-friendly" information support to allow less experienced people to operate adequately. During the KA sessions a point was made to ask the SMEs about what characterized expertise and what differentiated experts from novices.

4.1.12.1 What Characterizes "Expertise" in Maintenance Work?

The factors or features cited as generally indicative of "expertise" in maintenance work included:

- Experts are more proficient at making a "leap" from initial problem report to a likely diagnosis.
- Experts are quicker and more proficient at estimating the level of effort for repairs and the likely timeframe required to return the aircraft mission capable.
- Experts are more proficient at making a "leap" from initial discrepancy or diagnostic hypothesis to identifying the component that must be replaced.
- Experts are more knowledgeable about the details of the aircraft (sub)systems and how they interoperate.

4.1.12.2 What Distinguishes Expert from Novice/Inexperienced Maintainers?

In the course of the KA, it was learned that distinctions between experts and novices not only affect the quality and course of the maintenance process, but also affect the readiness with which other parties accept the results of a maintainer's diagnoses. The factors or distinctions cited as differentiating expert from novice maintenance performance included:

- Novices tend to scrupulously follow TOs step-by-step.
- Multiple SME groups characterized novice/younger maintainers as relying exclusively on the TO and BIT as the entirety of their diagnostic procedure (as opposed to digging into the fault via exploratory troubleshooting).

- There is a discernible difference between experts and novices in terms of how they view the TOs. Novices know only what is in the TO and are typically unable to troubleshoot beyond what is "in the book."
  - Experts are more proficient about relating symptoms to states or features of the physical aircraft layout (wiring, data network infrastructure, mechanicals).
  - Experts generally have more thorough knowledge of how the aircraft and its constituent subsystems actually work.
  - Novices are notably less knowledgeable and cognizant of details on how the aircraft works (and how its components and subsystems interact) as time goes on.
  - Novices are more reluctant to initiate free form exploratory troubleshooting when the available diagnostic procedures (e.g., tracing the fault tree via the FIs) fail to pinpoint the cause of a problem.
  - Novices are quicker and more amenable to stopping the maintenance process and "making the call" (invoking external technical support) once the cookbook diagnostic procedure bogs down.
  - The availability of BIT capabilities leads to both (a) increased reliance on the BIT tests and their results as well as (b) a lack of proficiency at "free form" troubleshooting. These factors tend to lead to atrophied or suboptimal troubleshooting expertise.
  - Because new maintainers are increasingly trained on aircraft offering these capabilities, they are never exposed to the need for exploratory troubleshooting (beyond what the BIT codes and FIs allow).
- More experienced maintainers often employ "non-standard" maintenance tactics (e.g., leaping to tentative candidate solutions; immediately doing "swapology" as recommended from their experience). Less experienced maintainers are often influenced by these non-standard habits observed in the more experienced personnel. Unfortunately, the younger maintainers emulate the expert behaviors without the benefit of the deeper knowledge upon which the experts proceed.
- It is becoming more common for maintainers to migrate among different aircraft types during the course of their maintenance careers. This works against gaining the experiential knowledge underlying expert performance. For one thing, after each migration the maintainer essentially has to start from scratch in learning the new aircraft. As time goes on, the maintainers acquire less and less experiential expertise with each passing aircraft on which they work, thus diminishing the cumulative degree of general expertise carried with them through subsequent migrations.
- Lesser-experienced maintainers, being generally younger, are typically more comfortable and adept in using computer-based aids.

4.1.13 Maintainers' #1 Recommendation for Information Improvement: Better Situation Awareness on In-flight Problem Context

In each session, SMEs were probed for their "wish lists" on what type(s) of data or information they felt would most improve their ability to perform flight control maintenance. For example, SMEs were consistently asked what one type of data or information they would desire to improve the flight control maintenance process. As each SME group gave their "wish list", their general suggestions were noted and were brought up with subsequent groups (in addition to whatever those subsequent groups cited as their "wish list").

Throughout all the sessions at both Nellis and Charleston, the #1 item on the SME "wish list" was better information on what was happening in flight when a flight control problem occurred. Even the riggers stated their #1 priority question is, "What did the jet do?" More abstractly phrased, the SMEs stated the single most important improvement would be better situation awareness (SA). The availability and completeness of such data will vary with the clarity and detail of the aircrew's fault reporting. These factors also vary with the type of aircraft, because different aircraft have differing mechanisms (if any) for capturing in-flight data and the data thus captured also varies from one aircraft type to another.

Additional discussion of this issue regarding cognitive aspects of the maintenance process will be provided in the section on CTA. A more detailed discussion of this issue with respect to current and prospective information assets will be provided in the section on information requirements analysis.

4.1.14 Maintainers' #2 Recommendation for Information Improvement: Ability to Simulate In-flight Conditions on the Ground

In the absence of information detailed enough to immediately discern a fault's root cause, the next best thing would be to simulate flight behavior with the aircraft on the ground. If such a simulation were possible, it would allow maintainers to replicate and observe anomalies directly, rather than being forced to rely on whatever information they could obtain from the aircrew and/or available in-flight data. By and large, this is difficult or impossible to do. More specific SME comments on this topic included the following:

- The ability to simulate or reproduce a reported problem would improve the diagnostic process.
- The ability to simulate in-flight conditions on the ground would help reduce "cannot duplicate" discrepancies.

- The operation of certain onboard safety devices (most particularly the weight-on-wheels or WOW switches) prevents even limited opportunities to attempt simulations on the ground. On some aircraft the WOW switches can be defeated to allow such testing, but such practices are frowned upon.[44]
- Some relevant parameters simply cannot be simulated on the ground (e.g., axes of in-flight orientation, G-forces).

4.1.15 Maintenance Training: A Consistent Focus for Improvement Recommendations

The subject of training surfaced again and again during the SME sessions at both Nellis and Charleston. The team had made a point to schedule KA interviews with trainers; however, training was cited repeatedly in the other (maintainer) SME sessions as well. Much of the discussion on training improvements mirrored the types of points made with respect to perceived differences between novice and expert maintainer capabilities (see Section 4.1.12.2 above). Some of the more significant points made in reference to training issues included:

- Experts are progressively more proficient about relating symptoms to states or features of the physical aircraft layout (wiring, data network infrastructure, mechanicals) than novices because novices, even those just out of training, exhibit a discernibly lower degree of knowledge about how the given aircraft (or any aircraft) works.
- The current flight control training scenarios typically involve simply stepping through the TO. In other words, student training is narrowly focused on cookbook procedures and not general diagnostic skills or experience in problem solving. This leads to a situation in which newer/younger maintainers may know how to do something, but are at a loss to understand why they are doing it.
- The Nellis Aero Repair SMEs noted a progressive deterioration in the ability of younger/newer maintainers to employ effective and accurate terminology and references to parameters in describing aircraft behaviors that must be accounted for. These people recommended better training on "what the pilots are telling you."
- Multiple SMEs (most particularly the trainers) generally characterized newer maintainers as coming out of technical school with noticeable deficiencies in general technical knowledge about how aircraft and aircraft subsystems operate.

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[44] For example, by using a screwdriver one can disable the WOW switches on an F-16 and thereby make it possible to test aircraft systems as if they were airborne. The FTD trainers who cited this example clearly stated both (a) this tactic is extremely effective and (b) it is potentially very dangerous and is only authorized under very specific circumstances.

- Other deficiencies noted for incoming trainees included deficiencies in the ability to use written reference materials, capacity for grasping abstractions, and ability to identify and project ramifications of observations and data obtained during troubleshooting.
- One F-15 trainer stated that flight control training attempts to address the full range of functions reflected in the process path diagram in Figure 1 (e.g., the paperwork and CAMS support implicit in the unit coordination steps). Nonetheless, the exercises trainees perform typically focus on the central (troubleshooting cycle) portion of the process path.
- In training, the tactic labeled "swapology" (switching out parts to see if that fixes the problem) is characterized as bad practice, and students are discouraged from relying upon it.
- There is a significant problem inducing the motivation and imparting the expertise to dig into flight control systems because such detailed troubleshooting requires both specific knowledge on the given aircraft and general knowledge of electrical, hydraulic, and mechanical technologies.
- Deep working knowledge of the aircraft comes from experience and practice. Neither the current training curricula nor classroom time affords the opportunities to develop such knowledge in the course of training.
- Extensive experience and practice are less and less likely on the newer aircraft (i.e., those equipped with BIT capabilities). Training curricula place less and less emphasis on delving into the aircraft as onboard capabilities such as BIT proliferate.
- Completion of a flight control course is a requirement for participating in an impoundment team. This course is not typically offered to junior or relatively inexperienced maintainers, but only to experienced maintainers and supervisory staff either as (a) refreshers or (b) opportunities for certification to work on impound teams.
  - The scope of material covered in the on-base flight control course extends from practical "theory" (as embodied in the TO) to standard or recommended procedures.[45]
  - Hands-on experience is usually limited to students working through scripted scenarios. These scenarios typically involve no more than stepping through the TO in relation to a sample problem.
  - These training scenarios do not usually involve giving students a problem that they must figure out on their own. In other words, the training scenarios usually begin with a specification of the problem up front. These scenarios usually do not incorporate elements of the operational context in which faults occur. These "by the book" stepwise scenarios do not force the students to explore the systems and infer what the problem might be. As such, it is difficult to see how they prepare

[45] The standard F-15 flight control curriculum at Nellis consists of 4 days of classroom training, 1 day of training on maintenance BIT, and 8 days of practical education working on a maintenance trainer or on a training aircraft. Flight control students may sometimes help out on the flightline, but that is not a prescribed part of the course.

the student for diagnosis. Because they do not involve context-sensitive fault conditions, these scenarios would not seem to sensitize the student to real-world faults.

- A big problem affecting new trainees is that out on the real world flightline there is rarely enough time or resources to conduct maintenance activities in the manner in which they were trained. This makes for a significant amount of adjustment once the trainees actually get to the flightline.

4.1.16 Other SME Recommendations for Information Improvements

Although better up-front SA on in-flight fault context was the obvious top choice for improved maintainer information, it was not the only thing the SMEs cited as being potentially helpful. Other items nominated for their "wish list" are enumerated and discussed in the following subsections.

4.1.16.1 Better Access to Experiential Info within the Maintainer Community

In spite of the generally voluminous "official" data found in the TOs, there is much relevant and useful information that can only be obtained from maintenance experience with a particular aircraft. Such information includes tips, tricks of the trade, and illustrative "lore" derived from experience with difficult maintenance problems. Such information is by definition inaccessible across units and to newer/younger maintainers unless some mechanism for recording and disseminating it is developed. Each unit logbook serves as the primary repository for such experiential knowledge. The SME groups uniformly cited the value of the unit logbooks as information resources. However, the logbook entries are not collated or compiled for general distribution, and they are "retired" after a few years. This means that the "rearward horizon" for logbook entries (and the attendant experiential knowledge) is limited.

The SMEs indicated there are no effective online channels for general discussion and note-sharing (e.g., chat rooms; bulletin boards, ListServ forums). The only established channel identified for dissemination of such experiential knowledge is an *Eagle Notes* newsletter that had been distributed in the F-15 community; although there was some question as to whether or not it still existed.

4.1.16.2 Faster or Better Access to Available Onboard Data

One of the ways in which maintainers can obtain better situation awareness on the in-flight discrepancies is to review any data captured and recorded during the flight. The existence, scope, volume, and format of such data vary from aircraft to aircraft. Those aircraft, which offer such onboard data resources, do not always provide the data in a form that maintainers can readily use. Some data sets have to be downloaded and sent out to another office to be transcribed and/or translated into a form the maintainers can access can access and use on the flightline. Time spent awaiting such processing is time added to the maintenance process path.

4.1.16.3 More Detailed Information on the Interplay Between Specific Parts and Specific Planes

Modern military aircraft are so complex that some tail numbers often exhibit their own peculiarities. One relevant aspect of this "individualism" is that a particular LRU may or may not function correctly on a given aircraft. This dysfunctional status may be peculiar to the particular pairing of that LRU and that aircraft (i.e., the LRU may work just fine on another aircraft). Multiple fighter SME groups (most especially the F-15 and F-16 SMEs) noted situations in which an LRU that failed on a given aircraft was cycled back to the test stations only to test good there and end up back on the flightline in another aircraft where it worked just fine. Without making provision for tracking such historical incompatibilities, maintainers may waste time swapping in an LRU already known to not work on a given aircraft.

This situation is distinct from that in which generally dysfunctional parts end up on the supply shelf, although that, too, was an issue cited by most of the SME groups. In this case, an LRU repeatedly goes back and forth between the flightline and the test station, possibly working for a few sorties in the meantime. In most units these bad actor LRUs are soon identified, tracked, and ultimately shipped for depot repair; although frequently not before they have caused several flight discrepancies and possibly lost sorties as well.

4.1.16.4 A Glimpse at the Future: Flight Control Maintenance for the RQ-1 and F/A-22

During the KA visit to Nellis the team was offered the opportunity to interview people working with the RQ-1 Predator UAV and the newly arrived F/A-22 Raptor. Because of the potential value of getting a glimpse at the future context for flight control maintenance, that offer was accepted.

4.1.16.4.1 The F/A-22 Raptor

One of the commonly cited innovations of the F/A-22 Raptor program was its approach to maintenance operations and diagnostics. The team took the opportunity to gather information on the new maintenance concept of operations and to explore what it signifies in terms of ongoing maintenance evolution. The most salient general points/issues arising in discussions with the Raptor personnel included the following:

- The highly automated maintenance concept for the F/A-22 is intended to accelerate the progress from diagnosis to repair/replacement action. Intervening steps for testing, exploratory troubleshooting, etc., are not only downplayed but intended to disappear as much as possible from the maintenance process. A primary goal of these innovations was to reduce the time and effort invested in probing the aircraft to diagnose a problem (i.e., to minimize the temporal costs of the troubleshooting cycle described in Figure 1).
- The F/A-22 incorporates a high degree of onboard self-test capabilities, because the maintenance concept emphasizes the aircraft's ability to self-test so as to efficiently deliver reliable diagnoses and action recommendations to maintainers.
- The fault isolation elements are to be absorbed into IMIS. The concept of operations is to interact electronically with the aircraft and have the aircraft provide informative responses/answers to probes. Troubleshooting on the F/A-22 is intended to be done via software, which is being inserted into the maintenance process and the maintainers' toolkit like never before.
- The IMIS-based diagnostic software will interact with the onboard systems, filtering and parsing along a virtual fault tree to vector in on a fault condition. The end point of this diagnostic process is to allow the combination of onboard and outboard diagnostic devices to tell the maintainer what part(s) need to be replaced. This IMIS-driven troubleshooting concept maximizes the role of the automation and minimizes any requirement for human involvement (in terms of guiding or advising the course of diagnosis).
- The F/A-22 includes a comprehensive in-flight data capture capability. It will record all flight data and parameters onto a Data Transfer Cartridge (DTC). This data can then be downloaded when the aircraft is back on the ground. The concept is intended to limit pilot reporting involvement to only those situations in which out-of-range values or conditions are encountered.
- A pilot debriefing will still be conducted; however, the pilot will not have to rely on memory and verbal communications. He/she will be able to take the DTC into the briefing, where the data will be downloaded into IMIS. Separately from the pilot's debriefing download of the DTC, a "sortie download" will also be routinely done.
- The F/A-22 maintainer's main tool will be the Portable Maintenance Aid (PMA) - a portable/luggable computer device that docks to the aircraft at any of three docking ports.[46]
- The concept is that maintainers will be doing the sortie download with the PMA in parallel with the pilot debriefing using the DTC.

[46] Two of these ports are located in each of the main wheel wells and one is in the cockpit.

- The F/A-22 SMEs concede it will probably take years to get this operational routine to the point it becomes "routine."
- The software-based diagnostic approach in the Raptor admittedly does not account for physically-based deficiencies or fault sources (e.g., wiring faults or poor connections).
- The only fallback/reachback position for F/A-22 maintainers at this early stage is to call in engineering technical support. There is a significant forward deployment of contractor technical staff to support this new aircraft at Nellis.
- The goal of the F/A-22 maintenance concept is to produce a completely paperless and integrated maintenance knowledge base. All FIs and TOs are planned to be incorporated into the software support suite. No provision is planned for providing FIs and TOs in paper form (at least not to the frontline maintainers).
- Once the on-site maintenance team runs through the technical data provided by the current systems, they are "done" (i.e., there is nothing more they are supposed to do). Once they reach this point, the frontline maintainers are expected to call in the technical support engineers. This immediate and unavoidable information reachback protocol is part and parcel of the F/A-22 maintenance concept, and it is fully expected to continue.
- A capability for the F/A-22 to transmit real-time in-flight data has been recommended, but it has not yet been funded. The issues explaining why this data transmission capability is not in progress apparently have more to do with security concerns than funding limitations.
- The SMEs were questioned about the unusual degree of reliance the F/A-22 concept places on the PMA devices.[47] Their responses are well illustrated by one SME's statement: "The conveniences outweigh the disadvantages."
- The SMEs concede that the current IMIS data-/knowledge base has been assembled on a site-specific and sometimes ad hoc basis. Now that the aircraft is being used, the F/A-22 team is starting to discover instances where this opportunistic knowledge base assembly has left gaps and variances.
- Advantages touted for the PMA included:
  - Portability + integration (i.e., everything you need can be carried in one package)
  - Ready access to complete technical data at the aircraft
  - Integrated "one-stop" access to forms, TOs, FIs, and other supporting documentation.
  - The windows interface provides a consistent and coherent basis for user navigation and drilldown.
- Disadvantages or problematical issues conceded for the PMA included:

[47] When asked if the F/A-22 could be effectively denied maintenance support if the PMA devices were inaccessible or destroyed, the SMEs acknowledged this would be the case.

- The software is currently immature.
- The knowledge base is both immature and not all that refined with respect to the parts that are already in place.
- The PMA hardware platform was state of the art around 10 years ago (when it was introduced in prototype form), but it is showing its age now.
- The PMA processor is relatively slow by today's standards.
- Combined with the complexity of the software, the PMA is quite sluggish in operation.
- There is no touch screen capability.
- The windows interface utilizes relatively few graphics, and it is predominantly text-based.

4.1.16.4.2 The RQ-1 Predator

Unmanned aerial vehicles (UAVs) are now acknowledged to be the "wave of the future." If for no other reason than their imminent ubiquity, the team believed it constructive to review the RQ-1 Predator to see what, if any, points could be discerned about flight control maintenance for this category of aircraft. The most significant points obtained in this session included the following:

- On the Predator, all flight control surfaces are operated via electromechanical servomechanisms. Because of this, all flight control problems on the RQ-1 are "electronic problems."
- Each individual flight control surface can be isolated and independently addressed via the ground pilot's control stick. Control inputs are interpolated from a variable voltage flight control controller. These inputs comprise the digital data stream outgoing to the aircraft.
- Flight control maintenance on the Predator is definitely distinct from such maintenance on the larger manned aircraft. Given the relative technical simplicity of the Predator airframe, there are not many details to troubleshoot. On the other hand, troubleshooting is fairly straightforward. Even on this simple airframe, rigging problems do occur. These are most commonly evidenced by recurrent error/variance in a single flight control surface.
- The primary guidance/computer support is not on the aircraft. It is in the ground control station (GCS) where there are two control consoles - one for the "pilot" and the other for sensors (controlling and monitoring the reconnaissance payload).
- The most difficult flight control issue to figure out is discriminating between an LRU fault and erroneous data attributable to the GCS or the communications link.
- The communications link back to the ground/pilot station can be a source of errors and variances. Because it adds another potential source of faults and glitches, the communication link represents the downside of the tradeoffs in using UAVs.

- The direct communication link is good to a maximum of about 100 miles with line-of-sight. Beyond this range control has to be routed through a satellite link. Use of the satellite link induces a communications delay of approximately three seconds.
- On the ground, troubleshooting is facilitated by hooking the aircraft systems directly to the GCS. When troubleshooting on the ground, one can switch between the pilot and sensor stations to cross-check (a) what was happening with one side when an event was occurring with the other and (b) to cross-check interactions between the two aspects during a mission, maneuver, etc.
- In effect, the RQ-1 has its "cockpit" on the ground. This means interactions between the pilot and the aircraft must be mediated by a communication link. One beneficial outcome is that there must be a single coherent two-way data stream carrying all aircraft status and control data back and forth. In other words, the extent of captured in-flight data aspired to by the other maintenance SMEs is available by definition with the UAV.
- There are two primary modes of data capture for a Predator mission: an 8 mm video trace and the data points archived from the digital communication link.
- It is easy to swap out aircraft/GCS pairs to crosscheck interactivity and determine which of the elements is the problem.[48]
- A total of 39 different displays or screens (termed Variable Information Tables - VITs) comprise the ground crew's interface for monitoring the RQ-1. All 39 VITs are being recorded. This means that every data element provided the ground crew is being archived - a 100% flight data recording capability.
- A constant data sampling rate is maintained on flight controls and other flight data during a mission. The recording medium is 8mm videotape cassettes with an effective recording time of about two hours. A full set of these tapes makes for a comprehensive mission data log.
- Problem duplication is a matter of a relatively straightforward process of elimination with the Predator.[49]
- The SMEs stated that RQ-1 pilots were good about being able to specify when and in what context flight control problems occurred.[50]
- The voluminous data that is recorded is in numerical format. The mathematical software package MatLab can be used to translate and display the data sets.

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[48] This may not sound significant, but consider that it is the equivalent of swapping out the entire cockpit in a manned aircraft.
[49] This was illustrated with an example of a recent flight control problem. The preceding week, a flight control problem had been reported by the pilot. The bird was checked against one known to be free of flight control defects. It turned out the bird checked out OK. This enabled the maintainers to quickly zero in on the GCS. They determined the problem resulted from an out of tolerance control stick.
[50] In other words, the sort of operator/pilot information the other SME groups rated as their #1 desire is already available with the Predator. One might hypothesize that the Predator pilot is operating with less situational distraction (G-forces, visual distractions) than a pilot inside a manned aircraft. This would reduce relative cognitive burden (from distractions) and should facilitate real-time SA and hence post hoc memory for problem conditions that occurred.

- The availability of so much relevant data allows the Predator team to diagnose relatively subtle problems in short order. An example was given concerning radio frequency interference with the flight controls. When the data sets were reviewed, they could readily see a correlation between the observed uncommanded movements and the triggering of certain radio equipment on-board.
- The TOs available for RQ-1 diagnostic support are "not good."
- There is no special or complicated test equipment required to service the Predator.
- At the present time, diagnosis of flight control problems is more a matter of experience than the sort of laborious test-and-analyze approach used on the manned aircraft that were reviewed.
- The only tool specifically cited as used for flight controls was an electronic inclinometer.
- Instead of abstract MFL codes, the RQ-1 maintainers deal with text messages.
- The SMEs gave a consensus estimate that flight control problems comprise approximately 20% of all maintenance discrepancies. This includes the tailboard removal/reinstallation that must be done anytime there is work done on the engine.
- The flight control servos are swapped out at approximately 85 to 200 flight hours. Service life data on the servos and other components is still being collated and analyzed. It is rare for a servo to completely fail.
- The documentation requirements for RQ-1 maintenance are the same as for the manned aircraft. Two sets of documentation are maintained - one for the GCS element and one for the aircraft itself.
- Local/on-site technical support is readily at hand and very deep.
- In the event of a flight control problem, there is an impound procedure. In the case of impoundment, there are two impound officials - one for the GCS and one for the aircraft.
- The SMEs stated their biggest maintenance constraint right now is access/display/analysis of all the data they have available to them.
- The use of MatLab to access the logged data carries an overhead for mathematical knowledge.
- The archived data constitutes a linear trace of the in-flight parameters. MatLab turns this raw data into a series of summary line graphs. Analytical interpretation is a matter of visually scanning these line graph depictions for significant indicators.
- One SME who had worked on both aircraft flatly stated flight control fault diagnosis on the Predator was "a lot faster than on the F-16."
- Data is captured for each of the flight control servos. This means it is relatively easy to zero in on the particular servo associated with a reported fault.
- Rigging tools for the Predator are fairly crude.

- One big advantage of the UAV setup is that the maintenance person can be called in to literally look over the pilot's shoulder while the aircraft is in flight. As one of the SMEs put it, this "beats any debrief." This may well be the most significant point obtained with respect to UAVs and their maintenance process path. Not only can the pilot notify a maintainer of a flight control issue while the flight is still in progress, the maintainer can literally be briefed on the problem as it is occurring. Combined with voluminous in-flight data capture and the ability to obtain clues on flight control issues by maneuvering the RQ-1 in flight, this means the Predator maintainer has access to a degree of situation awareness on the actual problem to a degree that other maintenance SMEs can only dream of.
- The maintainer and the pilot can jointly perform limited in-flight diagnostic tasks by maneuvering the aircraft and seeing what happens. If the Predator is carrying a camera package, the camera can even be exploited for flight control diagnosis. Within limits, it can be rotated to allow visual inspection of the flight control surfaces in flight.
- The maintenance reference assets are both new and problematical. An effort was only recently undertaken to totally re-do the Predator TOs. Predator maintainers do not use FIs. The available information support is peculiar because it is provided in a Navy diagnostic reference format.
- One particular problem is the flight control software support. Everything about the pilot's control over the aircraft is software-mediated.
- This software is complex, and multiple versions may be in use at any given time. There are frequent changes/updates/upgrades in the software. All this makes it difficult to become expert with the software, because it is always a moving target.

4.1.17 Summary: Knowledge Acquisition

The KA visits to Nellis and Charleston went very well, and the team obtained considerable data in a relatively short time. The attention to generating a KA plan (Appendix C) in advance of the trips allowed the team to coordinate the KA team effort and to make maximum use of on-site time. The "cascade approach" to incrementally fleshing out team understanding of flight control maintenance atop the initial process path map enabled them to remain organized. Attention to gathering data on auxiliary units of the maintenance organization (i.e., test stations; support sections) and currently peripheral information on both the RQ-1 and F/A-22 enabled the team to understand the core maintenance process in a wider context. The data presented above represents only a portion of what was obtained. Even if this were all that was gathered on the two KA trips, the outcome would still have to be considered a solid success.

4.2 Cognitive Task Analysis

Cognitive Task Analysis (CTA) concerns the examination and critical analysis of a work activity or process with regard to the cognitive aspects of work. Basically, this means analyzing the "mental work" associated with a given task in the same way that older methodologies analyzed that task's "physical work." A task's "cognitive aspects" are commonly taken to include:

- The perceptual acquisition of data in the course of a task
- The data and information elements critical to conducting the given task
- Mental models a worker employs for the task process itself and the subject matter he/she must address during the task
- The decisions that must be made to complete the task
- The critical dimensions of decisions made in the task (e.g., critical data, time to decide, confounding factors, mode of inference, means for testing alternatives)
- The degree of "cognitive workload" or "cognitive burden" entailed in performing the task
- Cognitive and informational factors which can induce errors and other degradations in task performance (e.g., data deficiencies, data overload)

Maintenance work is cognitively intensive. From the outset the maintainers must obtain and process potentially large amounts of data (problem reports, symptoms, diagnostic data). They have to correlate this data with their available models (internal/mental and external/diagrammatic alike) in the course of generating diagnostic hypotheses and evaluating both these hypotheses and the course(s) of action to be undertaken. There are decisions to be made on a range of topics in distinct referential contexts (e.g., procedures, functional data, hypotheses, coordination with teammates, aircraft performance and viability for duty, etc.). As a result, maintenance is an information-intensive task, and cognitive analysis is a significant tool in understanding this task.

In the following sections the approach to collating the KA results into a coherent cognitive model of the maintenance process path will be reviewed. In addition, the most significant points derived through analysis will be discussed.

4.2.1 Background: Temporal Orientation to Maintenance Performance Assessment

The MXM effort was geared to explore the interrelations between maintainers' information processes and their maintenance tasks. The majority of the points cited in the section on KA relate to data, information resources, and process. Applying all this information to the maintenance task requires stating what it is about task performance one is seeking to analyze. In the course of its KA work the team obtained summary statistics on USAF maintenance performance. A set of tabular compilations of such data (for fighter aircraft) is offered in Appendix I. A more concise summary table of performance statistics for four categories of fighter aircraft covered in the KA work is given in Table 6.

Table 6: CTA Overview--Performance Data for Four Fighters (FY93 - FY02)

	4 HR FIX RATE (Standard)	4 HR FIX RATE (Actual)	8 HR FIX RATE (Standard)	8 HR FIX RATE (Actual)
A-10				
10-Yr Average	65.2	67.5	81	82.57
Shortfall (10-Year Average)		+3.5% (better than standard)		+1.9% (better than standard)
10-Year Trend (First vs. Last)	Nominally Unchanged	-7.9%	-5.88%	-6.4%
F-15C/D				
10-Yr Average	57	53.92	75 (approx.)	72.9
Shortfall (10-Year Average)		-5.4% (short of standard)		-2.8% (short of standard)
10-Year Trend (First vs. Last)	Unchanged	-31.1%	Nominally Unchanged	-20.4%
F-15E				
10-Yr Average	59.4	53.6	75 (approx.)	73.2
Shortfall (10-Year Average)		-9.75% (short of standard)		-2.24% (short of standard)
10-Year Trend (First vs. Last)	+5.3%	-25.8%	Nominally Unchanged	-18.5%
F-16C/D				
10-Yr Average	66	63.45	85	81.28
Shortfall (10-Year Average)		-3.86% (short of standard)		-4.38% (short of standard)

	4 HR FIX RATE (Standard)	4 HR FIX RATE (Actual)	8 HR FIX RATE (Standard)	8 HR FIX RATE (Actual)
10-Year Trend (First vs. Last)	Unchanged	-20.1%	Unchanged	-14.13%

Some cursory points evident in Table 6 include the following:

- In absolute terms, 4- and 8-hour fix rate performance is trending worse for all aircraft over the 10-year period.
- With the exception of the A-10, performance results fall short of established standards for the 10-year period as a whole.
- There's no clear pattern to the summary outcomes with respect to average performance (relative to standard) over the 10-year period. For half the aircraft the shortfall for 4-hour rate performance is worse than for 8-hour performance, while the reverse is the case for the other half.
- For all aircraft, the first-versus-last year's downward trend over the ten years is more pronounced for the four-hour fix rate than for the eight-hour fix rate.

Because these particular statistics are framed with regard to time (percentage of aircraft fixed in a given number of hours), it is reasonable to characterize the evaluation context as temporal. The fact that the 4-hour rate performance has worsened farther than the 8-hour rate performance is consistent with a situation in which the maintenance process is taking longer and longer to effectively complete. Time to completion is the one general criterion that can be interpreted to subsume negative effects resulting from a variety of possible sources (e.g., error, grappling with ambiguity). Given its generality and its prominence in the available evidence, it is therefore reasonable to adopt temporal maintenance process performance as the general dimension for framing the analysis of the maintenance process.

4.2.2 General Observations about Temporal Performance Based on Available Statistical Data

It is, of course, very risky to venture conclusions about the projects focal topic (flight control maintenance in particular) on the basis of statistics compiled at a more general level of reference (all maintenance). Nonetheless, there are some broad observations that can be offered with respect to the informational aspects of maintenance that were emphasized in this study.

4.2.2.1 Observation Regarding Effects of BIT Data Capabilities

If BIT capabilities were uniquely influential in facilitating the overall maintenance process, one might well suspect that maintainers of aircraft with BIT capabilities would exhibit better temporal performance data than those lacking them. Conversely, one might well suspect that the worst temporal performance would be exhibited in maintaining aircraft without BIT capabilities. The data summarized in Table 6 does not clearly support this notion.

4.2.2.2 Observation Regarding the Effects of Automated Diagnostic Decision Aids

If automated diagnostic capabilities were uniquely influential in facilitating the overall maintenance process, one might well suspect that maintainers of aircraft for which such dynamic inferential support was available would exhibit better temporal performance data than those lacking it. Conversely, one might well suspect that the worst temporal performance would be exhibited in maintaining aircraft without such aids. The data summarized in Table 6 does not clearly support this notion. The one aircraft with the longest standing automated diagnosis aid (the F-16 with EDNA) is not the one with the best 4-hour and 8-hour fix rate performance statistics.

4.2.2.3 Observation Regarding the Effects of Complexity in the Aircraft and Associated Maintenance Decision Space

It is reasonable to hypothesize that the more complex the aircraft systems are the more complex the associated maintenance decision space will be. It is also reasonable to hypothesize that there would be a negative correlation between decision space complexity and the expedience with which it can be navigated (and hence the expedience with which maintenance processes are conducted). Given these notions, one might well suspect that the least complex aircraft systems would be correlated with better temporal maintenance performance statistics. Unlike the former two notions, this one is consistent with the statistics in Table 6. Of the listed fighter aircraft, the one with the simplest flight control systems is the A-10. As the figures illustrate, this is not only the aircraft with the "best" overall ten-year performance numbers, but it's also the only one of the listed aircraft which has met and even exceeded its maintenance performance standards.

As stated above, these are merely observations on the available data, not "proofs" of particular hypotheses. If anything these observations pertain not to what can be proven but rather what cannot be proven (at least readily and on the basis of this evidence). The team cannot prove that BIT capability or the application of automated logic improves maintenance performance. By the same token, the team cannot disprove that complexity in the subject systems (and hence in the associated diagnostic decision space) degrades maintenance performance. The bottom line is that there is no clear evidence indicating human cognitive performance should be any less a primary concern than the impacts of various technological capabilities. Having said that, attention will now turn to depicting and analyzing such human cognitive factors in the context of flight control maintenance.

4.2.3 General Points Concerning the Maintenance Process Path

The following points can be made about the maintenance process path outlined with the maintenance SMEs:

- *The general course of progress through the process path is not random.* There is a reliable course through the process path that is followed. One does not start or proceed with just any step in the path. As a result, an appropriate model of the process path should account for the general linearity of a representative instance of the process being modeled.
- *This general course is not invalidated by the leaps, cycles or truncations noted in the KA sessions.* The fact that one might jump ahead or backward in the overall path doesn't invalidate the process model because these leaps are transient moves in what remains an essentially linear line of progress. This same basic principle holds for cycles and truncations as well. As a result, an appropriate model for the process path should not be incapable of accounting for such optional events.
- *The most telling cumulative performance variable in evaluating outcomes of this process path is temporal duration (i.e., time to completion).* Measures of "quality" or "accuracy" do not unilinearly accumulate during the course of the process path. At any subsequent step, measures of these and similar abstract metrics can stagnate or even reverse (as when a good start leads to a misstep). Temporal duration, however, accretes linearly and irreversibly throughout the course of progress through the process path. As a result, an appropriate model for the process path should be capable of correlation with a linear timeline.
- *The maintenance process path entails considerable data and information processing.* From the outset (in receiving a pilot report) to the finale (when documentation of an outcome is compiled, presented, evaluated, and certified) the maintenance process is an information-intensive activity. As a result, an appropriate model for the process path has to make allowance for correlating data and information with other elements.
- *However information-intensive it is, the maintenance process path cannot be comprehensively portrayed solely in terms of information processing.* Resolution of a maintenance problem does not

stop with an abstract diagnosis. Tangible action is required to affect a solution. Along the way to this solution, many other tangible actions (e.g., testing) must occur in progressing through the process path. As a result, an appropriate model for the process path has to make allowance for correlating actions with other elements.

These points delineate a set of criteria for the model(s) that can appropriately be employed to usefully depict the maintenance process path. In the following section a model meeting these criteria will be introduced and discussed.

4.2.4 Selecting a Representational Framework for the MXM CTA Work

There are a number of models and frameworks available for collating and analyzing cognitive task performance issues. Many of these instruments are based on representation and analysis of one worker performing one single task. Given the shift of focus in the MXM program toward coverage across multiple aircraft, this one-worker/one-task arrangement does not fit the purpose. This meant the team needed to select a representational model capable of generalization across specific maintenance processes (for the subject aircraft) and capable of accounting for work processes undertaken by teams (as opposed to individuals). Second, the focus on the application of data and information in the maintenance process constrained the range of cognitive engineering models that recommended themselves for analytical purposes. This meant that a representational model allowing for correlation of data types with process steps had to be selected. Finally, maintenance work (although cognitively burdensome) is not purely a matter of information processing. It's not unfair to characterize maintenance as the physical manipulation of a malfunctioning artifact until it again meets expected performance criteria. The tangible actions required are not "informational," but they are guided and evaluated by informational (and hence cognitive) processes. This meant that a representational model providing a basis for interrelating information with the decisions and decided courses of action during the maintenance process path needed to be selected.

In summary, a cognitive model was needed that was capable of usefully representing:

- The overall course and stepwise sequencing of the maintenance process path (Figure 1)
- The practical actions or courses of actions undertaken at each step in this process path
- The mapping of data and information onto this path sequence
- The manner in which data and information interrelate with decisions made and actions taken

The two cognitive engineering approaches most widely invoked at this time each have deficiencies with respect to these selection criteria. The *means-ends hierarchy* (sometimes called an *abstraction hierarchy*) developed by Jens Rasmussen (Rasmussen, 1986) is a model for correlating top-level task goals to low-level activities and physical implements. This model yields a detailed picture of the "structural elements" descriptive of a given task. However, this model is a static "snapshot" of the most general or abstract elements involved. It is unable to depict processual elements such as the sequencing, feed-forward, and step-specific information requirements that the team sought to map out. Although Rasmussen does address diagnostic decision paths with his so-called *decision ladder* model (*Ibid.*), this model does not easily correlate, much less integrate, with the detailed abstraction hierarchy.

The approach labeled *naturalistic decision making (NDM)* (Klein *et al.*, 1992) emphasizes critical incidents and indicators associated with a decision maker selecting courses of action under conditions of high uncertainty (e.g., battlefield command and control). This approach is ill suited for MXM purposes for multiple reasons. First, its focus is on decision making in and of itself. Although (as mentioned above) the maintenance process path is laden with decisions to be made, it's not fully explainable in terms of decisions alone. Second, the NDM approach is geared to analyzing situations where the operational context is fluid and uncertain. Although this is perhaps characteristic of the early diagnostic phases of the maintenance process path, it is not characteristic of the latter phases (in which the maintainers are working in the context of the very deterministic decision space of "does it work or doesn't it?"). Finally, the typical NDM focus on individual decision makers makes this approach difficult to apply to collaborative team situations such as MXM subject matter.

The model or framework judged most amenable to MXM purposes is the *OODA Loop* of Col. John R. Boyd (Boyd, 1987). Boyd's OODA Loop has become a dominant analytical device in the C^4I literature, and it has been demonstrated to be an effective framework for describing and analyzing information operations (Whitaker & Kuperman, 1996). These well-known recent applications obscure the fact that the OODA model had its origins in explaining the perception-decision-response sequences entailed in high-performance activities for individual operators (fighter pilots).

The OODA Loop is a cyclical interrelating process path leading from perception of situational data through decision-making and on to resultant action(s). The acronym "OODA" stands for *Observation - Orientation - Decision - Action*, and the "loop" connotes a cyclic iteration through these four steps (Figure 2).

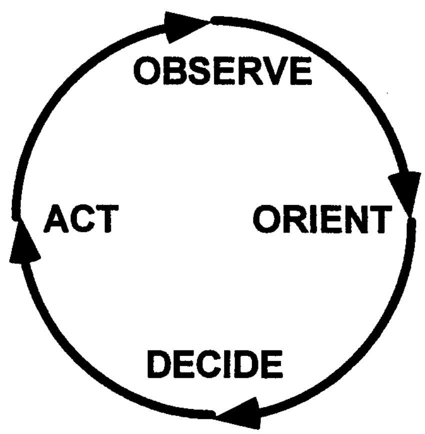

Figure 2: OODA Loop (per Boyd, 1987)

For all its deceptive simplicity, Boyd's OODA Loop incorporates several key features that make it useful in cognitive task analysis. First, it explicitly frames the subject matter in terms of continuous process from perception (Observe) through cognition (Orient/Decide) to response (Act). This affords a scope of referential context identical to that of MXM (maintainers perceiving data and making decisions for ongoing maintenance actions). This permits one to proceed without decomposing the subject process into multiple (and potentially irreconcilable) sub-models (as, e.g., would have been the case in applying Rasmussen's models). Furthermore, the fact that the OODA model encompasses the entire path from perception to action affords a framework for correlating relevant elements that could not be accounted for in other models (e.g., critical incident analysis).

4.2.5 Mapping the maintenance Process Path onto an OODA Representation

Having selected a representational schema, the next step is to map the process path (Figure 1) onto this schema and populate the schema's constituent "slots" with the data peculiar to the process being so mapped. For the purposes of this report, the summary results of this mapping are presented in the form of 11 tables below. The reason for using eleven OODA "maps" for the eight-step process path was to further break down the troubleshooting cycle into four segments so as to both (a) account for the subsidiary functions subsumed in the cycle and (b) make the clearest presentation of the O-O-D-A progression inherent with respect to each of these subsidiary components.

Each of the 11 tables provides a cursory enumeration of elements associated with each of the four OODA steps. For the "Observe" step, these will be elements (e.g., data, situations) that must be perceived. For the "Orient" step, these will be elements for which maintainers must achieve situation awareness. For the

"Decide" step, these will be the issues or topics for which decisions must be made. Finally, for the "Act" step, these will be the typical actions (or courses of action) deriving from that phase's Decide step.

As applicable, the tables also include a listing of the potential "leaps" (process path jumps other than simply moving forward to the next step) that might occur. The set of "leaps" noted herein reflect both (a) such occurrences specifically mentioned by the SMEs and (b) other such jumps discernible in the evidence or derivable from SME accounts.

4.2.5.1 Problem Identification/Reporting

This is the initial step in the maintenance process path identified by the SMEs. Using a brief summary set of elements derived from the KA materials, this step can be mapped onto an OODA structure as illustrated in Table 7.

Table 7: OODA Map for Problem Identification/Reporting

Problem Identification/Reporting			
Observe	**Orient**	**Decide**	**Act**
♦ Pilot notification ♦ Pilot description of problem/anomaly ♦ Indications and warnings (from pilot; from data assets)	♦ Determine nature of apparent flight control anomaly ♦ Contextualize anomaly with in-flight conditions/actions (with on-hand data) ♦ Discern basic symptoms ♦ Check readily-accessible A/C parameters (e.g., switchology)	♦ Viability/clarity of problem report ♦ Viability/reliability of reported symptoms ♦ Viability of trying a "quick fix" (e.g., reset) ♦ A/C subsystem(s) likely to be involved	♦ Probe for more info from aircrew? ♦ Switchology correction? ♦ Reset attempt? ♦ Explain why anomaly doesn't require fix (e.g., anomaly resulted from inappropriate in-flight action)? ♦ VERY QUICK FIX? ♦ OTHERWISE: Proceed to next

Potential "Jumps" in Process Path	
Forward	**Backward**
♦ Troubleshooting Phase 1 (Setup) - Immediate capture of volatile on-board data ♦ Troubleshooting Phase 2 (Diagnostic Hypothesis) for either future reference or for attempt at quick fix ♦ Troubleshooting Phase 3 (Acting on Diagnosis) for "quick fix" ♦ Solution Reporting/Documentation (if "quick fix" works and gets documented) ♦ OUT of process path (if immediate "quick fix" works and is not documented)	OUT of process path if there's a determination of no actionable problem

The basic elements to be observed are the fact and content of the aircrew problem report, along with any auxiliary data or clues that can be obtained. At this point, the maintainer needs to orient to the state of the aircraft and any available data to set an initial context for addressing the reported problem. Decisions to be made at this early point primarily relate to the report itself and (as the data allows) any readily discernible hypotheses about the problem's cause. Actions in this phase are most often directed toward fleshing out the problem report and/or making an immediate resolution response (i.e., a "quick fix"). Maintainers may "leap" forward to troubleshooting if confident about an initial hypothesis or even to solution reporting if a quick fix works (though according to the SMEs quick fixes often are not documented). In the event a "no-fix" condition is recognized, the maintainer may "leap" out of the maintenance process path altogether (i.e., he/she is "done").

4.2.5.2 Front-end Unit Coordination (Getting the Aircraft into the Maintenance Cycle)

This is the initial step beyond perfunctory "no-fix" or "quick fix" incidents in the maintenance process path. This step can be mapped onto an OODA structure as illustrated in Table 8.

Table 8: OODA Map for Front-end Unit Coordination

Unit Coordination (Get A/C Into Maintenance Cycle)			
Observe	**Orient**	**Decide**	**Act**
♦ Unit protocols and procedural standards ♦ Current state of personnel and resources ♦ Weather ♦ Available space ♦ A/Cs scheduled flight itinerary	♦ Roles that must be represented on impound team ♦ Prospects for working inside vs. outside ♦ Options for placing aircraft for the work ♦ General prospects for the aircraft's return to service	♦ Personnel to be assigned to team ♦ Area where maintenance work will be conducted ♦ Tentative prognosis for Pro Super ♦ QA/QC coordination requirements	♦ Advise Pro Super of A/C being removed from duty status ♦ Assemble impound team ♦ Designate Impound Official ♦ Designate Team Chief ♦ Coordinate with QA/QC ♦ Document impound ♦ Release A/C for maintenance work

At this point the maintainer's observations are made with regard to the maintenance organizational and task environments (as opposed to the aircraft per se). Similarly, the orientations made in this step have more to do with organizational context than the specific aircraft and its functionality. Decisions made at this point relate to matters surrounding conduct of the pending maintenance work and not the object of that work. Finally, the actions undertaken relate to the administrative requirements for entering the aircraft into the maintenance cycle. Given the potential complexities of the organizational space in which this step must be effected (e.g., scheduling conflicts; organizational rules; documentation requirements), it is as cognitively intensive as any of the others.

4.2.5.3 Maintenance Setup/Preparation

This is the step in which the maintainers actually begin their "maintenance work" per se. The cognitive elements of this step fit an OODA structure as illustrated in Table 9.

Table 9: OODA Map for maintenance Work Preparation

Mx Setup/Preparation			
Observe	**Orient**	**Decide**	**Act**
◆ A/C location and state ◆ Available space constraints ◆ Personnel availability ◆ Equipment availability ◆ Initial assessment of work to be done	◆ Prospects for parking A/C ◆ Feasible coordination of personnel and equipment	◆ Where to park A/C ◆ AGE required ◆ Tools & instruments required ◆ Tech data (e.g., reference aids) required ◆ Maintenance agenda ◆ Sourcing for required assets	◆ Move and park A/C for maintenance work ◆ Obtain AGE, tools, instruments, tech data

There are no obvious opportunities for leaping either forward or backward in the process path in this step. The maintenance preparations concern the ability to work on the aircraft, not the resolution of the reported problem. Because such resolution is by this point the exit criterion for the process path, nothing can be expected (and little can be conceived) to occur in this step that would satisfy that criterion and end the process.

4.2.5.4 Troubleshooting Phase 1: Setup

The next step in the process path is to enter the troubleshooting cycle that is its central component and the type of activity one most closely associates with "maintenance." As mentioned earlier, the troubleshooting cycle (Table 10) has been subdivided into four phases to facilitate clarity of illustration in applying the OODA framework. Phase 1 is aimed at assembling and collating the initial data and information relevant to diagnosis. This step may be leapt to as early as the original problem report - especially if immediate action is required to capture or preserve data (e.g., volatile digital data in the aircraft's onboard systems). Backward leaps are conceivable in two cases. The first and most likely one is leaping back to the problem reporting step when this step was leapt into as just noted. The second, less likely, one might occur if something in the data being assembled at this point indicates a need to back up because the probable root fault is recognized as something other than what may have been extemporaneously assumed at the point of the initial problem report.

Table 10: OODA Map for Troubleshooting Cycle: Phase 1

<table>
<tr><th colspan="4">Troubleshooting Cycle
Phase 1: Setup</th></tr>
<tr><th>Observe</th><th>Orient</th><th>Decide</th><th>Act</th></tr>
<tr>
<td>♦ Information from Problem ID phase
♦ Available in-flight data (e.g., pilot snapshots)
♦ Availability of BIT capabilities on A/C
♦ Fault data (e.g., MFL/BIT codes) already available</td>
<td>♦ Volatile data at risk of being lost
♦ Diagnostic data types available
♦ Transcription/ translation reqt's for available data
♦ Salient clues from earlier info
♦ Prospects for A/C returning to duty</td>
<td>♦ How to preserve volatile data
♦ Actions necessary to translate data so it can be mapped onto diagnostic aids
♦ Agenda for data collation/ translation
♦ External support req'd for collation/ translation
♦ Tentative guesstimate for when A/C might return to duty</td>
<td>♦ Download/capture volatile data
♦ Get data translation into motion
♦ Receive/collate available diagnostic data as it becomes available
♦ Advise Pro Super of tentative prospects for A/C return to duty</td>
</tr>
<tr><th colspan="4">Potential "Jumps" In Process Path</th></tr>
<tr><th colspan="2">Forward</th><th colspan="2">Backward</th></tr>
<tr>
<td colspan="2">NONE - Once this phase is entered, the subsequent phases have to be accounted for (though they may end up being "run through" perfunctorily)</td>
<td colspan="2">♦ Problem ID/Reporting if:
▪ Recognition of new/different problem
▪ Volatile data captured during "leap-ahead"</td>
</tr>
</table>

Phase 1 in the troubleshooting cycle would appear to be the point of "commitment" to the remainder of the process path. Once you've gotten this far, it will be incumbent upon you to follow the subsequent prescribed steps, even if only in a perfunctory fashion. This step is very much focused on data in and of itself, and not on what that data may mean for diagnostic and prognostic purposes. This step is distinct from the maintenance Preparation step in two ways. First, this step primarily addresses data compilation whereas maintenance Preparation addresses procedural and administrative ramp-up. Second, the maintenance Preparation step is more generally applicable to a variety or set of similar maintenance incidents, whereas this step is particular to this specific incident.

4.2.5.5 Troubleshooting Phase 2: Diagnostic Hypothesis Generation

The next step in the process path is to start the diagnostic troubleshooting. The OODA instantiation of this step is illustrated in Table 11.

Table 11: OODA Map for Troubleshooting Cycle: Phase 2

Troubleshooting Cycle Phase 2: Diagnostic Hypothesis Generation			
Observe	**Orient**	**Decide**	**Act**
♦ All data/information available from earlier phases ♦ Data incoming from parallel translation support ♦ Fault data (e.g., MFL/BIT codes) already available ♦ Diagnostic reference aid(s) such as FIs	♦ Coding/indexing of data (e.g., specific ID of each datum) ♦ Correlate data items with reference aid(s) ♦ Layout/procedures for using reference aid(s)	♦ Starting point in reference aid structure (e.g., fault tree) ♦ What option(s) or next step(s) the reference aid indicates for the given data item/code ♦ Any criteria for discriminating among multiple options ♦ Any test action req'd in conjunction with proceeding via aid ♦ What next step to go to	♦ Check data against reference aid ♦ Sort and select among alternatives (as req'd) ♦ Proceed stepwise through (e.g.) fault tree ♦ Conduct any auxiliary tests or data checks req'd ♦ REPEAT AS NECESSARY until a specific diagnosis is obtained

Potential "Jumps" in Process Path	
Forward	**Backward**
Troubleshooting Phase 4 (Closure) if problem determined to be non-existent or not actionable	♦ Problem ID/Reporting if there's recognition of new/different problem ♦ Maintenance Setup if additional preparation/assets are identified before we can proceed ♦ Troubleshooting Phase 1 (Setup) if new data/data resource invoked or new prognosis

The exploratory process of testing the aircraft and trying to figure out where a problem lies is at the core of the maintenance process. Success in conducting this phase is dependent on a variety of factors, and it is the phase in which the maintainers are most dependent on the data and information assets they have at their disposal (e.g., test equipment, the TOs, the FIs, their background knowledge, experiential knowledge, etc.).

This phase is particularly problematical in the case of flight controls (relative to, e.g., purely avionics maintenance work). Although the specifics vary from aircraft to aircraft, "flight control" always involves complicated interactions among (e.g.) electronic, electrical, hydraulic, and mechanical subsystems. A single reported anomaly in the aircraft's in-flight behavior might be attributable to a fault in one or more of these associated subsystems. This means that unless the fault is clearly (or luckily) isolated on the first pass, maintainers may have to repetitively test and evaluate the aircraft's various relevant subsystems before determining exactly what's wrong. Because different maintenance expertise may be required to delve into one or another subsystem, this exploratory effort may entail stopping to call in or coordinate among different personnel.

This situation is complicated by the fact the decision space (for diagnosis and for identifying the subsystem(s) underlying the fault) is not subject to clear and straightforward navigation. For example, the relationship between electricals and mechanicals involved in flight control is not all that deterministic. Granted, it is usually safe to say the electricals trigger or control the mechanical elements that in turn control the flight surfaces. However, this doesn't mean that an electrical or avionics fault that's been identified rules out a mechanical aspect to the problem. Indeed, the course of diagnostic process outlined by the various SME groups consistently started with avionics and moved forward (as circumstances warranted) toward the mechanicals. This is reflected in the fact that the FIs include occasional formal instructions to stop and "check rig" (i.e., call in the riggers to inspect and assess the mechanicals).

This doesn't mean that an immediate recognition of a mechanical fault allows the maintenance process to skip over avionics checks. Identification of a mechanical problem doesn't rule out an electrical or avionics component to the underlying fault. As a result, it can happen that mechanical troubleshooting can lead back to identifying a requirement for more work on the electricals or avionics. This typically occurs through process of elimination rather than through direct implications from the troubleshooting per se. Unlike the case with the electrical- or avionics-oriented FIs typically employed up front, the mechanical FIs don't often provide instructions to call in the avionics people. It is therefore important to be able to make a strong case when trying to kick the problem back into the electricals/avionics maintainer's court. This is something of an issue because the riggers can't readily invoke the FIs as direct evidence that such a handoff is mandated (in contrast with the opposite direction when the avionics FIs lead to "check rig").

These points mean that even during this exploratory diagnostic phase the maintainers are subject to time being dedicated to team and administrative coordination issues (as opposed to the diagnostic work itself).

4.2.5.6 Troubleshooting Phase 3: Acting on Diagnostic Hypothesis

As one or more diagnostic hypotheses are generated in Phase 2, the next step is to take action to either verify their viability or to affect the repair(s) they recommend. The OODA interpretation of this step is illustrated in Table 12.

Table 12: OODA Map for Troubleshooting Cycle: Phase 3

Troubleshooting Cycle Phase 3: Acting On Diagnostic Hypothesis			
Observe	**Orient**	**Decide**	**Act**
♦ All data/ information available from earlier phases ♦ Fault data (e.g., MFL/BIT codes) already available ♦ Diagnostic reference aid(s) such as FIs ♦ Diagnosis arrived at in preceding steps	♦ Implications of current diagnosis ♦ Implications of preceding indications and data ♦ A/C (sub)systems involved in current diagnostic implications	♦ Whether diagnosis is consistent with reports, indications, and preceding data ♦ IF SO - What repair or replacement actions are called for? ♦ Does it turn out to be a job for AR (rigging)? ♦ IF NOT - Should we proceed on basis of current best diagnosis? ♦ IF NOT - What should we do to backtrack and re-do the diagnostic process? ♦ If Backtracking - Do we stick with the diagnostic aid or start exploratory troubleshooting (e.g., tracing wires)? ♦ OTHERWISE - Is it time to start trying "swapology" to see if that fixes the problem? ♦ OTHERWISE - Is it time to give up and call for tech support?	♦ If Diagnosis Accepted - Proceed with repair/replacement action(s) ♦ If It's a Rigging Job - Call in the AR folks ♦ If Diagnosis Not Accepted - Backtrack to explore other possibilities ♦ REPEAT AS NECESSARY until the actionable implications of the current diagnosis are exhausted ♦ OTHERWISE - Start with "swapology" (replacing parts to see if that fixes the fault) OR ♦ OTHERWISE - Make the call to the next available layer of tech support (e.g., AFETS, contractor, depot)

Potential "Jumps" In Process Path	
Forward	**Backward**
NONE - Once this phase is entered, the subsequent phases have to be accounted for (though they may end up being "run through" perfunctorily)	◆ Problem ID/Reporting if there's recognition of new/different problem ◆ Maintenance Setup if additional preparation/assets are identified before we can proceed ◆ Troubleshooting Phase 1 (Setup) if new data/data resource invoked or new prognosis ◆ Troubleshooting Phase 2 (Diagnostic Hypothesis) if results (or lack thereof) lead us in another direction

This Phase 3 and the preceding Phase 2 comprise a possible cycle that may iterate any number of times. The reason for separating these two steps in this OODA layout is to provide segmentation with respect to the distinction between "theory" versus "practice." In Phase 2 the maintainers are addressing the current problem with respect to "theory," whereas here in Phase 3 they are addressing the "practice" implementing whatever that theory (i.e., diagnostic hypotheses) recommends. It is here in Phase 3 that something is done in accordance with the current diagnostic hypothesis. It is also here in Phase 3 that a decision may be made regarding whether to either (a) start trying component swapping in lieu of specifically prescribed repairs or (b) call in tech support in the absence of any perceived proper action.

4.2.5.7 Troubleshooting Phase 4: Reach Closure on Current Repair Action

At some point in the troubleshooting cycle, the maintainers must move on to declaring victory and assessing the viability of having done so. The OODA interpretation of this step is illustrated in Table 13.

Table 13: OODA Map for Troubleshooting Cycle: Phase 4

<table>
<tr><th colspan="4">Troubleshooting Cycle
Phase 4: Reach Closure On Current Repair Action</th></tr>
<tr><th>Observe</th><th>Orient</th><th>Decide</th><th>Act</th></tr>
<tr>
<td>♦ Diagnosis arrived at in preceding steps
♦ Completion of repairs/ replacements prior to stopping point</td>
<td>♦ Perceived assessment of completion
♦ Perceived viability of repairs/ replacements
♦ Implications of repair actions on mechanicals and flight surfaces (i.e., rigging matters)</td>
<td>♦ Do we think we've solved the reported problem?
♦ Do we need to call in the riggers to complete the repair action?</td>
<td>♦ Call in riggers if necessary to complete repair actions
♦ Perform final checks to ensure repairs are completed.</td>
</tr>
<tr><th colspan="4">Potential "Jumps" In Process Path</th></tr>
<tr><th colspan="2">Forward</th><th colspan="2">Backward</th></tr>
<tr>
<td colspan="2">NONE - Once this phase is entered, the subsequent phases have to be accounted for (though they may end up being "run through" perfunctorily)</td>
<td colspan="2">♦ Problem ID/Reporting if there's recognition of new/different problem on final check
♦ Troubleshooting Phase 1 (Setup) if new data/data resource invoked or new prognosis
♦ Troubleshooting Phase 2 (Diagnostic Hypothesis) if results (or lack thereof) lead us in another direction
♦ Troubleshooting Phase 3 (Acting on Diagnosis) if final checks indicate it's still not fixed</td>
</tr>
</table>

4.2.5.8 Solution Reporting/Documentation

Upon completion of the troubleshooting cycle, the next step is to record that a solution has been achieved and what that solution turned out to be. In terms of the OODA model, this step can be depicted as presented in Table 14. At this point the context begins to shift back toward administrative and organizational elements and away from the technical features which were the foci during the troubleshooting cycle.

Table 14: OODA Map for Solution Reporting/Documentation

Solution Reporting/Documentation			
Observe	**Orient**	**Decide**	**Act**
♦ Fault report, diagnosis, and repair actions from preceding phases ♦ Consensus that repairs now completed ♦ Unit protocols/procedures for documenting repair actions ♦ Supply/parts reqt's ♦ Supply/requisition actions to date	♦ The course and details for this maintenance action ♦ Documentation reqt's for completing this action ♦ Administrative reqt's ♦ QA/QC reqt's ♦ Outstanding issues with supply chain units	♦ What needs to be documented to finish off this action? ♦ Who needs to be notified of the completion? ♦ What follow-up checks are or will be done ♦ What needs to be done to "settle up" with supply?	♦ Advise Pro Super ♦ Coordinate with QA/QC as needed ♦ Document repair actions ♦ Document MIS assets (e.g., CAMS) ♦ Document Logbook ♦ Complete forms associated with this A/C and this maintenance event ♦ "Settle up" with supply ♦ Document supply actions taken

4.2.5.9 Completion Decision/Validation

In the next step the documented solution is submitted for formal review and certification that the maintenance action is now completed. The OODA interpretation of this step is illustrated in Table 15. In this step the context of attention continues its shift away from the technical toward the organizational or administrative.

Table 15: OODA Map for Completion Validation

Solution Validation/Verification And Completion Decision			
Observe	**Orient**	**Decide**	**Act**
♦ Fault report, diagnosis, and repair actions from preceding phases ♦ Consensus that repairs now completed ♦ Components changed out during maintenance process ♦ Unit protocols/ procedures for documenting repair actions ♦ Supply/parts reqt's ♦ Supply/requisition actions to date	♦ The course and details for this maintenance action ♦ Final consensus diagnosis ♦ Action(s) that fixed the reported problem ♦ Set of components swapped out ♦ Documentation reqt's for completing this action ♦ Administrative reqt's ♦ QA/QC reqt's ♦ Outstanding issues with supply chain units	♦ What needs to be documented to finish off this action? ♦ Who needs to be notified of the completion? ♦ What follow-up checks are or will be done ♦ What needs to be done to "settle up" with supply	♦ Advise Pro Super ♦ Coordinate with QA/QC as needed ♦ Document repair actions ♦ Document components swapped out ♦ Document MIS assets (e.g., CAMS) ♦ Document Logbook ♦ Complete forms associated with this A/C and this maintenance event ♦ "Settle up" with supply ♦ Document supply actions taken
♦ Documentation from preceding phases ♦ Impound team composition ♦ Unit protocols/ procedures for final sign-off on repairs	♦ Availability of maintenance Group Commander ♦ Documentation reqt's for sign-off briefing/meeting	♦ Time and place for meeting with MXG Commander for final sign-off ♦ The basic "story line" of the maintenance process to be presented	♦ Schedule meeting ♦ Conduct meeting ♦ Get MXG Commander sign-off on repair

Potential "Jumps" In Process Path	
Forward	**Backward**
None	In theory, something arising at this point might cause the team to fall back to an earlier phase. None of the SME groups mentioned a risk of backtracking once this phase had been entered

4.2.5.10 Maintenance Stand-Down

Once completion of the current maintenance action has been certified, the next step is the practical matter of cleaning up in preparation for moving on. As illustrated in Table 16, this is neither an information- nor a decision-intensive step in the process path.

Table 16: OODA Map for maintenance Stand-down

Maintenance Stand-down/Clean-Up			
Observe	**Orient**	**Decide**	**Act**
Evidence of final sign-off for this maintenance action	What needs to be done to stand down	Course of action to stand down	♦ Return tools and instruments to support section ♦ Perform other actions necessary to "clean up"

4.2.5.11 Back-End Unit Coordination (Returning the Aircraft to Duty)

The final step in the overall maintenance process path is to get the aircraft back to duty. This step is illustrated in Table 17. As was the case for maintenance stand-down, this is neither an information- nor a decision-intensive step in the process path.

Table 17: OODA Map for Back-end Unit Coordination

Unit Coordination (Return A/C To Duty)			
Observe	**Orient**	**Decide**	**Act**
♦ Mission itinerary for newly-fixed A/C ♦ Logistics of getting A/C back to duty location	♦ A/C features requiring setup for next mission ♦ Towing/parking requirements	♦ Any mission-related modifications/ adjustments to be made ♦ Mechanics of getting the A/C back to duty location	♦ Configure A/C for next mission ♦ Return A/C to duty location

4.2.6 Critical Cognitive Issues Discernible in the KA Results

The generation of a structured process path representation is a central goal for CTA work. However, it is not the only desired outcome of such an analysis. One other goal is to identify critical issues that affect the cognitive performance (and hence task performance) of the subject matter experts. In this section the most significant such cognitive issues identifiable in the SME groups' comments will be listed and discussed.

4.2.6.1 Issue: Complexity in the Problem or Decision Space for Flight Control Maintenance

In reviewing the aggregate performance statistics, it was noted that the negative effect of complexity was the only one of the three general hypotheses that seemed consistent with the available data at face value. Because "flight control" is a matter of interactions among electronic, electrical, hydraulic, and mechanical subsystems, it is referentially more complex than most other objects of maintenance (e.g., a single radar module). An in-flight problem might well derive from a fault in one or more of these interoperating subsystems. This means that in troubleshooting maintainers might have to repetitively test and evaluate multiple subsystems before isolating the precise cause of the reported problem. As a result, the decision space or problem space (abstract set of elements and alternatives) is of at least as high an order of complexity than is the case for most other aircraft subsystems.

Personnel specializations and topical foci for reference aids tend to reflect this subdivision of flight controls into distinct domains of apparatus to be collectively considered. This makes reference, inference, and progressive navigation difficult (within the abstract problem space). Unless the data available at the outset circumscribes a particular component or class of components as likely candidate fault sources, flight control maintainers must always undertake their process path at risk of having to grapple with these conceptual complexities.

4.2.6.2 Issue: Criticality of Good Up-front Information

For the sake of illustration, consider the entire maintenance process path as a single OODA loop. To take a final action requires an effective decision. This in turn requires adequate and accurate orientation to the reported problem and its characteristics. This orientation is itself contingent upon the availability of adequate information about the nature of the fault. In other words, the overall inferential process underlying diagnosis and hence repair is backward dependent on how much the maintainer knows (or can know) about the perceived problem at the very beginning. This means the best way to get a good "head start" on traversing even a truncated "quick fix" process path is to obtain a decent picture of what went wrong in this particular case. As a result, it comes as no surprise the #1 information innovation desired by the SMEs was better descriptions and clues at the point the problem is initially reported.

The importance of good up-front problem description can also be illustrated in terms of the temporal dimension emphasized in the aggregate performance measures. Deficiencies in initial situation awareness increase the amount of data remaining to be collected and reviewed before an initial hypothesis can be generated. This in turn increases the amount of effort (and hence time) required to accomplish this additional data acquisition and analysis. Increases in time spent at this early stage propagate through to the final cumulative duration of the given maintenance process. In addition, to the extent initial SA on the reported problem aids maintainers in focusing in on the fault, it contributes to minimizing time investments as the process moves forward into and through the troubleshooting cycle.

4.2.6.3 Issue: Criticality of Simulating or Reproducing the Perceived Problem

As discussed earlier, the #2 item on the SME groups' wish list for information interventions was a capability for simulating or replicating the flight control problem on the ground. This is an understandable backup tactic for understanding the problem in the absence of information detailed enough to immediately discern a fault's root cause. If such simulation were possible, it would allow maintainers to replicate and observe anomalies directly, rather than being forced to rely on whatever information they could obtain from the aircrew and/or available in-flight data. Unfortunately, this is difficult or impossible to do in practice. With respect to cognitive analysis, the most important aspect of this #2 desire is not its potential for implementation. Instead, it is important for the fact it reinforces the theme underlying the #1 wish - i.e., a need to better understand the nature of the problem the maintainer is being asked to resolve.

4.2.6.4 Issue: Fault Sources Unaccounted for in Available Diagnostic Aid Representations

Regardless of the sophistication attributable to available diagnostic aids, all the embodied models of the aircraft share something in common. This is the way in which their models delineate the subject matter in terms of discrete units of reference (e.g., particular LRUs). Such a mode of reference is unavoidable; however, it necessarily under-specifies those elements of the subject system of systems that lie among these unit objects. In the case of flight control systems, such interstitial elements include wires, connectors, valves, hydraulic lines, etc.

The KA data indicates that in dealing with non-trivial flight control problems maintainers have to dedicate considerable time and effort to addressing such interstitial elements. "Shooting the wires" is something the F-15 and F-16 maintainers repeatedly alluded to as a troublesome task. The relative importance of interstitial components as candidate sources of fault is well illustrated in the uniform and universal comments made regarding connections and connectors as "culprits." Understanding the underlying linkages and relationships among aircraft subsystems - one of the key characteristics attributed to expert maintainer knowledge - can be seen in terms of understanding "what lies among" the discrete units most commonly referenced in training and documentation.

Does this mean that diagnostic aids can and should be generated to deal with all the interstitial elements once and for all? No, because there will always be "interstices" among whatever set of referents is invoked to model the subject system and depict it to an maintenance user. Instead, it means that accounting for interstitial elements will always entail knowledge derived from dealing with the interrelationships among components - i.e., the very sort of experiential knowledge which typifies experts (relative to novices) and which goes relatively undocumented and unshared.

4.2.6.5 Issue: Progressive Deskilling in the Maintainer Population

In the course of the KA activities the team probed for perceived distinctions between expert and novice abilities. Naturally, such distinctions are to be expected in any task environment. In this case, however, the SMEs repeatedly noted states or trends with regard to the relationship between expert and novice capabilities that are causes for concern. It is no surprise to hear that novices are neither as proficient at diagnostic troubleshooting nor as knowledgeable about a subject aircraft as their more experienced colleagues. It is, however, a disturbing surprise to hear an apparent consensus (among trainers and experienced maintainers) that these relative disadvantages are trending both (a) more common among the maintainer population and (b) more permanent as features of newer maintainers' careers.

First, there were consistent (senior/experienced) SME comments critical of the general technical knowledge evidenced by younger or novice maintainers. It is not just that younger maintainers do not know how *this* aircraft functions, the problem is that they display little understanding of how *any* aircraft functions. For example, the trainer SMEs at both Nellis and Charleston consistently claimed new staffers emerge from technical school with less basic technical understanding than was once the case. This puts newer maintainers at a disadvantage in being able to undertake free-form exploratory troubleshooting once they've exhausted the standard diagnostic guides (e.g., the FIs).

Second, there's a decreasing potential for the younger maintainers to acquire such technical knowledge in the course of their work. As time goes on, maintenance becomes geared more and more to divining faults on the basis of given BIT codes and the canned logic of fault trees. Furthermore, the trend toward modularizing the subject matter into LRUs, which are swapped out rather than dissected, diminishes the opportunities for novices to explore and learn about how the aircraft's internal components operate.

Finally, and most disturbingly, the above-cited factors are claimed to have engendered a growing reliance on whatever troubleshooting guidance is made available in canned form, whatever courses of action can result from procedures designed and trained in strict accordance with simply following that canned guidance, and whatever repairs can be effected by changing out LRUs. The often-cited ability of experts to "dig into" the aircraft after the easy solutions have been ruled out is based on knowledge and skill. The novices are in effect denied this sort of knowledge and skill as time goes on. In other words, newer or younger maintainers are subject to progressive "deskilling" as time goes on.

This increasing proportion of relatively deskilled workers cannot help but result in diminishing performance for the workforce as a whole. Multiple examples of such performance-degrading effects were cited by the SMEs. Novices are more likely to call in technical support personnel when they exhaust their diagnostic cookbooks. This necessarily adds external coordination costs (in time and effort) to the maintenance effort. Novices can't very well be expected to dig into the aircraft's internals when they haven't been trained to do so. In any case they are claimed to lack the technical knowledge to support such courses of action. Their reliance on canned diagnostic logic makes them vulnerable to each and every gap or deficiency within that logic (and such gaps and deficiencies were noted by all SME groups).

4.2.6.6 Issue: Value of Experiential Knowledge to the Maintainers

There is much relevant and useful information that can only be obtained from maintenance experiences with particular aircraft in specific instances. Such information includes tips, tricks of the trade, and illustrative "lore" derived from difficult cases. The SMEs uniformly alluded to such experiential knowledge in terms of the following points:

- Experiential knowledge is a key discriminator between expert and novice maintainers.
- Experiential knowledge can often prove a valuable asset in handling tough cases - particularly once the official diagnostic logic is exhausted.
- Experiential knowledge is shared within a maintenance unit only to the extent it propagates via personal interactions and whatever portion gets entered into the logbook.

- Generally speaking, there are no formal means for disseminating such experiential knowledge among units.
- The current training curricula and training timeframes do not permit such detailed experiential knowledge to be imparted to trainees.

Such experiential knowledge is therefore a key component of the knowledge base the maintainers exploit in the conduct of their work. The fact that this key component is under-supported by formal procedures and support tools constitutes a significant cognition-related deficiency in the way maintenance work is accomplished today.

4.2.7 Summary: Cognitive Task Analysis

The data obtained during the KA effort has been applied to generate a coherent process path map in accordance with a model selected as best suited to this project's goals. This process path map has been leveraged to illustrate the general linkages between data/information, decisions, and actions at each step in the process path. Finally, the most important subset of the cognitive issues identified from the KA has been reviewed.

4.3 Information Requirements Analysis

Information Requirements Analysis (IRA) concerns the examination and critical analysis of a work activity or process with regard to:

- The set of data and information required to perform the given task
- The set of data and information typically available to the worker during a task
- The differences between these two sets and their implications for improving task support

In the knowledge acquisition section the team reviewed the key issues and questions the SMEs cited as important in pursuing the flight controls maintenance process path. Each of these items reflects or recommends a data element that should be available for maintainers to exploit. In the section on cognitive task analysis the types of data or information in the context of an ordered OODA representational schema were reviewed. This mapping correlated the issues and questions obtained during KA with a structured model of the maintenance work being studied.

4.3.1 Information "Reachback" in the Maintenance Process Path

One of the most salient characteristics of the maintenance process is that it is collaborative in that it involves multiple players jointly working to diagnose and repair the reported fault. It is not the case that all possible players participate in all reported cases. Some sources of data and expert knowledge participate only if invoked by the front line maintainers. This constitutes a discretionary *reachback* [51]for relevant information as circumstances warrant.

Although the precise details vary from aircraft to aircraft, the SMEs outlined three representative steps in a progression of information reachback. The first is to on-base tech support personnel (e.g., AFETS, forward-deployed contractors). The second is to remote (off-base) technical expertise accessible via telecommunications (e.g., hot line). The third is to technical expertise accessible by calling in personnel stationed at the relevant depot (e.g., "depot assist"). Each of these reachback assets is in possession of technical data resources exceeding the scope and/or depth of those available on the flight line. The general form of this reachback progression is illustrated in Figure 3.

In general, maintainers attempt to complete the maintenance process path using their available information assets on-site. It is only when they reach a perceived impasse that they begin to exercise their options for information reachback.[52] The first line of recourse is on-base tech support. Where available, the second line consists of remote tech support that can be accessed via telephone. The third line of recourse is to call in support personnel from the depot.

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[51] Use of the term "reachback" has become widespread during the 1990s. However, its connotations are not precisely the same in all USAF communities. For example, in the logistics community "reachback" is used to generally refer to supply transactions in support of front line operations. The use of the term "reachback" in this section is based on the usage of that term in information operations (IO) - i.e., the concept of a warfighter (or other operator) having the means to "reach back" to rearward support elements to obtain data or information as needed to support decisions and actions in the present task or situation. In this usage, "reachback" connotes the front line operator's capacity for proactively initiating demand-pull transactions (i.e., the "supply side" component of the objective of "getting the right information to the right warfighter at the right time.")

[52] The exact course of immediate reachback will, of course, vary with circumstances and exact location. Comments from the SME groups indicated that on-base tech support personnel are more or less accessible or proactively involved in checking on maintenance actions in progress. For example, F-16 SMEs at Nellis seemed to indicate their AFETS technical staff are more readily at hand than the C-17 tech support staff at Charleston, who seemed to remain in the background until and unless actively summoned. Another source of variation derives from whether or not manufacturer/contractor support staff happen to be deployed on base (as is the case with the Boeing support staff at Charleston).

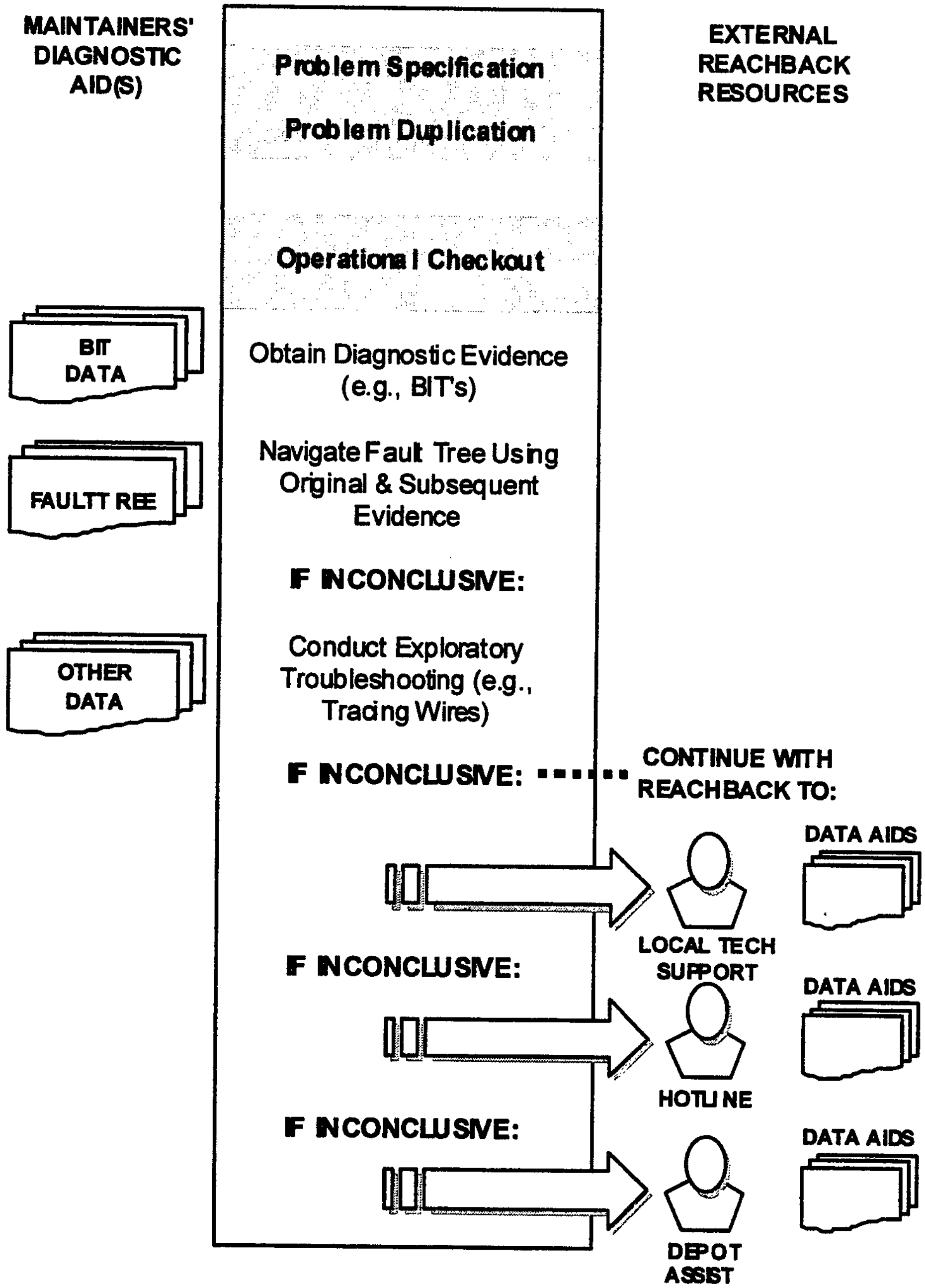

Figure 3: General Outline for Diagnostic Reachback

4.3.2 Information Reachback as a Negative Influence on Overall Maintenance Performance

With regard to maintenance performance, the key point is that each reachback action serves as a drag on maintainers' ability to resolve the reported maintenance problem in a given timeframe. More specifically, reachback degrades temporal performance metrics because:

- Setting aside the maintenance activity to call in outside help may involve practical actions (e.g., parking, putting away tools, etc.) which either consume time or mandate time consumption for getting back on task.
- Some amount of time will have to be consumed in making effective contact with the next reachback resource.
- Some amount of time will have to be consumed in relating the maintenance problem and the work so far to the reachback resource.
- Where personal contact on-site is needed, there will be time consumed in coordinating (e.g.) travel, meeting times, etc.
- Where personal contact is needed, there may be redundant time consumption for briefing the technical support staff once they arrive.

These general points pertain whether the reachback asset is on base or at a remote location. The main point is that each reachback action consumes time and therefore lengthens the end-to-end duration of the given maintenance process.

4.3.3 Primary Information Needs Identified in the KA and CTA Efforts

Given the discussions above and in the preceding sections, the main information deficiencies (and hence information needs) for flight control maintenance staff can be summarily listed as follows:

- Detailed and comprehensive description of the perceived problem as it was encountered during flight (the SMEs' #1 wish list item).
- Access to experiential knowledge to fill in the gaps in the formal information base.
- Capture and dissemination of experiential knowledge to help bring less experienced maintainers up to more expert levels of performance.
- Dissemination of experiential knowledge across maintenance units to minimize the need to "reinvent the wheel" in developing tips and tricks of the trade.
- Attention to real-world operational context in training materials and courses.
- Better background technical knowledge for incoming trainees.

- Better knowledge of an aircraft's inner workings to provide less experienced maintainers with a foundation for analyzing the data their reference and diagnostic aids provide them.

4.3.4 Information Capacities and Requirements for Addressing SMEs' #1 Desire for Improvement

As discussed earlier, the SME groups clearly and uniformly cited better situation awareness on in-flight fault context as their #1 desired improvement. Modern military aircraft are complex systems, and their flight control mechanisms are complicated aggregates of avionics, hydraulics, and mechanical components. As a result, the decision space for diagnosis is relatively complex. Any and all clues available up front allow the maintainer(s) to more expeditiously vector in on a likely diagnosis and proceed toward resolution or repair. The most straightforward approach to maximizing such up-front SA is to capture and record as much in-flight data as possible.

With some aircraft, the maintenance staff already enjoys a relative abundance of such data, while for other aircraft they have to make do with what little they can get. The maintainer SMEs who seemed most content with their current or prospective in-flight data access were those working with the C-17, the RQ-1 Predator UAV, and the F/A-22 Raptor. The C-17 is a relatively new aircraft (compared to the fighters surveyed), and its onboard computer systems afford a good capability for capturing data in a form that can be downloaded and made available for maintainer reference and analysis. Assuming its highly centralized and automated systems work as advertised, the F/A-22 promises to offer maintainers a degree of insight into in-flight events and parameters unparalleled in any previous fighter. The unexpected surprise is the situation enjoyed by the UAV maintainers, who have it best of all. Not only are they afforded a comprehensive data set, they also have the ability to consult with the pilot and jointly examine flight behavior while the flight is still in progress.

Multiple SMEs involved with the older fighters touted the utility of data "snapshots" (pilot-triggered recordings of selected system data). The A-10 SMEs claimed their snapshot access was a big help in analyzing reported problems. The older fighters' maintenance SMEs at Nellis all made envious reference to the CDDS system installed on the B-1B, which allows a pilot to capture a voluminous snapshot of current data and parameters, including cockpit "switchology." The F-15E maintainers were happy to report that a snapshot capability was finally being made available on this most recent edition of their aircraft.

Though certainly better than nothing at all, snapshots are not the ultimate answer to improving maintainers' SA on operational anomalies. For one thing, many of the snapshot facilities cited have to be actively triggered by the pilot. This means that correlation of the snapshot's timeframe with the timeframe of the anomalous behavior is a function of the pilot's reaction time. It is also reasonable to suggest that in the case of severe anomalous behavior (e.g., uncontrolled movement) triggering a data snapshot may not be the pilot's most pressing concern.

The ultimate solution is of course to dynamically record as full a record of in-flight data as the available hardware permits, so as to offer maintainers the most comprehensive possible picture of what happened and when it occurred. This is the happy prospect the emerging RQ-1 and F/A-22 maintainers face. However, it is currently out of reach for maintainers working with the older aircraft (A-10, F-15, and F-16). Though not cheap in absolute terms, it would seem proportionally cost-effective to consider adding a more comprehensive onboard data capture and recording capability to these older aircraft. More expensive still would be the prospect of adding in-flight data capture combined with real-time telemetry. This more complicated approach would offer the prospect of giving more maintainers the clear advantages enjoyed by the RQ-1 personnel.

4.3.5 The Advantage of Better Up-front SA versus Probabilistic Prediction of Likely Faults

Earlier, in discussing the CTA, it was claimed that the best way to get a good "head start" on traversing even a truncated "quick fix" process path is to obtain a decent picture of what went wrong in this particular case. The qualification with respect to "particular case" is very relevant to evaluating informational interventions, because it illustrates the higher relative criticality of initial situation awareness in the particular case versus situation awareness of the general class of cases. Flight control maintenance is done on a recurring basis. This means that in the aggregate one can evaluate the relative incidence of candidate fault conditions and provide a statistical basis for "playing the odds" when initially hypothesizing what fault may underlie the current case. However, it is just as true that each time a flight control problem is reported, it is reported for this aircraft and in the context of these in-flight conditions and behaviors. In other words, maintainers don't deal with the aggregate; they deal with the particular. This limits, but does not negate, the potential applicability of statistical aids in predicting diagnoses for one or another specific case. Still, this limitation is such that it is safe to claim that good particular information up front (e.g., at the Problem Reporting step) is more likely to improve overall process path performance than advice on the odds of it turning out to be this or that based on prior cases. In any case, the surprisingly substantial proportion of maintenance "quick fixes" purported to go unreported diminishes the confidence one could attribute to statistics derived from past documentation.

4.3.6 The Prospects for Better Capture and Dissemination of Experiential Knowledge

As has been discussed multiple times in the course of this report, the SMEs repeatedly cited the importance of experiential knowledge. All types of SMEs interviewed (e.g., maintainers, riggers, managers, and trainers) indicated experiential knowledge (tips, hints, lore) was an effective facilitating factor in improving maintenance task performance. The SMEs just as uniformly noted that there are few if any mechanisms in place for capturing such knowledge and even fewer channels for disseminating it.

The SMEs consistently stated the logbooks are a very useful, very important, and often overlooked source of information and experiential knowledge. They were unable to cite any other significant means for capturing experiential knowledge in place at this time. However, this deficiency is apparently going to improve with the arrival of more comprehensive and integrated data resources associated with the latest aircraft. In particular, the F/A-22 IMIS-based system permits the addition of history notes into the database. The SMEs often cited this oncoming capability and suggested it would be useful to have available for all aircraft types.

There are two straightforward innovation paths that would reasonably address this deficiency:

- *Improve capture and collation of logbook entries.* This is easier said than done - especially if this were to be pursued in the most obvious fashion (digitization). For one thing, there's an alleged correlation between maintainer experience and general computer aversion. This suggests a computerized logbook capability might not be used (or not be as well used as hoped) by the senior or experienced maintainers presumably serving as the main sources for such knowledge. Another issue concerns privacy and confidentiality. Maintainers are unlikely to entrust lessons learned to a digital medium if such reports reflect badly on them personally (e.g., warnings about one's mistakes made) or provide evidence of unsanctioned procedures (e.g., a trick of the trade whose execution requires violating standard practices or rules).
- *Provide effective channels for disseminating access to capture experiential knowledge*. There are a number of issues to be decided in trying to make experiential knowledge available to a wider audience. Should it be offered in a "supply-push" manner (e.g., a print publication or email newsletter) or on a "demand-pull" basis (e.g., a central data library or bulletin board)? In the long run, the approach most likely to be both effective and efficient would be a ListServ-style discussion forum

combining login access to a data repository along with optional subscriptions to topically-delineated message threads.

4.3.7 The Prospects for Addressing Novice Deficiencies in Background Knowledge

The KA indicates reasonable consensus that novice or younger maintainers are deficient in general technical knowledge, appreciation for operational context influences on actual maintenance work, and understanding of the inner workings of the aircraft and aircraft subsystems they're expected to service. Strictly speaking, the means for addressing these deficiencies fall largely outside this project's purview. Because the general and aircraft-specific technical knowledge deficiencies are clearly subjects to be addressed with respect to training, they lie outside the scope of the maintenance process itself. A greater appreciation for the exigencies and influences of real-world situational context is somewhat more addressable in conjunction with daily maintenance work. However, this issue still would seem to insinuate innovation in terms of, for example, personal mentoring with more experienced personnel, and not an "information" or "technical" innovation of the sort the team set out to examine. By the same token, any improvements in capturing and making available the experiential knowledge that has been repeatedly emphasized would peripherally aid novices in learning how maintenance work is actually performed.

5 Technology Search

5.1 The Decision Criteria Development Workshop

To provide high-level system requirements needed to facilitate a broad technology search, the MXM Team hosted a Decision Criteria Development Workshop 30-31 July 2003 at the Northrop Grumman facility in Fairborn, Ohio. Originally scheduled for May, it was slipped as a result of KA trips being pushed back due to base access problems discussed earlier and because of on-going heavy taskings which made it difficult for potential attendees to commit to coming to the workshop.

The purpose was to bring together experienced field level maintainers and their leaders in a structured environment to gain their input on what a potential tool or set of tools to enhance diagnostics and troubleshooting should generally do.

The workshop began with the team providing background and an introductory MXM project overview to orient everyone to the goal at hand. That done, the lead facilitator gave a brief description of the process that would be followed and the tools that would be used to capture and manipulate the data. After a short question and answer session the group began the process of developing the decision models upon which everything else would build.

5.1.1 Structured Decision Making Process

There are several benefits to the structured decision-making process that the team employed during the workshop. The group is lead through a comprehensive process that encompasses all the inputs of the attendees. This allows the group to focus on developing decision models, while the facilitating team focuses on the process. In addition, because a diverse group is involved in the development of the decision model, there is an increased opportunity to gather wider ranging ideas. Group consensus is also reached as the group has an opportunity to compare and contrast the various criteria against each other. Finally, the use of a structured process enables clear documentation showing how the decision model was developed. In guiding the group through the process a funnel approach was used to move them from very broad concepts and gradually bring them to a more specific focus. This approach is depicted in Figure 4.

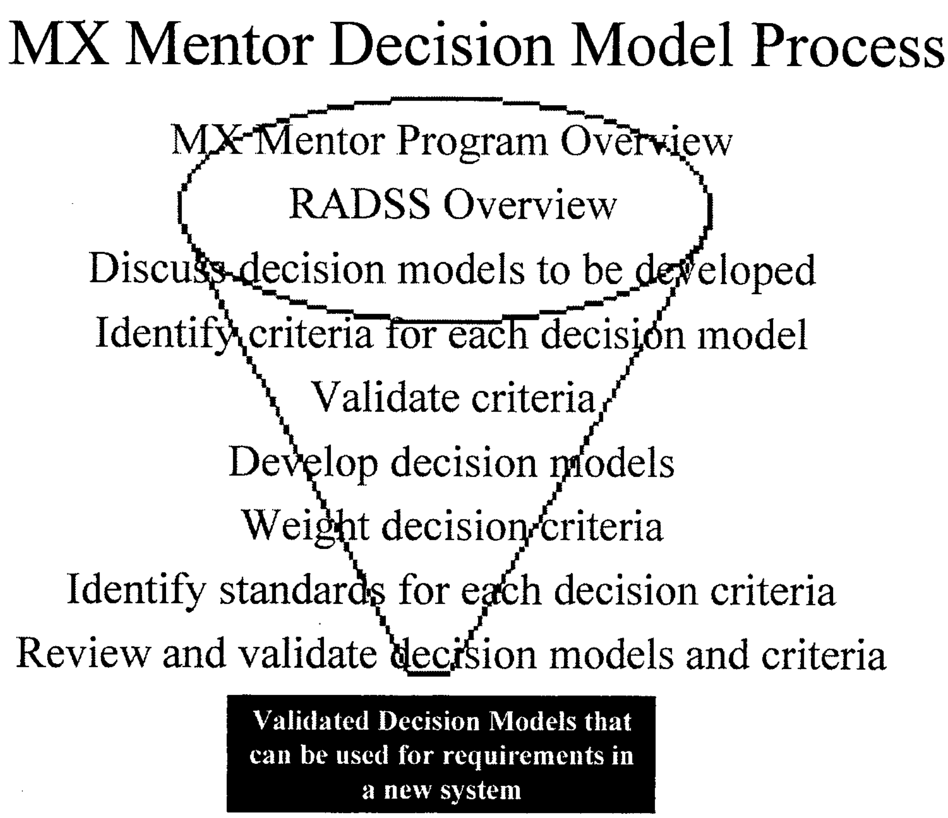

Figure 4: The Funnel Approach

5.1.1.1 The Decision Models

In order to set the boundaries for the decision models, the facilitator asked the group the following question: "What can be done to improve the aircraft maintenance technician's performance by improving their troubleshooting capability and identifying the information required for technicians to better schedule aircraft repairs based on imminent system failures?"

The group then generated several ideas through a "brainstorming" session. The facilitator then grouped similar ideas together and the grouping was reviewed, discussed in detail, and validated by the attendees. This resulted in seven possible decision models:

- Deployability
- Tech Data
- Hardware
- Prognostics/Scheduling
- Training

- Corporate knowledge
- A new software development that contains the software modules identified above

The groupings are listed in the following (Tables 18 – 24):

Table 18: Deployability

Deployability
Software should be usable on desktop, portable laptop, palm pilot, etc.
♦ Portability: End product needs to deploy with one airframe/person ♦ Whatever you need to troubleshoot (GO-81, CAMS). Solution needs to go with troops in their pocket (CD/DVD) ♦ The F16 community is doing this now (system in a pocket)
New diagnostic aid should be deployable
♦ Wireless LAN on flight line with CAMS, CFRS, CFI ♦ Able to troubleshoot and order parts without leaving the flight line

Table 19: Prognostics/Scheduling

Prognostics/Scheduling
Overall system should get smarter, provide probability of success based on TO recommended solutions
Capture LRU maintenance data. Details for predictive behavior
♦ Failure prediction: if something was predicted to fail and there was a malfunction in that system alert the end user to check that part first. ♦ If something has 80MTBF and it is at 80 hours of operation, check this item
Maintenance scheduling tool with predictive capability. If a jet is going into heavy maintenance, the system should prompt you to look at upcoming items that are coming due.
Verify condition of LRUs installed before removed or/and installed
♦ System troubleshooting aid. Gets smarter as time moves "core" trouble sources ♦ Evolve system to automatically update FIs or maintenance data is collected (something like 8 quarters of data of charts).

Table 20: Hardware

Hardware
Hands-free interactive TO so maintenance technicians can inspect more efficiently
Universal test equipment (standardized software)
Diagnostic tester using a laptop that's programmable and upgradeable quickly
Software that can be connected to a printing device that given a certain task, will generate all necessary warning tags

Table 21: Training

Training
Seamless training from tech schools to MDS. Students are assigned to: ◆ Same TO formats ◆ Intuitive reference system
Write the training as an XBox game
Software training on in-depth wiring troubleshooting this is becoming a lost art
Software training in basic analytical thinking

Table 22: Corporate Knowledge

Corporate Knowledge
Capture LRU maintenance data. Details for predictive behavior
Capture corporate knowledge
Corporate knowledge—must be able to capture it
Automatic cross tell/sharing of secrets to troubleshooting
If a Boeing request for engineering disposition has been answered previously for a current write-up what was the response?
Communication between units throughout the world. There are problems encountered some places that would be great for the rest of that airframe's people everywhere would like to know. How they fixed them and what to look for.

Corporate Knowledge
Better access to historical data on aircraft
Data capture (troubleshooting). We need the ability to capture logbook entries. Logbooks are a hundred times more descriptive than current CAMS entries. Analysis of how people actually troubleshoot the system and its fix could be beneficial to incorporate into tech data.
Develop a web portal that I could post questions and answers to. Needs to include tech reps (Boeing, Northrop, etc.)
When put something into CAMS/G0-81, have system automatically go out and tell you what similar gigs have occurred and what corrective action were
Capture data to CAMS/GO-81 automatically. Be able to pull all info into log books and have log book automatically update CAMS/GO-81
Capability to instantly access aircraft history worldwide
Ability to view previous solutions to similar problems
MDS specific automatic cross talk calculated from maintenance data analysis
TO Aide. Sometimes TOs don't have all the information we need. Fault trees often lead to dead ends. Needs to be a process for past experiences from other troubleshooters who have similar problems and be able to access their knowledge.
Access/store LRU histories
Access to AMU log books, loaded on a computer for instant search and analyze capability
When new items are developed and purchased for airframes get all information associated with those items form the companies and engineers. To often companies out there hold certain information back from the people working the jets in hopes they can get more money (i.e., BIT codes that are not diagnosable or understandable by the maintainers).
♦ Ability to strip CAMS/GO81 of all relevant data. ♦ We should define data sets ♦ Technician needs complete access to post maintenance actions on jet and LRU history
System status and BIT to maintainers before aircraft lands
Instantly usable aircraft data. Not have to go to manufacturer to analyze download
Elimination of false BIT codes
Capture aircraft flight data
Translation of BIT data to usable information
Eliminate ambiguous BIT solutions

Corporate Knowledge
Accurate recording of flight parameters at time of fault
With aircraft in chocks ability to interface with a running aircraft (read MFLs, view switches, etc.)

Table 23: Tech Data

Tech Data
Overall system should get smarter, provide probability of success based on TO recommended solutions
Software that will allow C-17 technician to order correct part/software # for specific tail number
Automated update of time changes when an item is changed for unscheduled maintenance
Interactive wiring diagrams that are aircraft specific. Be able to plug a PDA into job and it automatically "knows the job" with all flags and updates
TOs/Display system for easier reading of schematics
Laptop system, windows based, that incorporates FIs, TOs, Gee Wiz information, etc.
Electronic tech data. JG, WD, SD, FI on flight line using hyperlink
♦ Tech data (general 00-series)- general troubleshooting procedures non-system specific. ♦ Someplace to start when no aircraft TO is available
Tech Order "movies" that are interactive
Availability of digital tech data
♦ Software that will tell technician instantly what tools (i.e. socket, wrench) will be needed to do a certain task. ♦ Tells maintainer which toolbox to take to the line.
Hands-free interactive TO so maintenance technicians can inspect more efficiently
Data capture (troubleshooting). We need the ability to capture logbook entries. Logbooks are a hundred times more descriptive than current CAMS entries. Analysis of how people actually troubleshoot the system and its fix could be beneficial to incorporate into tech data.

Table 24: Not Assigned to a Group

Not Assigned to a Group
Self-healing systems (magic fairy dust)
Automatic location tracking of age and CTK items (RFID?)
Reduce number of wires on aircraft (data bus?)
Deviation from organization structure to maximize the skilled people
Scheduling system "more efficient use of available skills"
Improved personal transport for flight line personnel-each tech has mobility

From this list the group was asked to prioritize the groupings, now called modules, by casting votes for the ones they considered most important. Corporate Knowledge was identified as the most import, followed by Tech Data and Training. It should be noted that this matches quite closely with the emphasis areas that were seen during the KA trips.

5.1.1.1.1 Developing the Decision Models

The facilitator then used the Expert Choice tool to develop and weight each decision model. Expert Choice uses the Analytical Hierarchy Process (AHP) to develop decision models. The AHP is a powerful and comprehensive methodology that uses a hierarchical model comprised of a goal, criteria, and sub-criteria for each decision. This hierarchical approach is very common when making decisions with multiple objectives. Using the AHP enables the decision-maker to derive weights as opposed to arbitrarily assigning them. The AHP also allows decision-makers the capability to incorporate both objective and subjective considerations in the decision-making process. The AHP's flexible and efficient hierarchical framework guides a decision group to an agreed upon conclusion. Because all parts of the hierarchy are interrelated, it is easy to see how a change in one factor will affect all the other factors.

5.1.1.1.1.1 Decision Model Goals

For each decision model, the facilitator asked the group develop a goal for the decision model. Those goals are depicted in Table 25.

Table 25: Decision Model Goals

Model	Goal
Corporate Knowledge	Allow technicians to have ready access to information about the system
Tech Data	Instant access to accurate approved guidance for system repair
Training	Technicians are trained to maximize their trouble shooting skills
New Software System	Improve field level troubleshooting capability worldwide
Hardware	Enable worldwide wireless connectivity

5.1.1.1.1.2 Criteria

Once a goal was established for each model, the group was asked to identify criteria that would be used to make sure the goal was met. The facilitator used a Round-Robin technique to gather the criteria from each attendee. All the criteria were then captured in Expert Choice's Structuring Mode, with no discussion about any of them. Once all ideas were captured, the group refined the criteria by combining similar ideas and clarifying the criteria that were presented. This is where the bulk of the group discussions took place, as individuals further clarified their criteria. In preparation for assigning weights to the criteria, the individual criteria were grouped into common areas, thereby developing criteria and sub-criteria. Figure 5 shows the criteria and groupings for the Tech Data decision model.

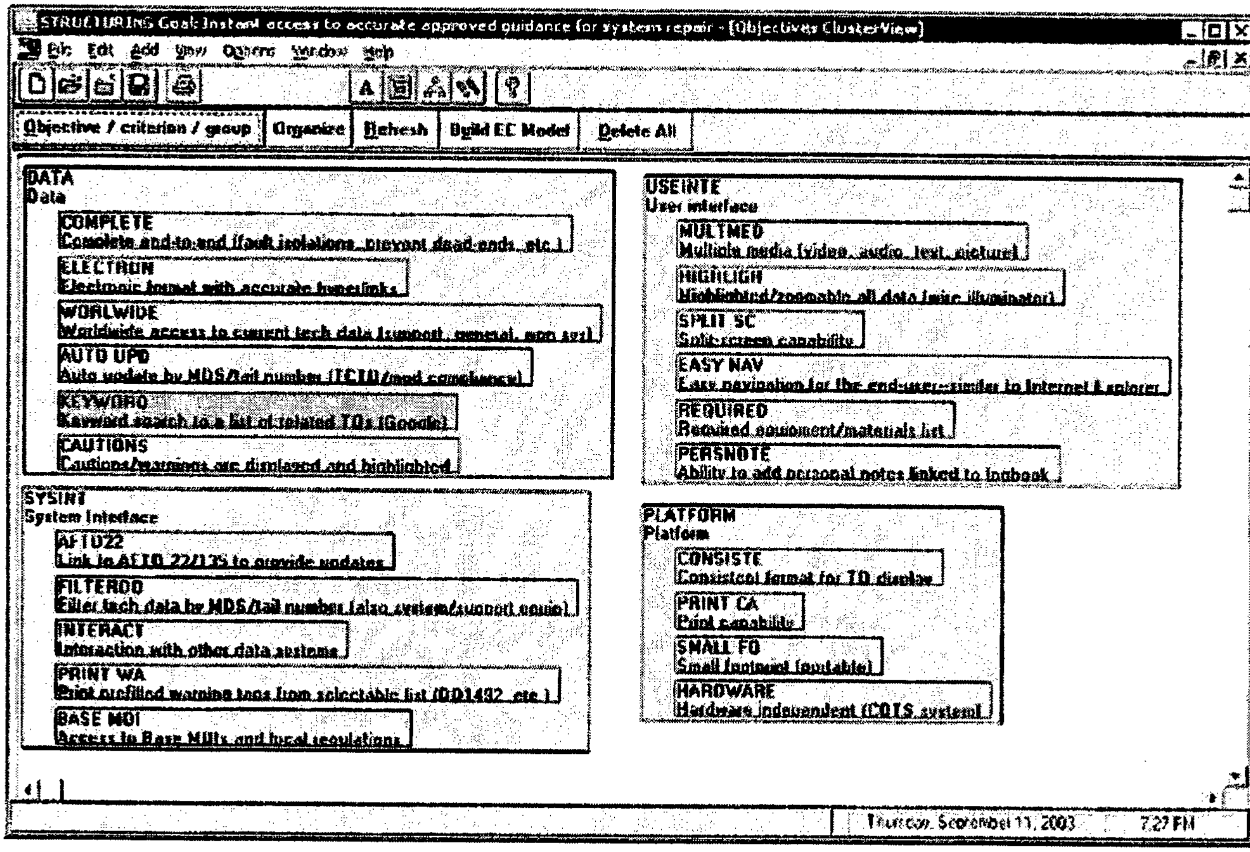

Figure 5: Tech Data

Figure 6 shows the criteria and groupings for the Training decision model.

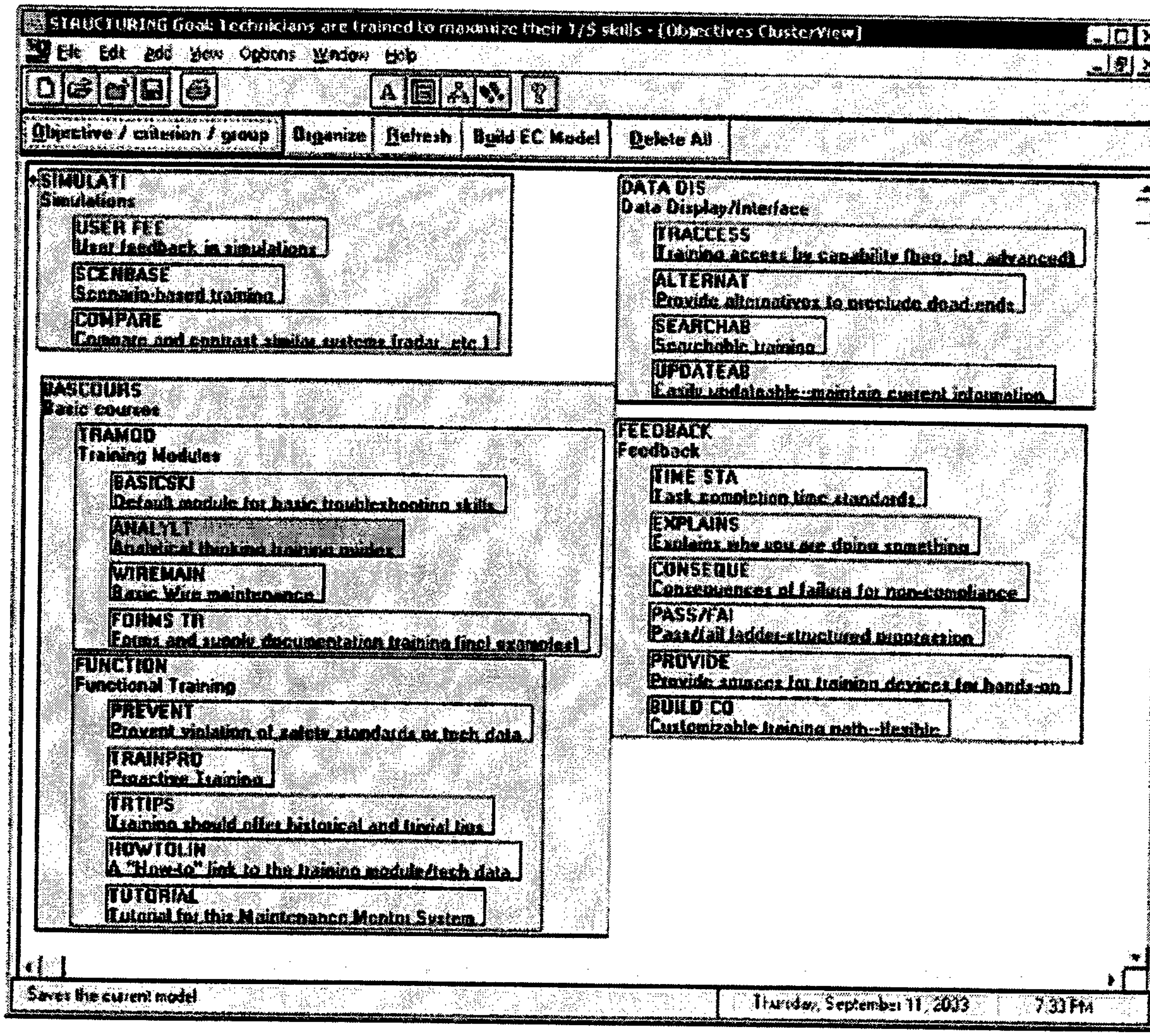

Figure 6: Training

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Figure 7 shows the criteria and groupings for the Corporate Knowledge decision model.

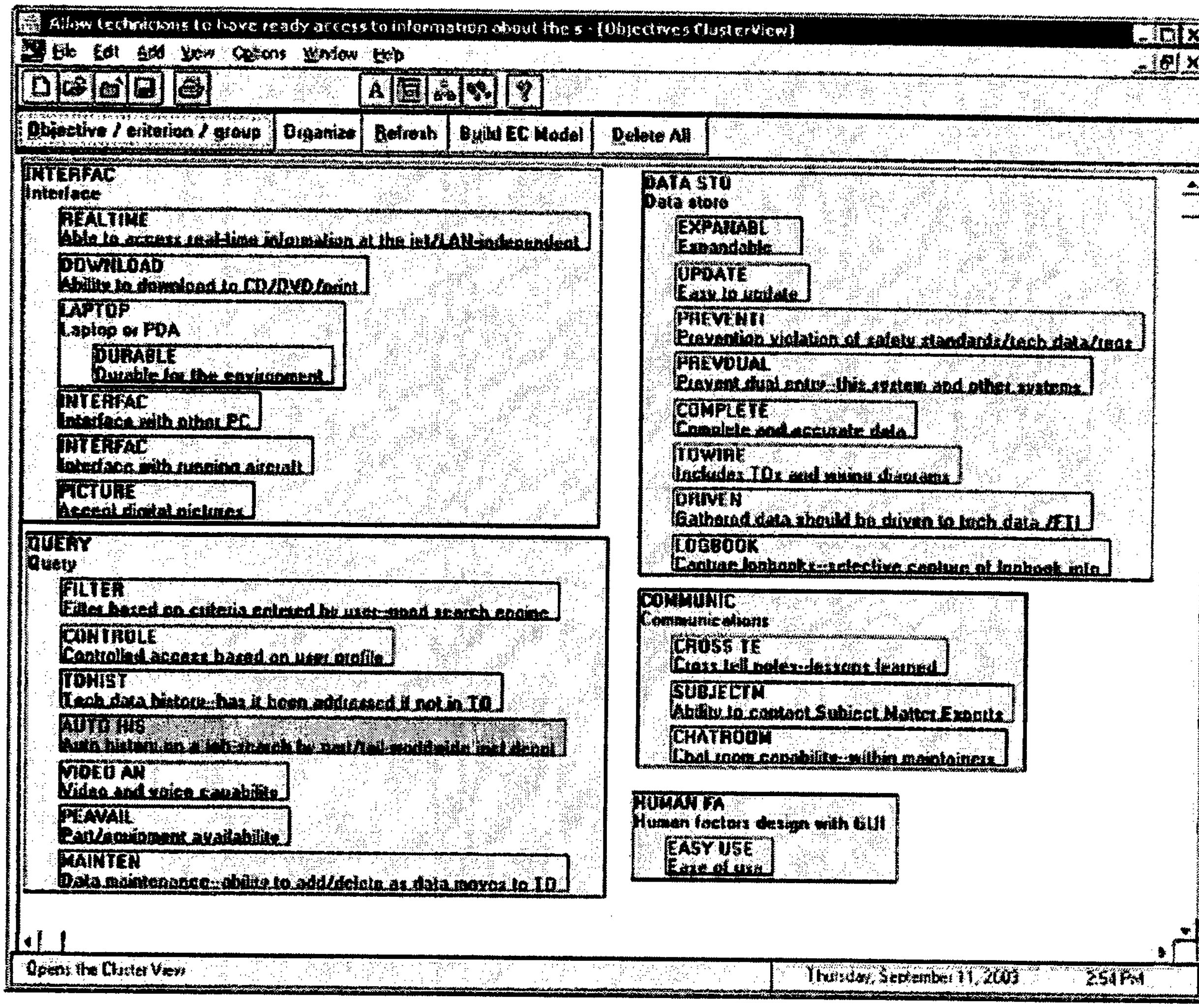

Figure 7: Corporate Knowledge

Once the group agreed on the appropriate groupings for the criteria and sub-criteria, the facilitator used Expert Choice's Evaluation & Choice mode to establish weights for each standard. The group made pair-wise comparisons of the criteria within each grouping. For each criterion, the group was asked which is more important: "a" or "b," "b" or "c" and "a" or "c," etc. The number of pair-wise comparisons required for each level of the decision model is determined by the following formula: **(n)(n-1)/2.** For three criteria, there would be (3)(2)/2 = 3 judgments, while four criteria would require (4)(3)/2 = 6 judgments. The number of judgments is represented by colored squares in the lower right corner of the screen. Figure 8 shows the process comparing Data and Platform for the Tech Data decision model.

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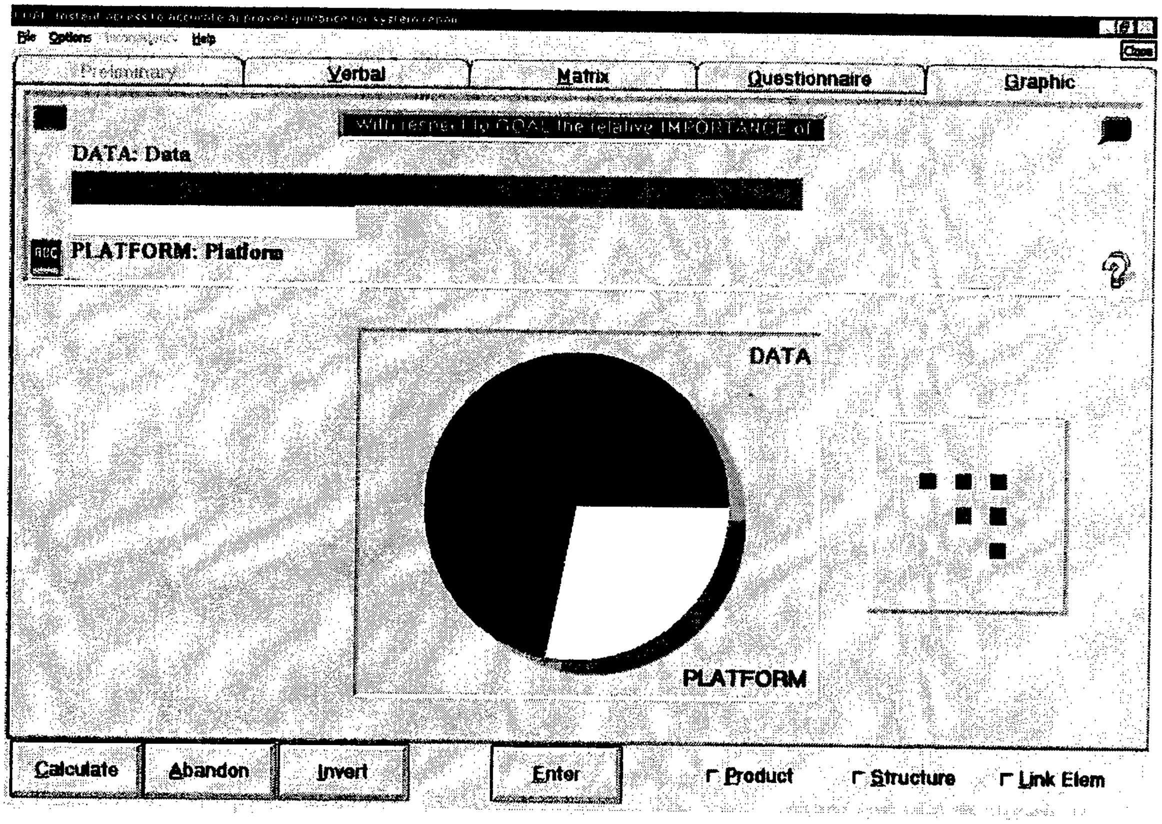

Figure 8: Pair-wise Comparison

The group judged Data (how data is stored and maintained) to be more important than Platform (hardware and operating systems). Once comparisons were made between all criteria, the results are displayed in Figure 9.

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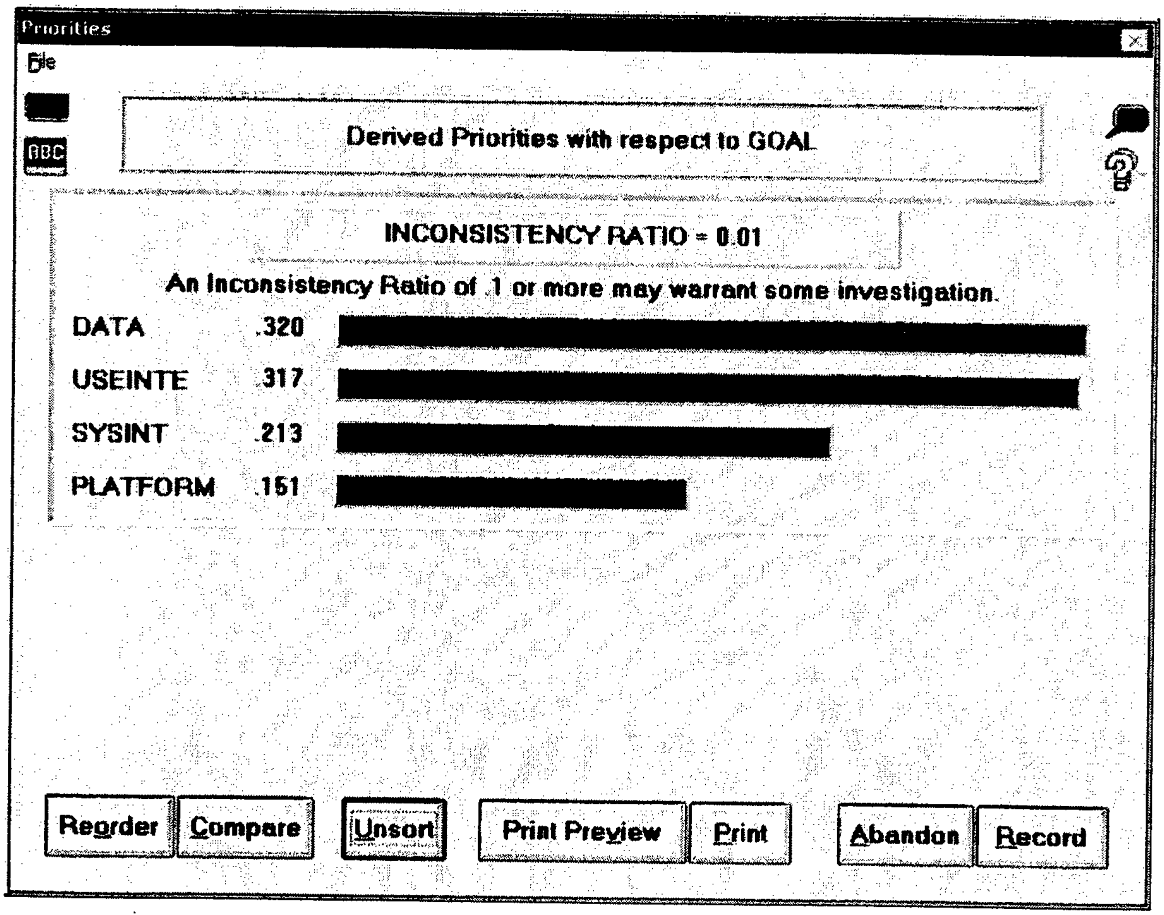

Figure 9: Results

Based on the judgment of the group when looking at two items at a time, the most important criterion is Data, followed by User Interface, System Integration, and finally Platform. The top-level comparisons for Tech Data also had an inconsistency ratio of 0.01. The inconsistency ratio shows how well the group compared the items. An inconsistency ratio shows the percentage of time the group was inconsistent in making judgments on a set of particular elements. An inconsistency ratio of 0.00 indicates the group was always consistent when making judgments, while an inconsistency ratio of 1.0 indicates the group was always inconsistent when making judgments. In general, any inconsistency ratio less than 0.1 is acceptable.

Table 26 shows the overall inconsistency ratio for each model the group developed.

Table 26: Inconsistency Ratios

Model	Inconsistency Ratio
Corporate Knowledge	0.05
Tech Data	0.02
Training	0.02
New Software System	0.0
Hardware	0.05

5.1.1.1.2 Standards

After the criteria for the decision models were identified, grouped, and weighted, the group began the process of identifying standards for each of the criteria. Standards are used to judge how well an alternative (in this case, software package) meets the criteria. Most MXM criteria are judged using three categories (high, medium and none) for each. Other MXM criteria are judged using only two categories (High or none). Standards are given a numerical rating using a logarithmic scale so that alternatives that provide a great value to the organization come out at the top of the list, while those alternatives that do not provide a benefit to the organization drop to the bottom of the list. The standard scale for the MXM analysis is:

- High-100%
- Medium- 33%
- Low-0%

A total benefit score for an alternative is derived using the following formula:

Total Benefit Score = **Criteria 1 Weight * Standard 1 Weight +**
Criteria 2 Weight * Standard 2 Weight +
...+

Table 27 shows the standards for the user interface grouping of the Tech Data model.

Table 27: Standards for Tech Data User Interface

Criteria	High	Medium	None
Multiple media (video, audio, text, picture). The group would like to have the data displayed in a variety of formats.	All	One or more	None
Highlighted/zoomable all data. The group would like to be able to highlight portions of data and zoom into parts of a diagram. This is especially important for wiring diagrams. They mentioned a specific tool called Wire Illuminator that has this capability	Yes		No
Split-screen capability. This would allow the group to view a drawing/video while at the same time reviewing a textual description.	Yes		No
Easy navigation for the end user-similar to internet explorer	Internet Explorer Familiarity	Intermediate	Significant training
Required equipment/materials list. A listing of tools, parts, etc. that are required for the repair. This enables the technician to gather all required equipment and materials prior to starting the maintenance action and shorten the maintenance time.	Yes		No
Ability to add personal notes linked to logbook. This allows the maintainer to keep personal notes that aren't shared with the global community.	Yes		No

The complete listing of standards for all criteria can be found in the section for each decision model.

5.1.1.1.3 Corporate Knowledge Decision Model

During the initial discussions the team recognized Corporate Knowledge as the area that could provide the greatest impact in improving maintenance troubleshooting times. The decision model (Figure 10) shows the structure the team developed to prioritize requirements for a corporate knowledge software system.

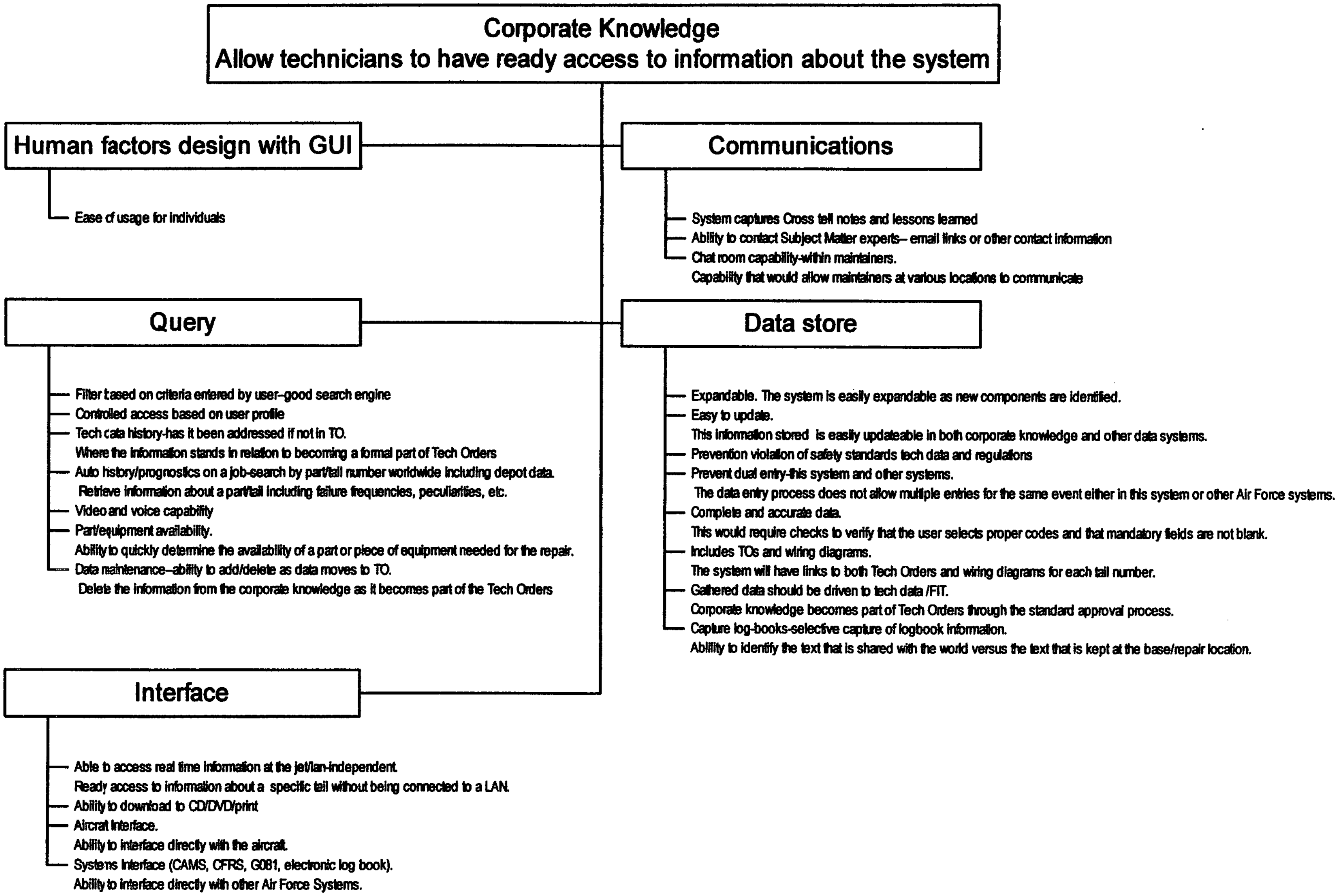

Figure 10: Corporate Knowledge decision model

5.1.1.1.3.1 Corporate Knowledge Requirement Priorities

Table 28 lists the corporate knowledge requirements identified by the group in order of priority assigned by the group. The high, medium, and low columns show the standards the group identified for each criterion.

Table 28: Corporate Knowledge Requirements Priorities

Grouping	Criteria	Weight	High	Medium	None
Human factors design with GUI	Ease of usage for individuals	0.471	Basic computer skills (minimal training needed)	Intermediate training	Advanced (much-needed training)
Data store	Prevention violation of safety standards tech data and regulations	0.181	Yes		No
Query	Filter based on criteria entered by user—good search engine	0.062	Google-style	Basic word search	Not available
Query	Auto history/prognostics on a job-search by part number or /tail number worldwide including depot data. This allows the user to retrieve information about a part or tail including failure frequencies, peculiarities about the part or tail, etc.	0.055	Summarized and grouped	Available	Not available
Interface	Able to access real-time information at the jet/LAN-independent. The team wants to have ready access to information about a specific tail without being connected to a LAN.	0.048	Instant	Delayed	Never
Communications	System captures Cross tell notes and lessons learned	0.039	Information pushed	Info pulled	Info not available
Interface	Systems Interface (CAMS, CFRS, G081, electronic log book). The group would like the ability to interface directly with other Air Force systems.	0.039	Access all systems	Access some systems	No access

Query	Controlled access based on user profile	0.016	Windows login		Separate user name and password
Communications	Ability to contact Subject Matter Experts—system can contain e-mail links or other contact information	0.013	One-click access in real time	E-mail/messages reports	Not available
Interface	Ability to download to CD/DVD/print	0.013	Selectable	All	None
Interface	Aircraft Interface. The group would like to have the ability to interface directly with the aircraft.	0.011	Remote access	Local access	No access
Query	Data maintenance—ability to add/delete as data moves to TO. As corporate knowledge becomes a formal part of the Tech Orders, the group would like to be able to delete the information from the corporate knowledge.	0.011	Available		Not available
Query	Video and voice capability	0.009	Both	Only one capability	Not available
Communications	Chat room capability-within maintainers. This is a small chat room capability that would allow maintainers at various locations to communicate.	0.008	One-click access in real time	E-mail/messages reports	Not available
Interface	Accept digital pictures	0.005	All formats	Limited formats	None
Query	Tech data history—has it been addressed, if not in TO? This gives the users information about where the information stands in relation to becoming a formal part of Tech Orders	0.005	Available		Not available
Data store	Complete and accurate data. This would require checks to verify that the user selects proper codes and that mandatory fields are not blank.	0.004	Automatic	Manual	None

Data store	Capture log-books-selective capture of logbook information. The team would like to be able to identify the text that is shared with the world versus the text that is kept at the base/repair location.	0.002	Selective capture	Capture all	Capture none
Data store	Easy to update. This information stored in corporate knowledge is easily updateable in both corporate knowledge and other data systems.	0.002	Automatic	Manual	None
Data store	Gathered data should be driven to tech data /FI. The group wants the corporate knowledge to become part of Tech Orders through the standard approval process. For FIs, the group also wants the order of testing reordered as the testing reveals the most likely cause of failure. For example if the third step of the FI reveals the most problems, it should become the first item to help decrease the troubleshoot time for the maintainer.	0.002	Automatic	Manual	None
Query	Part/equipment availability. This allows the maintainer to quickly determine the availability of a part or piece of equipment needed for the repair.	0.002	Estimated delivery time	Available	Functionality not available
Data store	Expandable. The system is easily expandable as new components are identified.	0.001	Yes		No
Data store	Includes TOs and wiring diagrams. The system will have links to both Tech Orders and wiring diagrams for each tail number.	0.001	Yes		No
Data store	Prevent dual entry—this system and other systems. The team wanted to be sure that the data entry process did not allow multiple entries for the same event either in this system or other Air Force systems to which this system is linked.	0.001	Automatic	Manual	None

Figure 11 provides a graphical representation of the weights of the group assigned to each of the requirements for Corporate Knowledge. Note: To fit within the graph, the descriptions of the criteria have been shortened.

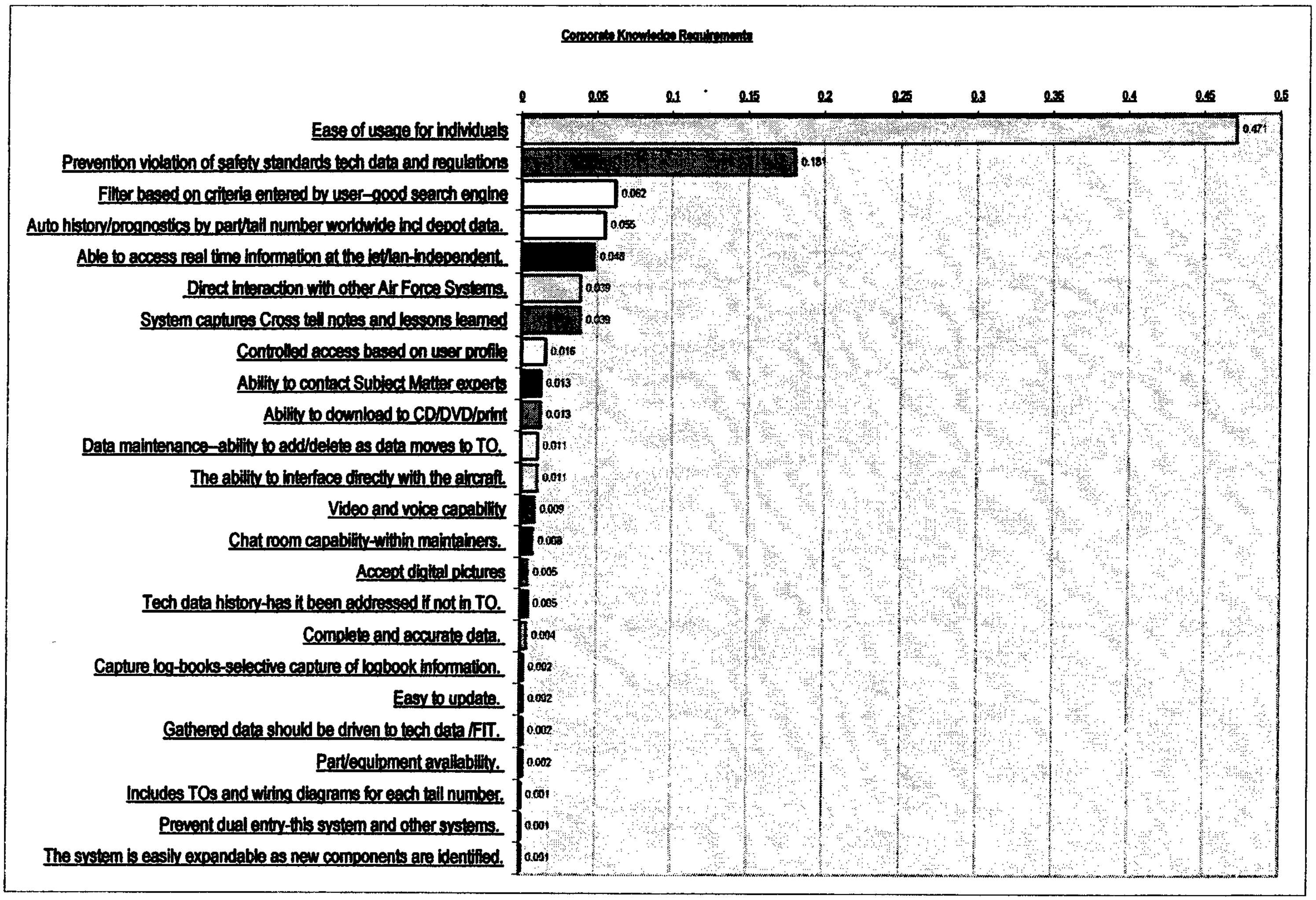

Figure 11: Prioritization of Corporate Knowledge Requirements

5.1.1.1.4 Tech Data

Ready access to tech data and wiring diagrams was another key factor in improving maintenance troubleshooting times. The group developed the following decision model (Figure 12) to capture the criteria that are important for a tech data software system.

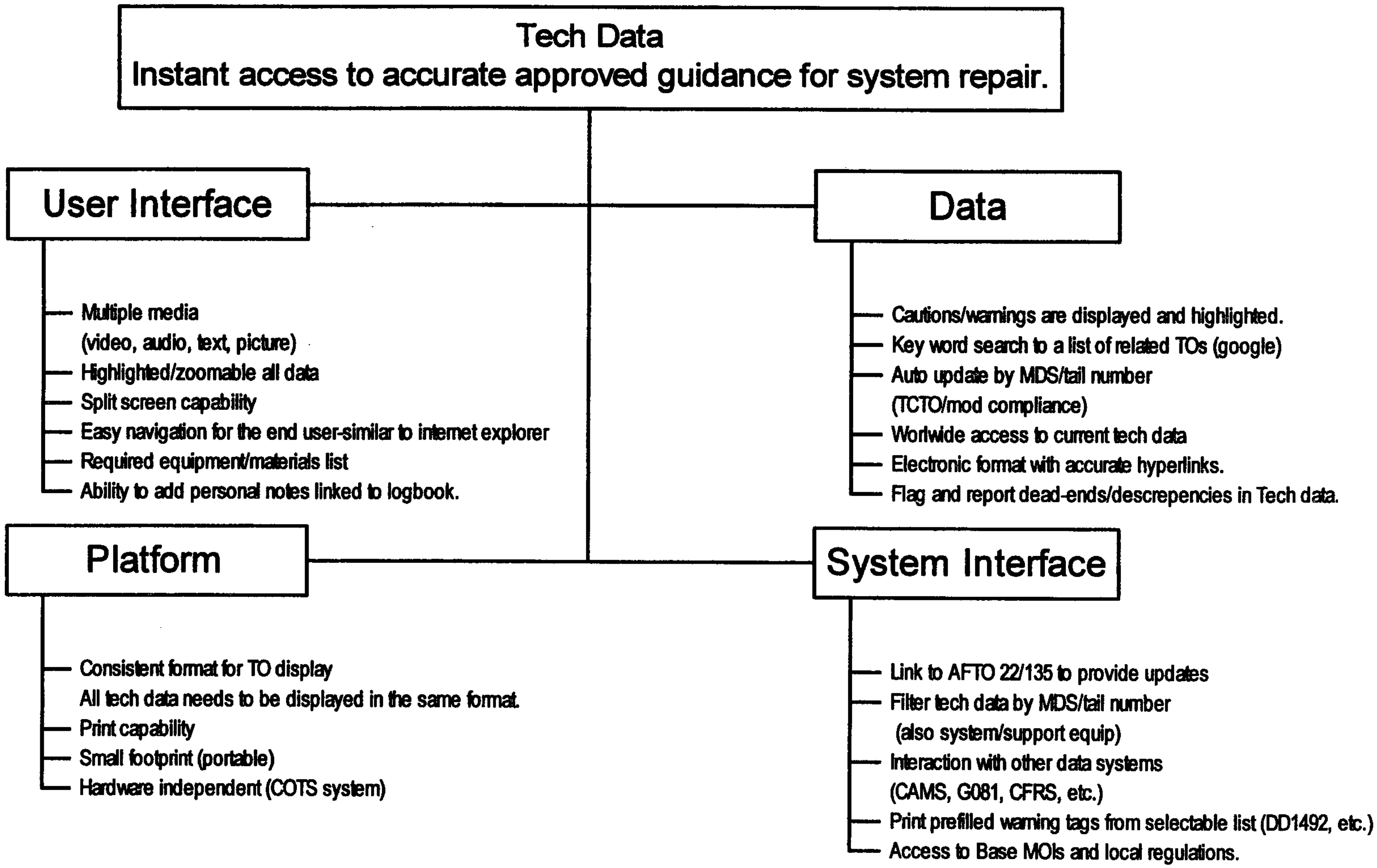

Figure 12: Tech Data Decision Model

5.1.1.1.4.1 Tech Data Requirements Priorities

Table 29 lists the tech data requirements identified by the group in order of priority assigned by the group. The high, medium, and low columns show the standards the group identified for each criterion.

Table 29: Tech Data Requirement Priorities

Grouping	Criteria	Weight	High	Medium	None
System Interface	Filter tech data by MDS/tail number (also system/support equip)	0.089	Yes		No
User interface	Easy navigation for the end user-similar to Internet Explorer	0.085	Internet Explorer Familiarity	Intermediate	Significant training
User interface	Highlighted/zoomable all data. The group would like to be able to highlight portions of data and zoom into parts of a diagram. This is especially important for wiring diagrams. They mentioned a specific tool called Wire Illuminator that has this capability.	0.075	Yes		No
Data	Worldwide access to current tech data (support, general, weapon system, tail). The team would like to be able to have access to up-to-date tech data throughout the world. They want quick access to information about the weapon system in general and specific topics regarding it.	0.074	Yes		No
Data	Electronic format with accurate hyperlinks. The group wants to be able to navigate between related tech data using hyperlinks embedded within the electronic document.	0.07	All	Some	None
Data	Auto update by MDS/tail number (TCTO/mod compliance). The group wants to be able to show that aircraft have complied with various tech orders and aircraft modifications.	0.064	Automatic	Manual	None
Data	Keyword search to a list of related TOs (Google)	0.056	Yes		No

Grouping	Criteria	Weight	High	Medium	None
System Interface	Interaction with other data systems (CAMS, G081, CFRS, etc.)	0.054	All		None
User interface	Multiple media (video, audio, text, picture). The team would like to have the data displayed in a variety of formats.	0.052	All	One or more	None
Platform	Small footprint (portable)	0.046	Laptop/Palm	Suitcase	No
User interface	Split-screen capability. This would allow the team to view a drawing/video while at the same time reviewing a textual description.	0.046	Yes		No
Platform	Consistent format for TO display (HTML or SGML or XML, etc). All tech data needs to be displayed in the same format. This will allow the maintainers to quickly navigate through the data.	0.043	Yes		No
Platform	Hardware independent (COTS system)	0.043	Yes		No
User interface	Required equipment/materials list. A listing of tools, parts, etc. that are required for the repair. This enables the technician to gather all required equipment and materials prior to starting the maintenance action and shorten the maintenance time.	0.034	Yes		No
Data	Cautions/warnings are displayed and highlighted. Any cautions or warnings that are associated with a weapon system or aircraft are displayed and highlighted for the user.	0.029	Yes		No
System Interface	Access to Base MOIs and local regulations. This helps the maintainers quickly identify variances in the "normal" way of doing things.	0.027	Yes		No
System Interface	Print pre-filled warning tags from selectable list (DD1492, etc.). The team identified a need to print warning tags in a pre-defined format.	0.027	Yes		No

Grouping	Criteria	Weight	High	Medium	None
Data	Flag and report dead-ends/discrepancies in Tech data. This is meant to help improve the tech data by identifying paths that do not resolve problems. The group mentioned several cases where Tech Order 1 referred to Tech Order 2, which referred to Tech Order 3, and finally back to Tech Order 1.	0.026	Automatic notification	Manual Notification	None
User interface	Ability to add personal notes linked to logbook. This allows the maintainer to keep personal notes that aren't shared with the global community.	0.024	Yes		No
Platform	Print capability	0.019	Yes		No
System Interface	Link to AFTO 22/135 to provide updates	0.017	Link to pre-filled form with instructions	Link to system with manual inputs	None

Figure 13 provides graphical representations of the weights the group assigned to each of the requirements for Tech Data. Note: To fit within the graph, the descriptions of the criteria have been shortened.

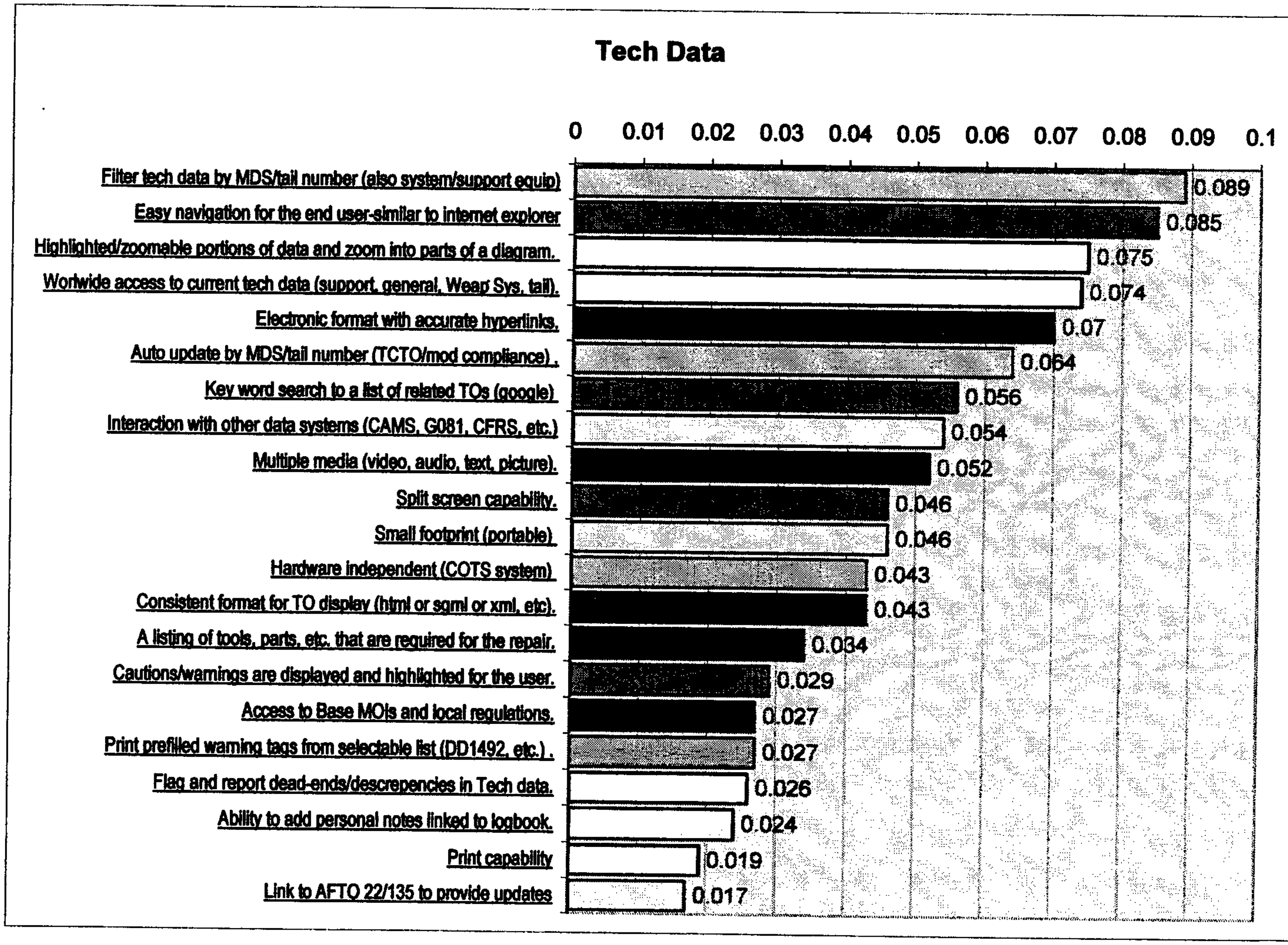

Figure 13: Prioritization of Tech Data Requirements

5.1.1.1.5 Training

There was a great deal of discussion among the group members about the need to have a training system that could support the training needs of each maintenance organization and specialty. Training, covering a broad range of topics from basic troubleshooting skills to weapon system-specific training, would help improve maintenance troubleshooting times. The group developed a decision model (Figure 14) to capture the criteria that are important for a training software system.

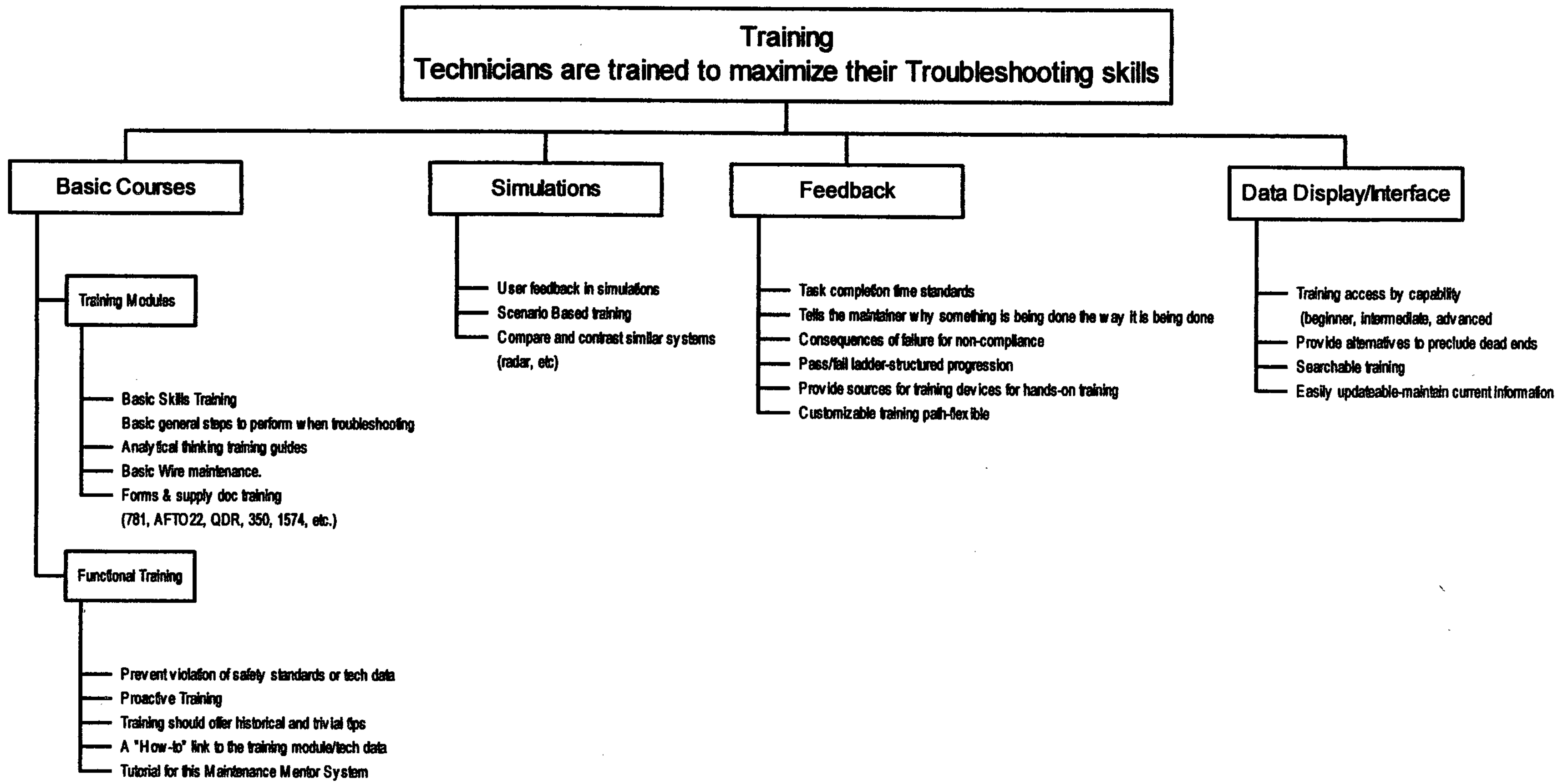

Figure 14: Training Decision Model

5.1.1.1.5.1 Training Requirements Priorities

Table 30 lists the training requirements identified by the group in order of priority assigned by the group. The high, medium, and low columns show the standards the group identified for each criterion.

Table 30: Training Requirements Priorities

Grouping	Criteria	Weight	High	Medium	None
Basic courses-Functional Training	Prevent violation of safety standards or tech data	0.128	Interactive	Static	None
Basic courses -Training Modules	Default module for basic troubleshooting skills. This module will teach maintainers the basic general steps to perform when troubleshooting.	0.107	Interactive	Static	None
Simulations	Scenario-based training. The user will be presented with various scenarios (problems to solve). The user will then work through the scenarios leaning better ways to troubleshoot problems.	0.103	Interactive	Static	None
Data Display/Interface	Easily updateable-maintain current information. Training needs to be updated as corporate knowledge and tech data changes	0.078	Automatic	Manual	No
Basic courses -Training Modules	Analytical thinking training guides. This module will provide the maintainer with methods for analytical thinking.	0.076	Interactive	Static	None
Data Display/Interface	Searchable training	0.076	Google	Word search	None
Simulations	User feedback in simulations. The user will receive feedback during the training to identify areas of strength and areas that need improvement.	0.073	Yes		No

Grouping	Criteria	Weight	High	Medium	None
Data Display/Interface	Training access by capability (beginner, intermediate, advanced). Users will be allowed to only take training for which they are ready.	0.07	Selectable	Sequential	None
Basic courses -Training Modules	Basic Wire maintenance. Wire maintenance was discussed thoroughly throughout the 2-day session. The team highly stressed the importance of wire maintenance.	0.059	Interactive	Static	None
Basic courses -Training Modules	Forms & supply doc training (781, AFTO22, QDR, 350, 1574, etc.). This training will help the maintainer navigate the paper world of maintenance.	0.033	Interactive	Static	None
Feedback	Tells the maintainer why something is being done the way it is being done.	0.033	Yes		No
Data Display/Interface	Provide alternatives to preclude dead ends. This helps maintainers work through dead-ends in the tech data.	0.032	Automatic	Manual	No
Feedback	Pass/fail ladder-structured progression. This will allow the maintainer to re-take courses hen there is a need to refresh skills for an activity that has not been performed for a period of time.	0.031	Selectable	Sequential	None
Feedback	Customizable training path-flexible. This allows a supervisor to schedule training for a maintainer based on the priorities of the supervisor or unit.	0.03	Selectable	Sequential	None
Simulations	Compare and contrast similar systems (radar, etc). This will allow the maintainer to leverage his knowledge of a system he currently understands to more quickly understand the system he will be maintaining.	0.026	Yes		No
Feedback	Consequences of failure for non-compliance. This allows the maintainer to understand what happens if they fail to comply with maintenance standards.	0.018	Yes		No

Grouping	Criteria	Weight	High	Medium	None
Feedback	Task completion time standards. This will provide the maintainer with a way to judge how well she compares with the standard. If the maintainer is taking too long to complete a task, then she can take proactive training to improve her skills.	0.012	Automatic	Manual	No
Feedback	Provide sources for training devices for hands-on training. This will the maintainer the location of materials required for hand-on training	0.007	Yes		No
Basic courses-Functional Training	Proactive Training. This allows a technician to take training before it is required.	0.002	Interactive	Static	None
Basic courses-Functional Training	A "How-to" link to the training module/tech data	0.001	Interactive	Static	None
Basic courses-Functional Training	Training should offer historical and trivial tips. This allows corporate knowledge to be shared with the maintainer.	0.001	Interactive	Static	None
Basic courses-Functional Training	Tutorial for this Maintenance Mentor System	0.001	Interactive	Static	None

5.1.1.1.6 New Software System

The new software system (Figure 15) incorporates all the requirements of the other three models.

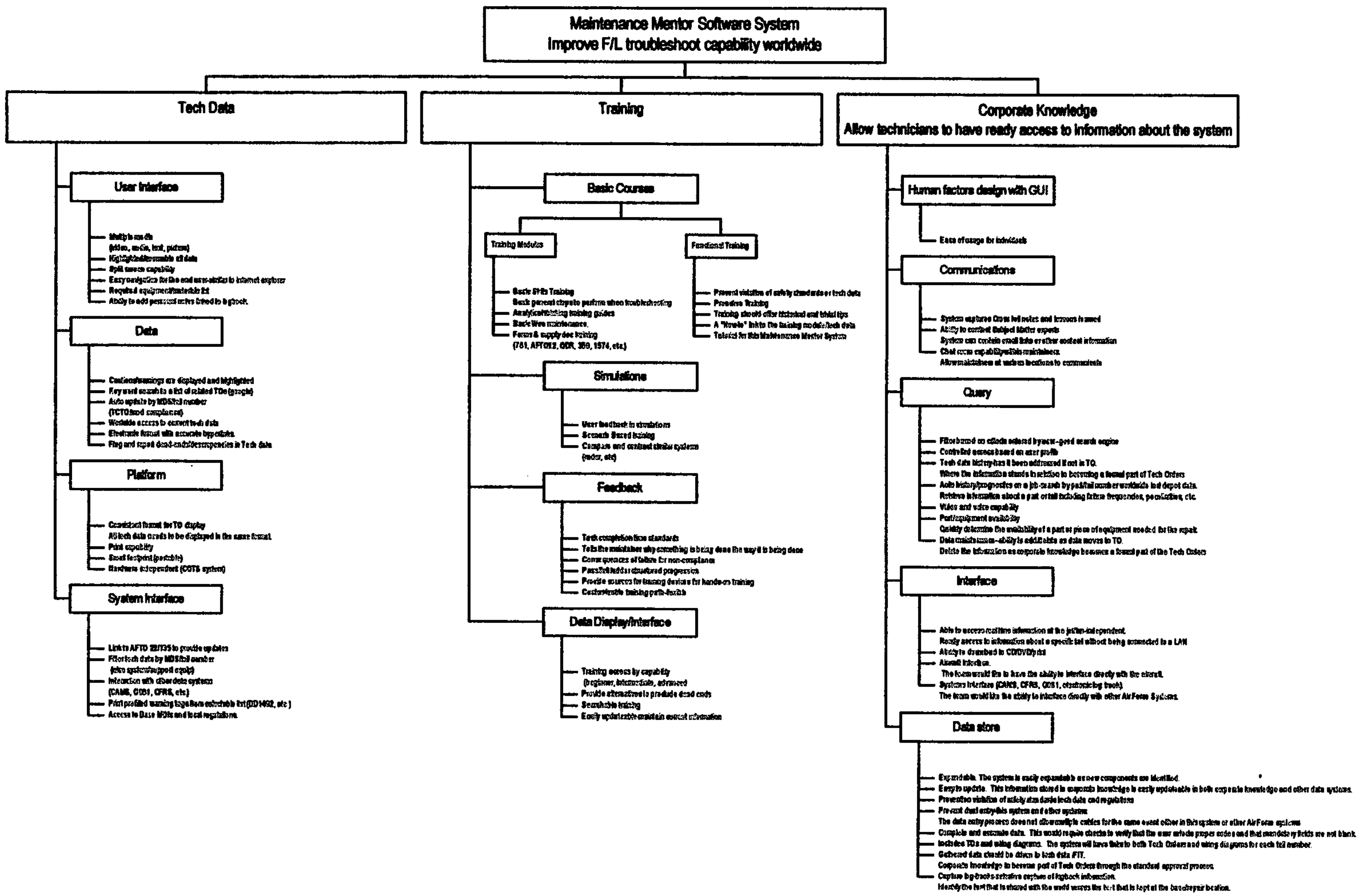

Figure 15: New Software System Decision Model

5.1.1.1.6.1 New Software System Requirement Priorities

Table 31 lists the new software system requirements identified by the grouping in order of priority assigned by the group. The standards identified by the group are included in the sections above.

It is important to note that these requirements were developed by a focused group of aircraft maintainers and do not reflect the entire requirements for the new software system. Other system users, such as management, engineers, equipment specialists, tech data writers, etc. need to be included to further develop the high-level requirements for the new software system.

Table 31: Combined Prioritized Requirements

Decision Model	Criteria	Weight
Corporate Knowledge	Ease of usage for individuals	0.178715
Corporate Knowledge	Prevention violation of safety standards tech data and regulations	0.068678
Training	Prevent violation of safety standards or tech data	0.042767
Training	Default module for basic troubleshooting skills. This module will teach maintainers the basic general steps to perform when troubleshooting.	0.035751
Training	Scenario-based training. The user will be presented with various scenarios (problems to solve). The user will then work through the scenarios leaning better ways to troubleshoot problems.	0.034414
Training	Easily updateable-maintain current information. Training needs to be updated as corporate knowledge and tech data changes	0.026061
Tech Data	Filter tech data by MDS/tail number (also system/support equip)	0.025494
Training	Analytical thinking training guides. This module will provide the maintainer with methods for analytical thinking.	0.025393

Decision Model	Criteria	Weight
Training	Searchable training	0.025393
Training	User feedback in simulations. The user will receive feedback during the training to identify areas of strength and areas that need improvement.	0.024391
Tech Data	Easy navigation for the end user-similar to Internet Explorer	0.024348
Corporate Knowledge	Filter based on criteria entered by user—good search engine	0.023525
Training	Training access by capability (beginner, intermediate, advanced). Users will be allowed to only take training for which they are ready.	0.023388
Tech Data	Highlighted/zoomable all data. The team would like to be able to highlight portions of data and zoom into parts of a diagram. This is especially important for wiring diagrams. They mentioned a specific tool called Wire Illuminator that has this capability	0.021483
Tech Data	Worldwide access to current tech data (support, general, weapon system, tail). The team would like to be able to have access to up-to-date tech data throughout the world. They want quick access to information about the weapon system in general and about specific weapon systems.	0.021197
Corporate Knowledge	Auto history/prognostics on a job-search by part number or /tail number worldwide including depot data. This allows the user to retrieve information about a part or tail including failure frequencies, peculiarities about the part or tail, etc.	0.020869
Tech Data	Electronic format with accurate hyperlinks. The team wants to be able to navigate between related tech data using hyperlinks imbedded within the electronic document.	0.020051
Training	Basic Wire maintenance. Wire maintenance was discussed thoroughly throughout the two-day session. The team highly stressed the importance of wire maintenance.	0.019713
Tech Data	Auto update by MDS/tail number (TCTO/mod compliance). The team wants to be able to show that aircraft have complied with various tech orders and aircraft modifications.	0.018332
Corporate Knowledge	Able to access real-time information at the jet/LAN-independent. The team wants to have ready access to information about a specific tail without being connected to a LAN.	0.018213

Decision Model	Criteria	Weight
Tech Data	Keyword search to a list of related TOs (Google)	0.016041
Tech Data	Interaction with other data systems (CAMS, G081, CFRS, etc.)	0.015468
Tech Data	Multiple media (video, audio, text, picture). The team would like to have the data displayed in a variety of formats.	0.014895
Corporate Knowledge	System captures Cross tell notes and lessons learned	0.014798
Corporate Knowledge	Systems Interface (CAMS, CFRS, G081, electronic log book). The team would like the ability to interface directly with other Air Force Systems.	0.014798
Tech Data	Small footprint (portable)	0.013176
Tech Data	Split-screen capability. This would allow the team to view a drawing/video while at the same time reviewing a textual description.	0.013176
Tech Data	Consistent format for TO display (HTML or SGML or XML, etc). All tech data needs to be displayed in the same format. This will allow the maintainers to quickly navigate through the data.	0.012317
Tech Data	Hardware independent (COTS system)	0.012317
Training	Forms & supply doc training (781, AFTO22, QDR, 350, 1574, etc.). This training will help the maintainer navigate the paper world of maintenance.	0.011694
Training	Tells the maintainer why something is being done the way it is being done.	0.011026
Training	Provide alternatives to preclude dead-ends. This helps maintainers work through dead-ends in the tech data.	0.010692
Training	Pass/fail ladder-structured progression. This will allow the maintainer to re-take courses hen there is a need to refresh skills for an activity that has not been performed for a period of time.	0.010358

Decision Model	Criteria	Weight
Training	Customizable training path-flexible. This allows a supervisor to schedule training for a maintainer based on the priorities of the supervisor or unit.	0.010024
Tech Data	Required equipment/materials list. A listing of tools, parts, etc. that are required for the repair. This enables the technician to gather all required equipment and materials prior to starting the maintenance action and shorten the maintenance time.	0.009739
Training	Compare and contrast similar systems (radar, etc). This will allow the maintainer to leverage his knowledge of a system he currently understands to more quickly understand the system he will be maintaining.	0.008687
Tech Data	Cautions/warnings are displayed and highlighted. Any cautions or warnings that are associated with a weapon system or aircraft are displayed and highlighted for the user.	0.008307
Tech Data	Access to Base MOIs and local regulations. This helps the maintainers quickly identify variances in the "normal" way of doing things.	0.007734
Tech Data	Print pre-filled warning tags from selectable list (DD1492, etc.). The team identified a need to print warning tags in a pre-defined format.	0.007734
Tech Data	Flag and report dead-ends/discrepancies in Tech data. This is meant to help improve the tech data by identifying paths that do not resolve problems. The team mentioned several cases where TO 1 referred to TO 2, which referred to TO 3, and finally back to TO 1 again.	0.0007448
Tech Data	Ability to add personal notes linked to logbook. This allows the maintainer to keep personal notes that aren't shared with the global community.	0.006875
Corporate Knowledge	Controlled access based on user profile	0.006071
Training	Consequences of failure for non-compliance. This allows the maintainer to understand what happens if they fail to comply with maintenance standards.	0.006014
Tech Data	Print capability	0.005442
Corporate Knowledge	Ability to contact Subject Matter experts--system can contain email links or other contact information	0.004933

Decision Model	Criteria	Weight
Corporate Knowledge	Ability to download to CD/DVD/print	0.004933
Tech Data	Link to AFTO 22/135 to provide updates	0.00487
Corporate Knowledge	Aircraft Interface. The group would like to have the ability to interface directly with the aircraft.	0.004174
Corporate Knowledge	Data maintenance--ability to add/delete as data moves to TO. As corporate knowledge becomes a formal part of the Tech Orders, the team would like to be able to delete the information from the corporate knowledge.	0.004174
Training	Task completion time standards. This will provide the maintainer with a way to judge how well she compares with the standard. If the maintainer is taking too long to complete a task, then she can take proactive training to improve her skills.	0.004009
Corporate Knowledge	Video and voice capability	0.003415
Corporate Knowledge	Chat room capability-within maintainers. This is a small chat room capability that would allow maintainers at various locations to communicate	0.003035
Training	Provide sources for training devices for hands-on training. This will the maintainer the location of materials required for hand-on training	0.002339
Corporate Knowledge	Accept digital pictures	0.001897
Corporate Knowledge	Tech data history-has it been addressed if not in TO? This gives the users information about where the information stands in relation to becoming a formal part of Tech Orders	0.001897
Corporate Knowledge	Complete and accurate data. This would require checks to verify that the user selects proper codes and that mandatory fields are not blank.	0.001518
Corporate Knowledge	Capture log-books-selective capture of logbook information. The team would like to be able to identify the text that is shared with the world versus the text that is kept at the base/repair location.	0.000759
Corporate Knowledge	Easy to update. This information stored in corporate knowledge is easily updateable in both corporate knowledge and other data systems.	0.000759

Decision Model	Criteria	Weight
Corporate Knowledge	Gathered data should be driven to tech data /FI. The team wants the corporate knowledge to become part of Tech Orders through the standard approval process. For FIs the team also wants the order of testing reordered as the testing reveals the most likely cause of failure. For example if the third step of the FI reveals the most problems, it should become the first item to help decrease the trouble shoot time for the maintainer.	0.000759
Corporate Knowledge	Part/equipment availability. This allows the maintainer to quickly determine the availability of a part or piece of equipment needed for the repair.	0.000759
Training	Proactive Training. This allows a technician to take training before it is required.	0.000668
Corporate Knowledge	Expandable. The system is easily expandable as new components are identified.	0.000379
Corporate Knowledge	Includes TOs and wiring diagrams. The system will have links to both Tech Orders and wiring diagrams for each tail number.	0.000379
Corporate Knowledge	Prevent dual entry-this system and other systems. The team wanted to be sure that the data entry process did not allow multiple entries for the same event either in this system or other Air Force systems to which this system is linked.	0.000379
Training	A "How-to" link to the training module/tech data	0.000334
Training	Training should offer historical and trivial tips. This allows corporate knowledge to be shared with the maintainer.	0.000334
Training	Tutorial for this Maintenance Mentor System	0.000334

Figures 16 and 17 provide a graphical representation of the weights of the group assigned to each of the requirements. Note: in order to improve readability, the figure has been separated into two parts and the requirement has been shortened to fit the graph. Each requirement has a prefix designating which part of the new software system it belongs to: CK designates Corporate Knowledge; TD represents Tech Data; and TR identifies the Training Requirements.

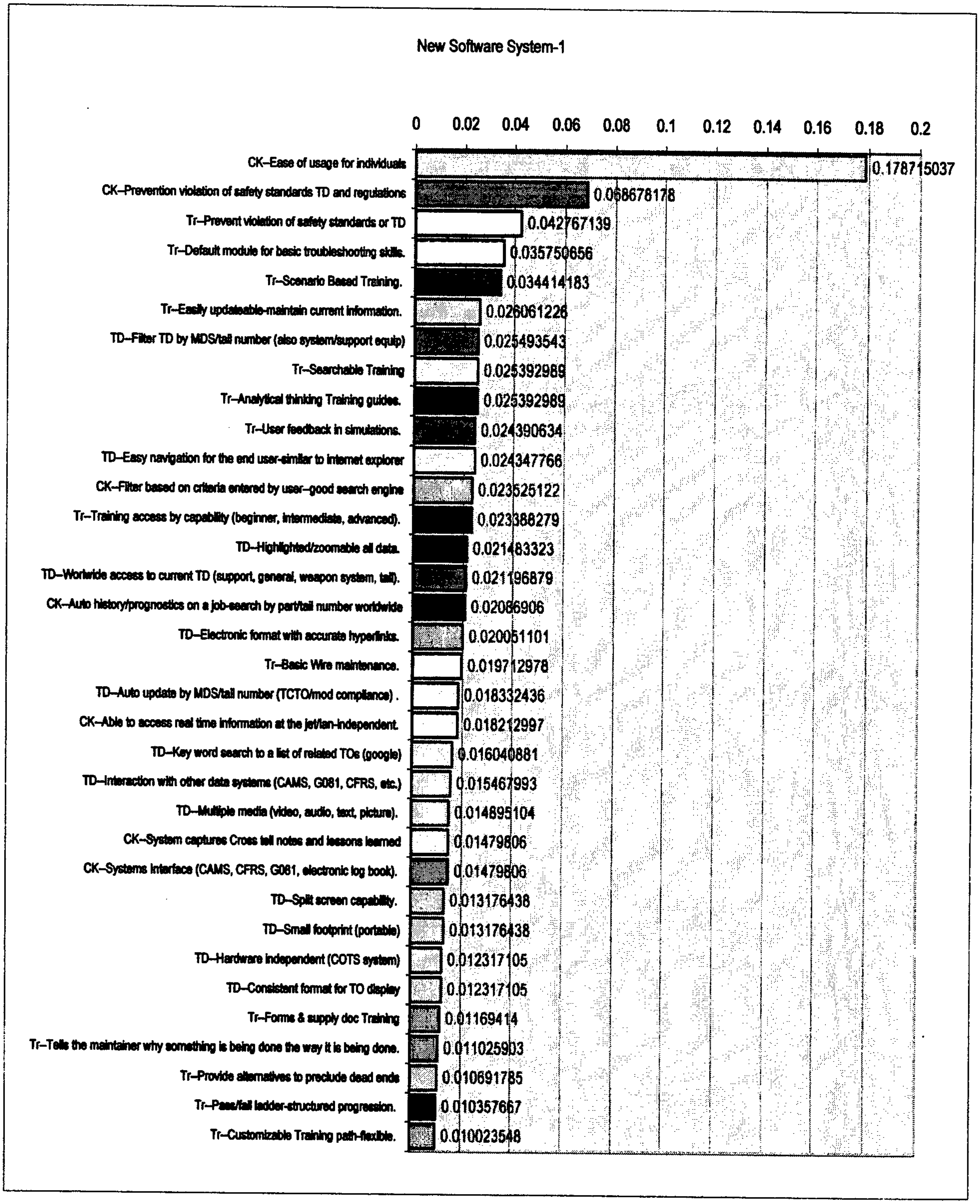

Figure 16: New Software System, Part 1

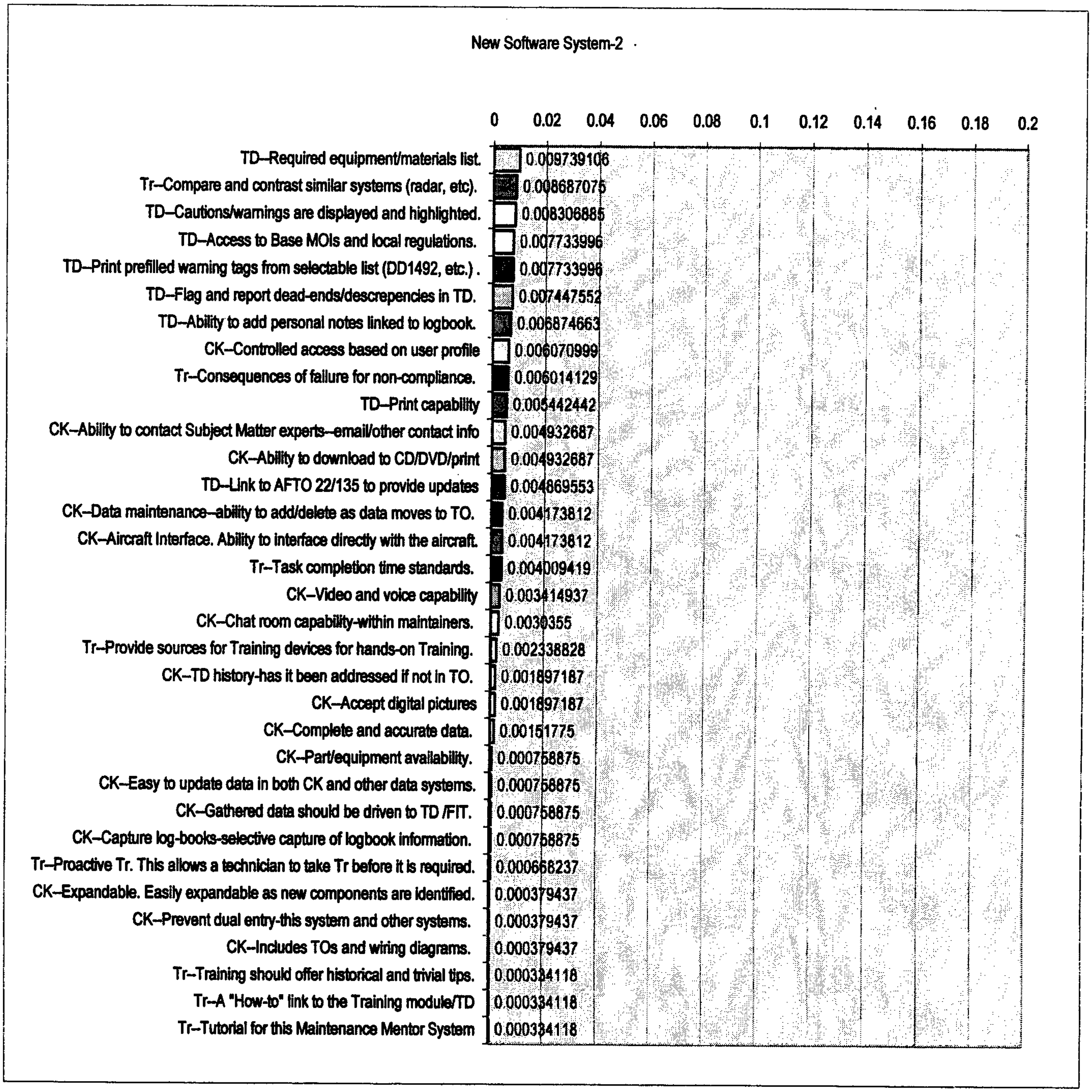

Figure 17: New Software System, Part 2

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5.1.1.1.7 Hardware

Once the group completed identifying and weighing all the software requirements, they performed the same process for hardware. The decision model (Figure 18) identifies the groupings and criteria for the hardware needed to support the software system.

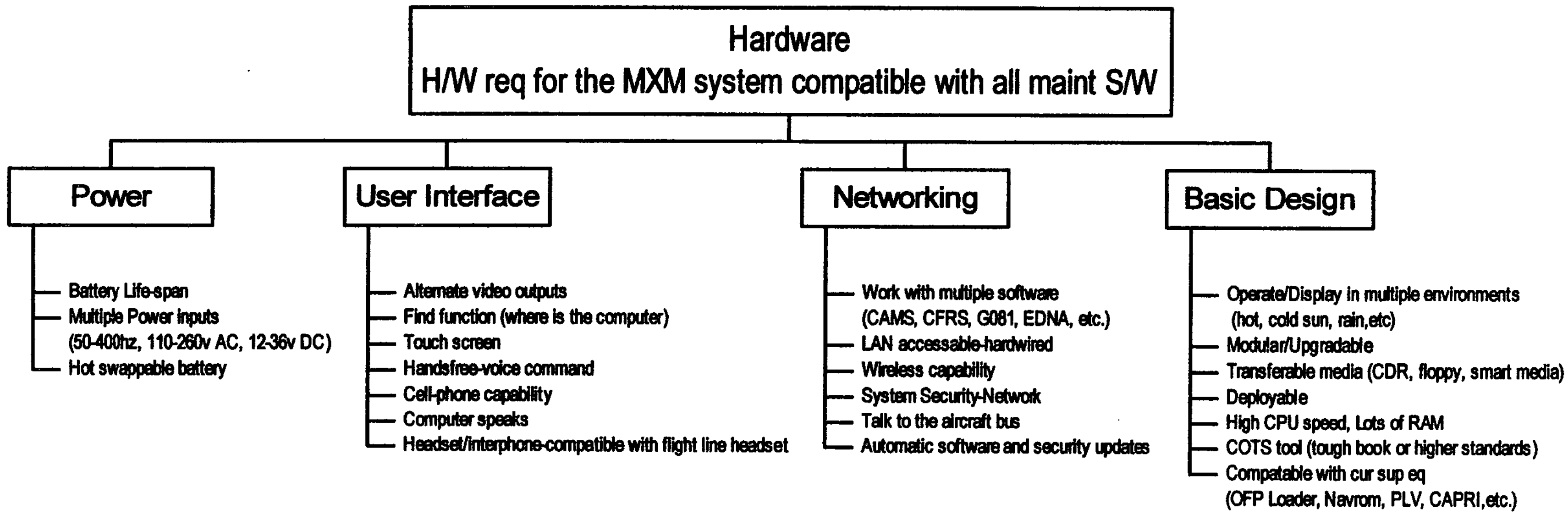

Figure 18: Hardware Decision Model

5.1.1.1.7.1 Hardware Requirements Priorities

Table 32 lists the hardware requirements identified by the group in order of the priority assigned by the group. The high, medium, and low columns show the standards the group identified for each criterion.

Table 32: Hardware Requirements in Priority Order

Grouping	Criteria	Weight	High	Medium	Low
Power	Battery Life-span	0.13	More than 8 hours	4 -8 hours	Less than 4 hours
Power	Hot swappable battery	0.101	Yes		No
Networking	Wireless capability	0.092	Yes		No
Basic design	Operate/Display in multiple environments (hot, cold sun, rain, etc.)	0.061	All		None
Basic design	High CPU speed, Lots of RAM	0.059	State of the art	Last Year	> 1GigaHz
User Interface	Hands-free voice command	0.059	Yes		No
User Interface	Touch screen	0.055	Yes		No
Basic design	Deployable	0.053	Laptop	Suitcase	No
Basic design	Compatible with current support equipment (OFP Loader, NAVROM, PLV, CAPRI, etc.)	0.048	All	Some	None
Basic design	COTS tool (tough book or higher standards)	0.046	Higher than tough book	Tough book	No
Networking	Talk to the aircraft bus	0.041	All	Some	None
Power	Multiple Power inputs (50-400hz, 110-260v AC, 12-36v DC)	0.04	All	Some	None
User Interface	Headset/interphone-compatible with flight line headset	0.034	Yes		No
Networking	Automatic software and security updates	0.026	Yes		No
Basic design	Modular/Upgradeable	0.025	Yes		No

Grouping	Criteria	Weight	High	Medium	Low
User Interface	Alternate video outputs	0.025	Yes		No
Networking	Work with multiple software (CAMS, CFRS, G081, EDNA, etc.)	0.024	All		None
User Interface	Computer speaks	0.022	Yes		No
Basic design	Transferable media (CDR, floppy, smart media)	0.019	All	Some	None
Networking	System Security-Network	0.018	Compliant		Non-compliant
Networking	LAN accessible-hardwired	0.014	Yes		No
User Interface	Find function (where is the computer)	0.006	Yes		No
User Interface	Cell-phone capability	0.003	Yes		No

Figure 19 provides a graphical representation of the weights the group assigned to each of the requirements for hardware. Note: To fit within the graph, the descriptions of the criteria have been shortened.

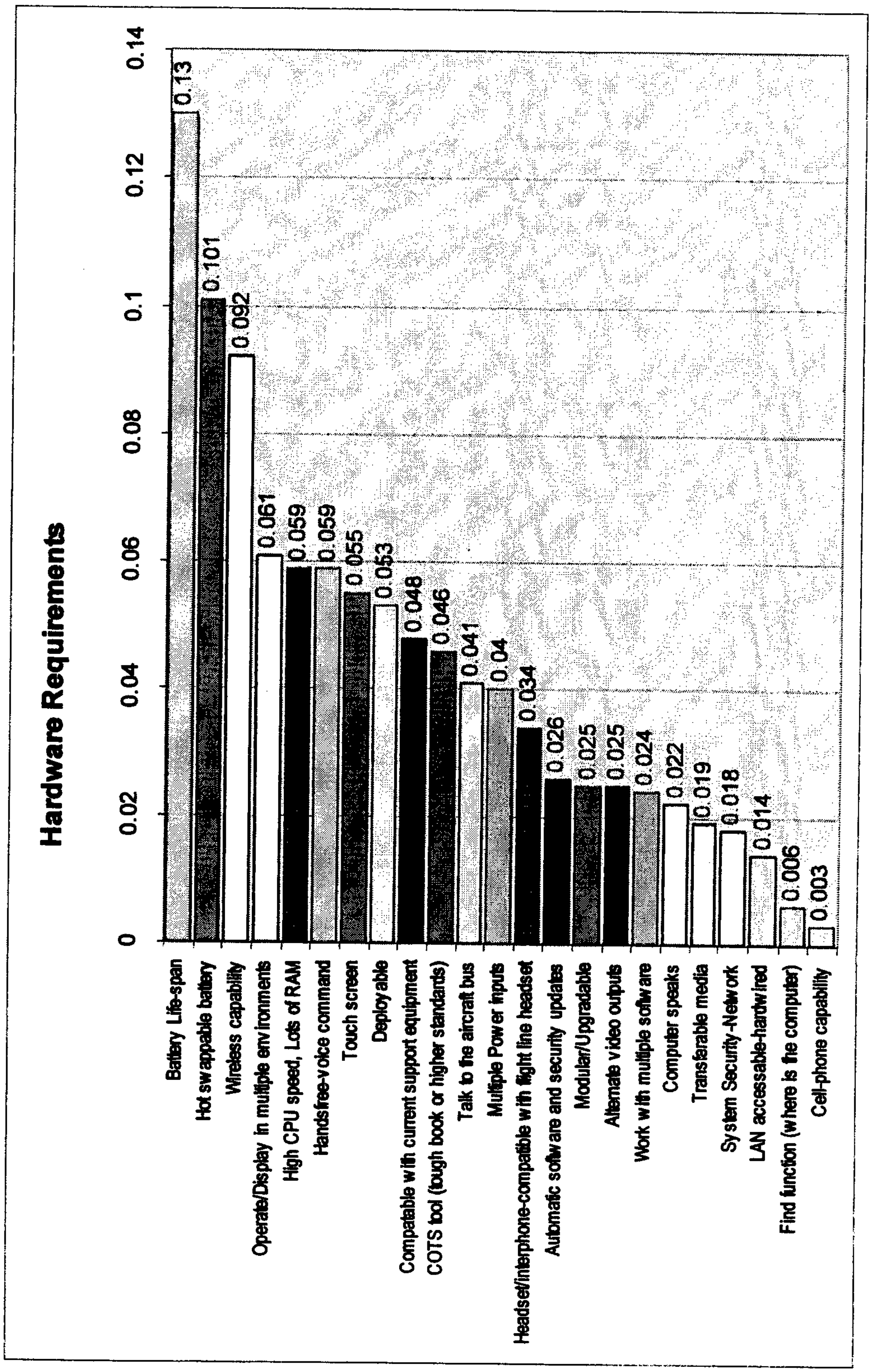

Figure 19: Hardware requirements

5.2 Potential Tool/Technology Options

A broad-based search was performed in order to determine what tools were available or in production that might potentially suit the needs of flightline maintainers to better facilitate fault isolation and repair. The criteria for the search centered mostly around products that advertised high reliability diagnostics and fault isolation. The initial search resulted in 1360 "hits," most of which were eliminated almost immediately when it was determined that they were actually such things as individual resumes or were repeats of items elsewhere in the list. A high level review brought the resulting list down to 71 that warranted a third level review. Following a functional and technical review, the list was reduced to products from 29 companies that warranted a further look. The products were selected based on the high-level requirements developed during the Decision Criteria Development Workshop and were included even if there was even a remote possibility of a match.

5.2.1 Search Results

It should be noted that the information obtained through this search was gathered from marketing material from each organization's web site. The organization names and the URLs to the respective web sites are listed in Table 33, along with the products and their general advertised features.

Table 33: Potential Tools and Features

Organization	2Maintain, Inc.
Web Site URL	http://www.2maintain.com/
Product	2MAINTAIN preventive maintenance software
Advertised Features	◆ Schedule PM ◆ Track Repairs ◆ Generate Cost Reports ◆ Track Inventory ◆ Assign Worksheets and Worksteps ◆ Track Tenant and Building Work Orders ◆ Minimize Downtime ◆ Maximize Savings ◆ Track Estimated Paybacks for Replacements ◆ Provide Cross Referencing to most Fixed Asset Systems ◆ Export/Import to most Microsoft Office Products

Organization	AeroInfo Systems Inc.
Web Site URL	http://www.aeroinfo.com/Default.htm
Product	MaintStream Component Set
Advertised Features	◆ Efficiently Manage all Aircraft Requirements ◆ Job Cards Carry Requirements to the Hangar Floor ◆ Plan Compliant Work Packages & Improve Productivity ◆ Real-time Line Planning for Multiple Stations ◆ Create and Manage Long Term Forecasts for all Fleets ◆ Gain In-depth Manageability of the Production Process ◆ Large Capacity On-Line Access to Historical Data ◆ Unprecedented Predictability and Insight of Maintenance Execution ◆ Export Event Packages Via the Web
Organization	Airline Maintenance Training, Limited
Web Site URL	http://www.amti-training.com/index.html
Comments	AMTI is a Mobile Training Organization Specializing in Transport Category Aircraft Providing "Hands-On" and Classroom Maintenance and Avionics Training.
Organization	Aircraft Tool & Maintenance Equipment Inc.
Web Site URL	http://www.atme-usa.com/index.htm
Product	ATA100A
Advertised Features	The purpose of the APU Tester is to provide the aircraft operator a tool for troubleshooting, testing and problem isolation of the Allied Signal GTCP-85-129CK Auxiliary Power Unit (APU). Use of this tester will reduce the number of premature engine removals on the 737-100/200/300 Boeing Commercial aircraft.

Product	ATA300A
Advertised Features	The purpose of the APU Tester is to provide the aircraft operator a tool for troubleshooting, testing and problem isolation of the Allied Signal GTCP-331-200 Auxiliary Power Unit (APU) and the Engine Control Unit (ECU). Use of this tester will reduce the number of premature engine removals on the 757/767 Boeing Commercial aircraft.
Product	ATA600A
Advertised Features	The purpose of the APU Tester is to provide the aircraft operator a tool for troubleshooting, testing and problem isolation of the Allied Signal GTCP-660 Auxiliary Power Unit (APU) and the Engine Control Unit (ECU). Use of this tester will reduce the number of premature engine removals on the 747-SP/100/200/300 Boeing Commercial aircraft.
Product	F1600
Advertised Features	The purpose of the Fault Isolator is to provide the aircraft operator an easily identifiable indication for each of the potential causes of an automatic shutdown of the Allied Signal GTCP660 Auxiliary Power Unit (APU) and the Engine Turbine Control (ETC). Use of this unit will reduce the number of premature engine removals on the 747-SP/100/200/300 Boeing Commercial aircraft.

Organization	Boeing
Web Site URL	http://www.boeing.com/defense-space/aerospace/techdata/pdf/CFRS.pdf
Product	Computerized Fault Reporting System (CFRS)
Advertised Features	◆ Determine the operational status of complex systems based on data downloaded from a data source and/or operator input ◆ Isolate faults using an expert based system that processes data from built-in tests and operator input ◆ Schedule and record maintenance functions ◆ Standardization of Aircrew Debriefing ◆ Reduction of "could not duplicate" Maintenance Actions ◆ Reduction of Maintenance Work Hours ◆ Improved Testing and Troubleshooting ◆ Maintenance Management Interface ◆ Asset Manager ◆ Data Warehouse
Organization	CaseBank Technologies Inc.
Web Site URL	http://www.casebank.com/products/spotlight.asp
Product	Spotlight
Advertised Features	◆ Experience-Driven Decision Support Expert System ◆ Designed for Complex Systems with Thousands of Interacting Components and Sub-Systems ◆ Web-Based

Organization	Champs Software, Inc.
Web Site URL	http://www.champsinc.com/cmms_solutions/ichamps.html
Product	*iCHAMPS*
Advertised Features	♦ Enables Enterprises to Increase Operational Efficiencies ♦ Provides Efficient Work-flow ♦ Fosters Work Force Collaboration ♦ Enhances Communication ♦ Optimizes Assets to Increase Profits ♦ Fully Web-Achitected CMMS
Organization	ClickSoftware, Inc.
Web Site URL	http://www.clicksoftware.com/
Product	ClickSoftware Service Optimization Suite
Advertised Features	♦ Workload Forecasting ♦ Optimized Workforce Planning ♦ Optimized Service Scheduling ♦ Intelligent Problem Resolution ♦ Wireless Workforce Management ♦ Service Business Analytics

Organization	CompuTrak
Web Site URL	http://www.computrak.org/
Product	CompuTrak
Advertised Features	◆ Maintenance Tracking ◆ Discrepancy Awareness ◆ Weight and Balance ◆ Purchasing ◆ Inventory Control ◆ Inventory Receiving ◆ Fleet Maintenance
Organization	Data-Trak, Inc.
Web Site URL	http://www.maintenance-software.com/index.htm
Product	Atlas 2000
Advertised Features	◆ Equipment Reports ◆ Unlimited Task Scheduling ◆ Task Reports ◆ Work Order Reports ◆ Work Order History ◆ Inventory Reports ◆ Purchasing Reports ◆ Automatic Reordering

Organization	EDO Technical Services Operati
Web Site URL	http://www.ailtso.com/advanced_diagnostic_software_virtual_engineering_support_training.htm
Product	Advance Diagnostic Software
Advertised Features	◆ Heuristic System Knowledge ◆ Assist Less Experienced Personnel in Performing Maintenance Tasks ◆ Augments Technician Knowledge ◆ Tools for Performing Tests, Fault Isolation, and System Repair ◆ Provides Maintenance Knowledge at Organizational, Intermediate, and Depot Level ◆ Commercial-off-the-shelf (COTS) Expert System Shell ◆ CD-ROM based information Tool ◆ Interface with Systems via Interface Cards
Organization	Emerson Process Management
Web Site URL	http://www.emersonprocess.com/ams/
Product	Asset Management Solutions (AMS) 6.1
Advertised Features	◆ Predictive Maintenance Software ◆ Diagnose Control Valve and Field Instrument Problems ◆ Capture and use Diagnostic Data from Intelligent Instruments ◆ Single Tool for Device Configuration, Documentation, Calibration Management, and Diagnostics ◆ More than 220 HART devices and 80 field bus devices ◆ Enhanced support of Ovation and DeltaV System Interfaces

Organization	Honeywell International
Web Site URL	http://www.emersonprocess.com/ams/
Product	Airplane Information Management System (AIMS)
Advertised Features	◆ Flight Management ◆ Displays ◆ Navigation ◆ Central Maintenance ◆ Airplane Condition Monitoring ◆ Flight Deck Communications ◆ Thrust Management ◆ Digital Flight Data ◆ Engine Data Interface ◆ Data Conversion Gateway

Organization	Intelligent Automation Corporation
Web Site URL	http://www.iac-online.com/Products/
Product	PC-GBS
Advertised Features	◆ Windows-based Software ◆ Imports Measurement Data from the Vibration Management Unit (VMU) On-board System ◆ Database Storage ◆ Collects and Transfers Data from Field Locations to Centralized Servers ◆ Portable Laptop Capable ◆ Automatic Software Updates ◆ Improves Readiness and Availability
Organization	Iotech, Inc.
Web Site URL	http://www.iotech.com/
Product	Daqbook
Advertised Features	◆ Portable Data Acquisition Device ◆ Analog Input, Frequency Input, Timer Output, Digital I/O, and Analog Output ◆ All in one Compact and Portable Enclosure ◆ Expandable ◆ Digital calibration – no potentiometers ◆ Multi-unit scan synchronization ◆ Vehicle Network Interface Option

Organization	Lambda Corporation
Web Site URL	http://www.lambdacorp.com/html/software.html
Product	Relex R&M analysis software
Advertised Features	◆ Reliability Predictions ◆ Fault Tree Analysis ◆ Maintainability ◆ Store and Reuse Characteristics, Failure Modes, Causes, and "Lessons Learned" ◆ Life Cycle Cost Analysis ◆ Intuitive "Drag and Drop" functionality ◆ Reports for Design Verification Activities, Manufacturing Quality Control, and Supplier Controls Required ◆ Bill of Material analysis
Organization	Mercury Computer Systems, Inc.
Web Site URL	http://www.mc.com/literature/literature_files/hw-diagnostic-sw-tools-ds.pdf
Product	RACE++ Series hardware diagnostic software to
Advertised Features	◆ Monitor System Operation ◆ Detect and Report System Problems ◆ Confidence for Mission-Critical Systems ◆ Fast Testing on Boot-up ◆ Continuous, Non-Invasive, Runtime System Monitoring ◆ Extensive Offline Diagnostics

Organization	Meridium, Inc.
Web Site URL	http://www.meridium.com/default.asp
Product	Enterprise Reliability Management System
Advertised Features	◆ Information Brought to Central Location for In-Depth Reliability Analysis and Reporting ◆ Supports Bi-Directional Interfaces with any ODBC-Compliant Database ◆ Scheduled Updates Sync with Existing Systems ◆ Easy to use Graphical User Interface ◆ Configurable Equipment, Locations, and Event Database ◆ Easy to use Queries, Reports, and Graphs ◆ Calculates Inspection and Retirement Dates ◆ Historical Profile of Equipment Condition ◆ Defines Future Inspection Activities
Organization	MRO Software
Web Site URL	http://www.mro.com/
Product	MAXIMO 5
Advertised Features	◆ Asset Acquisition ◆ Asset Tracking ◆ Asset Maintenance Planning ◆ Status and Condition Monitoring ◆ Workforce Management ◆ Resource Management ◆ Equipment Decommissioning and Disposal Management

Organization	MXI Technologies
Web Site URL	http://www.mxi.com/template.php?SECTION_ID=maintenix
Product	MAINTENIX
Advertised Features	◆ Reduced Maintenance Costs ◆ Increased Aircraft Availability ◆ Optimized Supply Chain Management ◆ Ensured Regulatory Compliance ◆ Configuration & Records Management ◆ Diagnostics & Prognostics ◆ Capture, Decode, and Archive Fault Messages ◆ Automated Troubleshooting of Aircraft Faults ◆ "Case-Based Reasoning" Expert System
Organization	Pacific Northwest National Laboratory
Web Site URL	http://www.pnl.gov/dsom/DSOMfinal.pdf
Product	Decision Support for Operations and Maintenance (DSOM)
Advertised Features	◆ Improves Process Efficiency ◆ Reduces Maintenance Costs ◆ Reduces Energy Consumption ◆ Dramatically Extends Equipment Life ◆ Condition-based Management Expert System ◆ Provides Information for Deciding How and When to Change Operations to Avoid Failure

Web Site URL	http://www.pnl.gov/redipro/papers/tedann_adpa94.pdf
Product	TEDANN: Turbine Engine Diagnostic Artificial Neural Network - STUDY
Organization	Qualtech Systems Inc.
Web Site URL	http://www.teamqsi.com/
Product	Testability Engineering And Maintenance System (TEAMS)
Advertised Features	♦ Multi-Signal Flow Modeling Methodology and Information Theory-AI Algorithms ♦ Graphical Interface Simplifies the Creation, Integration, Validation, and Revision of Models of Large, Complex, Reconfigurable, Fault-Tolerant, Hierarchical Systems. ♦ Model Individual Subsystems and Integrate them into Models ♦ Analyze and Quantify Testability of Systems and Subsystems ♦ Visually Pinpoint the Diagnostic Inefficiencies of a System ♦ Make Recommendations Toward the Design of Completely Testable Systems
Organization	Reliability and Maintainability (R&M)
Web Site URL	http://www.dtic.mil/ndia/2002systems/westervelt2d4.pdf
Product	Common Built-In-Test Evaluation Criteria – STUDY
Organization	Reliability Analysis Center (RAC)
Web Site URL	http://rac.alionscience.com/pdf/HumanFactorAnalysisInProduct.pdf
Product	Human Factor Analysis in Product and System Maintenance – STUDY

Organization	Sinex Aviation Technologies
Web Site URL	http://www.sinex.com/home.htm
Product	FleetCycle Software Suite
Advertised Features	◆ Controllability / Accountability throughout the Maintenance Process ◆ Easy Integration / Customization ◆ Internet Enabled ◆ Enhances Operating Efficiencies, Reducing Maintenance Costs ◆ Advanced Biometric Technologies for Maximum Data Security ◆ Real-Time Tracking and Reporting of Aircraft Status ◆ Improved Operational Problem-Solving and Process Management ◆ Progress Toward Paperless System
Organization	Spirent Systems
Web Site URL	http://www.gold-mro.com/mro/htm/home/home.htm
Product	GOLD Ground Maintenance and Supply Systems
Advertised Features	◆ Configuration Management and Maintenance ◆ Workflow Management and Recording ◆ Forecasting and Replenishment ◆ Inventory and Material Management ◆ Supply / Material System ◆ Wholesale Item Management ◆ Bar Code Support ◆ Work in Process Subsystem ◆ Web Portal

Organization	Tech S.A.T.
Web Site URL	http://www.techsat.com/welcome.html
Product	Flightline Rover
Advertised Features	♦ Hosting of Digital Aircraft Maintenance Documents ♦ Avionics Fault Diagnostics and Flight Data Analysis ♦ ARINC Software Data Loading ♦ Aircraft Maintenance Manuals and Fault Isolation Manuals ♦ Illustrated Parts Lists ♦ Wiring Diagrams ♦ Job Cards, Engineering Orders, and Service Bulletins
Organization	Telispark
Web Site URL	http://www.telispark.com/docs/MRO.PDF
Product	Maintenance, Repair & Overhaul
Advertised Features	Increase Readiness through Real-Time Status Maintained in a Centralized Location Improve Safety and Compliance through Automated Checklists and Electronic Sign-Off of Completed Work Orders Decrease Maintenance Cycle Time Access to Part and Equipment Availability ♦ Access Fault Isolation and Repair Procedures

5.2.2 Team Evaluation

The next step of the Technology Search consisted of a team review of the available products. The goal was to further identify the products and technologies that might have a more direct impact on the MXM project. Each offering was discussed and either discarded or categorized for further evaluation.

The list of applicable candidates was narrowed down to technologies from the following organizations/companies:

Boeing, CaseBank, ClickSoftware, Data-Trak, EDO, Emerson, Honeywell, Intelligent Automation, Iotech, Mercury Computer Systems, Pacific Northwest National Laboratory, Qualtech Systems, and Telispark.

5.2.3 In-depth Evaluation

The remaining products were evaluated against the MXM high-level requirements generated during the Decision Criteria Development Workshop. These requirements include the areas of Corporate Knowledge, Technical Data, and Training needs. Each product was rated using a direct point-for-point requirement match.

After a technical review, there were 5 remaining candidates that indicated a partial or better correlation. These include technologies from Boeing, Casebank, EDO, Emerson, and Telispark.

Although, on the surface it appears as if the products from Boeing and Casebank meet over 80 percent of the Corporate Knowledge and Technical Data requirements, there are a number of issues with these findings. Those issues are briefly discussed below.

5.2.4 Issues

5.2.4.1 Requirements

The requirements against which the technologies in this research were validated are high level and thus extremely general. They can be separated into two major categories: operational and data manipulation.

The operational requirements describe how the final product will look and perform. The majority of the requirements in this category apply to all modern software efforts. These include specifics like Ease of Use, GUI Interface, Web Access and Portability, and Real-Time Updates. Requirements like these are very important, but do not contain the specifics to make a valid technical comparison.

The data manipulation category is the big concern. Data, and how it will be manipulated in a software system, is the most important and most difficult part of any software development effort. The decision models developed during this research include several high-level examples of data manipulation requirements. Those requirements dictate how data is to be defined and behave as well as how that data will flow through separate modules of the same system. They even describe how data will interact with outside data sources.

Databases must be precisely designed to meet specific demands. Interaction with other data sources is a project in and of itself, requiring research and cooperation from all affected parties. It is a much easier process to define what data is to enter and exit a system than it is to define how data will be stored and processed inside a system.

5.2.4.2 Scope

Commercial-Off-the-Shelf (COTS) products are generally designed to meet a specific need within a specific set of business processes and a standard operational environment. The focus of these products is typically quite narrow and well defined. They contain a collection of features and functionality that are often quite rigid. COTS products are developed to meet general requirements that will fit the needs of as many customers as possible within the framework of the given business processes. Issues with COTS products include product inflexibility, unwanted or missing features, system incompatibilities, and integration difficulties, to name just a few.

5.2.5 Conclusion

MXM covers a very broad scope of requirements and the solution must function within a set of unique processes and run on a variety of machines with interaction to many outside sources. It must do all this reliably in a wide range of operational environments where even minor "glitches" may often be out of the question. In order to meet these challenges, it is the opinion of the research team that a custom development effort will need to be initiated.

This provides the notable advantage of allowing the specific needs of the warfighters to be addressed right from the beginning. Furthermore, it enables a "clean slate" approach to definitizing and prioritizing requirements for the system, helps ensure that the desired features and functionalities actually become reality, develops customer buy-in and support along the development path, and ultimately aids in transitioning the system to operational use. In addition, long-term system maintenance and support are much easier to address since all source code is accessible.

In recommending a custom development approach, the research team in no way intends to lead anyone to believe that a MXM solution will flawlessly come into being over night—that is not likely to be the case. It is far more likely, however, that the solution that does ultimately reach the flightlines will stand a greater chance of being accepted and used because it will actually meet the specific needs of the hands-on maintainers. In the opinion of this research team, that is the bottom line.

Appendix A: References

Boyd, J. R. (1987, August). *A Discourse on Winning and Losing*, Air University Library, Maxwell AFB Report no. MU 43947 (unpublished briefing).

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Whitaker, R., and Kuperman, G. (1996, October). *Cognitive Engineering for Information Dominance: A Human Factors Perspective*. Dayton OH: USAF Armstrong Laboratory Technical Report AL/CF-TR-1996-0159, October 1996.

Appendix B: Glossary

ACC - Air Combat Command

AFETS - Air Force Engineering & Technical Services. Organic specially trained USF civil service technicians who provide technical and advisory support to the maintainers.

AFRL/HESR - The Logistics Readiness Branch of the Deployment and Sustainment Division within the Air Force Research Laboratory's Human Effectiveness Directorate; sponsor of the Maintenance Mentor research

AHP - Analytical Hierarchy Process

AMC - Air Mobility Command

AOA - Angle of attack

AR - Aero-Repair Flight in the Maintenance Squadron (commonly called the AR Shop or AR, also known as Repair and Reclamation - a label for the riggers

BIT - Either (a) "built-in test" (capability for testing using onboard integrated equipment) or (b) "binary digit" (a data result from testing)

CADC - Central Air Data Computer. An onboard computer providing basic flight data to various systems in the aircraft

CAMS - Core Automated Maintenance System

CCU - Communications Control Unit (C-17)

CSFDR - Crash Survivable Flight Data Recorder.

CFRS - Computerized Fault Reporting System (F-15)

COTS - Commercial Off the Shelf

CSMU - Crash Survivable Memory Unit (F/A-22)

DFLCS - Digital Flight Control System

DHM - Diagnostic Health Management. Built-in fault tracing/diagnostic capabilities on the new F/A-22 Raptor.

DTC - Data Transfer Cartridge (F/A-22 in-flight data capture device).

DTM - Data Transfer Module (F - 15 non-volatile data capture device).

DTOS - Digital Technical Order System (computer-based documentation for C-17)

EDNA - Enhanced Diagnostic Aid

EFIS - Electronic Flight Instrument System (C-17)

flight control - Non-standard acronym used in this report for "flight control."

FI - Fault isolation guide. An Air Force TO used for maintenance troubleshooting. Fault isolation ready reference cards, although not official TOs, were often referred to as FIs as well.

FM - Flight Manual

"FLTS Tester" - A label used to denote the AN/ASM 497 Flight Control Test Set used with the F-15. Pronounced "flits tester."

FRC - Fault Report Code (F/A-22 formal fault indicators).

FSU - Flight Situation Unit (Predator onboard subsystem).

FTD - Field Training Detachment

GCS - Ground control station (Predator).

IMIS - Integrated Maintenance Information System

IPB - Illustrated Parts Breakdown

JFS - Jet Fuel Starter used on the F-15 and F-16. The Falcon (F-16) group mentioned among the equipment shared with other groups/units a laptop for running "JFS" aids or tool(s).

LRU - Line replaceable unit. An aircraft component or unit set of components capable of replacement on the flight line.

MXM - Maintenance Mentor - (a) The title of the project under which this report was done. (b) Informally, the label used to denote a system or product deriving from this effort.

MFL - Maintenance Fault List. A list of fault codes or indices used as procedural pointers during maintenance. As evidenced during the KA sessions, this term is also loosely used to connote any of the indices therein.

MX - Acronym for "maintenance."

MXG - Acronym for "Maintenance Group."

NDM - Naturalistic Decision Making (Klein *et al.*, 1992)

OEF - Operation Enduring Freedom

OIF - Operation Iraqi Freedom

OODA Loop (also *O-O-D-A Loop*) -- Observation, Orientation, Decision, Action Loop (cited by many and ascribed to Boyd, 1987). Taken to describe a single iteration of the cycle proceeding from data acquisition, through information integration and decision making, to enaction of a response.

PDR - Pulse domain reflectometer (tool)

PFAD - Predictive Failures and Advanced Diagnostics (an AFRL/HESR research program)

PMA - Portable Maintenance Aid. (a) A label for any self-contained computerized maintenance analysis and decision aid. (b) The laptop-style computer serving as the primary diagnostic and maintainer interface to the F/A-22 Raptor.

PQDR - Product Quality Deficiency Report. The main document for noting and reporting problems with parts/components.

QA - Quality Assurance

R & R - Repair and Reclamation Flight in the Maintenance Squadron, also known as Aero-Repair or the AR Shop - a label for the riggers.

Red Ball - A priority maintenance call for an aircraft scheduled to take off in the immediate future, typically the pilot/crew is already at the aircraft.

situation awareness - "The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." (Endsley, 1988, p. 97). Acronym = SA.

SPO - System Program office

swapology - A pun on "switchology" introduced by this author during the KA sessions to denote the maintenance strategy of "swapping out parts until the plane is fixed." The maintainers seemed to grasp my intended meaning right off the bat, but I have no indication they use this term themselves.

switchology - A casual term for (e.g.) "the science of configuring the controls, switches, and settings." Used by maintainers to denote corrective actions consisting solely of resetting or reconfiguring controls, switches, etc.

TCTO -Time Compliance Technical Order

TDR - Time domain reflectometer (tool)

TO - Technical Order(s) - the primary reference manuals associated with a given aircraft

UAV - Unmanned Aerial Vehicle

VIT - Variable Information Table (RQ-1 Predator)

WOW - "Weight on Wheels" switch

Appendix C: Knowledge Acquisition Plan

(as distributed prior to KA visits)

TRS DO24: MAINTENANCE MENTOR (MXM)

Knowledge Acquisition Plan
Nellis AFB KA Visit
April 2003

KA Location/Date: Nellis AFB Nevada 15 - 17 (and/or early 18) April 2003

KA Subject Matter: Work Domain: Maintenance (maintenance): Squadron maintenance activities.

KA Subject Matter: Work Focus: Aircraft F-15, F-16, A-10

KA Subject Matter: Work Focus: System(s) Flight controls (flight control) - broadly defined.

KA Subject Matter: Work Focus: SubSystem(s) Electrical, electronic, hydraulic, and mechanical subsystems participating in the control of flight surfaces and related components of the aircraft.

KA Subject Matter Experts (SMEs):

Frontline maintainers responsible for diagnosing and repairing flight control problems with the target categories of aircraft.

I. KA Overview

TRS DO24 is aimed at demonstrating a capability for leveraging decision models and criteria in RADSS to determine optimum or preferred strategies for supporting aircraft maintainers. The focus for this demonstration will be flight control maintenance.

NOTE: It is important to bear in mind that the outcomes of the KA phase are to be fed into the RADSS framework. As such, detailed examination and analysis of individual and collective maintainers' cognitive work performance is less important than identifying support strategies, support needs, support constraints, criteria for support assessment, and those quantitative/qualitative metrics and measures relevant to these criteria.

I.A. The Maintenance Domain: 3 Tiers of Relevant Knowledge/Information

In effect, there are 3 "tiers" or "sets" of knowledge and information which are relevant to the MXM effort. These are differentiated on the basis of topical generality. Figure 20 illustrates these tiers.

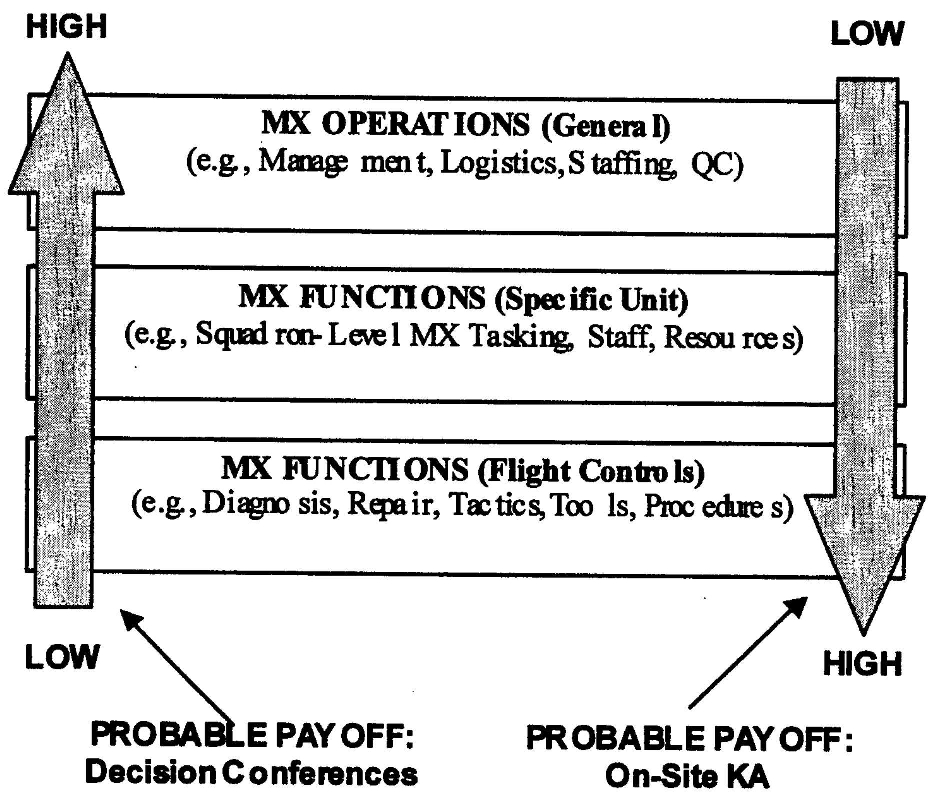

Figure 20: Tiers of Relevant Knowledge/Information

The reason for differentiating these three tiers is to clarify what our KA targets are for the project (overall) as well as what targets are most likely to be addressed in one or another of the planned TRS DO24 KA activities. As Figure 1 illustrates, the most general tier (maintenance Operations - General) is most likely to be illuminated in the planned decision conferences, while the most particular tier (maintenance Functions - Flight Controls) is most likely to be illuminated in the on-site KA exercises.

In the following sections the "topology" or "structure" of the KA effort will be introduced and reviewed. The points made in these subsequent sections are based on a variety of factors, including:

- The stated goals of the TRS DO24 effort (overall)
- The more specific goals of the TRS DO24 on-site KA visits
- The time and resource constraints pertaining to the KA effort
- The scope and depth of cognitive task analysis (CTA) appropriate to the RADSS decision analysis demonstration
- The scope and depth of CTA that is feasible given the resources and timeframe on this project

II. A Breakdown of Topics/Foci for the On-Site KA Effort

The end goal is to generate a set of data about tools and instruments employed in flight control maintenance. This means gathering that information most pertinent to assessing tools and instruments (broadly defined) will need to be prioritized.

To accomplish this, it will be necessary to try and dig into a series of aspects of the flight control maintenance functions and related resources. In the following subsections the most important of these general aspects will be reviewed. The ordering of the aspect reviews does not reflect any rigid prioritization or ranking.

II.A. ASPECT 0: Flight Control maintenance Operations (General)

Obtain an overview of the flight controls maintenance operations as currently performed for 3 classes of aircraft: F-15, F-16, and A-10. The scope of this aspect is general - i.e., the operational context within which flight control maintenance functions are performed. This aspect includes overhead, administrative, and organizational factors comprising that context. Primary attention should be paid to factors including:

- Administrative context for the maintenance functions[53]
- General data on maintenance operational units[54]
- General data on overall unit maintenance operations[55]
- General data on flight control maintenance operations[56]

[53] Such features include: command structure, staffing, technical requirements; administrative requirements; reporting requirements, etc.
[54] This means data on things like (e.g.): staffing; personnel; maintenance team composition; resource allocation, etc.
[55] This means data such as (e.g.): volume of maintenance "cases;" time/resource data on the overall maintenance operations flow; QC data on overall unit maintenance operations, etc.
[56] This includes things such as (e.g.): frequency of incidents; duration of maintenance cycles for flight control issues; QC data on flight control maintenance, etc.

II.B. ASPECT 1: Flight Control maintenance Functions (Tasks/Actions/Activities)

Obtain an overview of the flight controls maintenance functions as currently performed for 3 classes of aircraft: F-15, F-16, and A-10. Such overview info will need to be obtained for both individual maintainers and flight control diagnostic teams. Primary attention should be paid to factors including:

- Temporal features of flight control maintenance actions and efforts[57]
- Personnel features for flight control maintenance and repair functions[58]
- Indications and warnings motivating maintenance actions on flight controls[59]
- Criteria employed in evaluating flight control adequacy[60]
- Range of physical activities during a typical flight control maintenance activity[61]
- Range of discernible time/effort expended for activity support (as opposed to direct maintenance action)[62]
- Criteria employed in determining completion of maintenance activity.
- Criteria employed in determining adequacy/quality of maintenance outcomes.
- A general/representative process map for the flight control maintenance activity.
- Breakdown conditions[63]
- Demonstrable improvements/detriments[64]

II.C. ASPECT 2: Flight Control maintenance Tools and Instruments

Obtain an overview of the flight controls maintenance support tools (instruments, gadgets, manuals, diagnostic aids, etc.) currently employed for the three classes of aircraft. Such overview info will need to be obtained for both individual maintainers and flight control diagnostic teams. Primary attention should be paid to factors including:

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[57] Such features include: frequency of maintenance actions; duration of maintenance actions; time consumption for diagnostic and repair aspects of the maintenance function; time factors pertaining to team organization, meeting, consultation, etc.; time required for testing and flight-readiness certification; time dedicated to record keeping and paperwork; time spent obtaining/returning tools and instruments; time spent using tools and instruments.

[58] These include: number of personnel typically involved; categories of personnel involved; auxiliary personnel involved (e.g., supply, testing); individual vs. team involvement; team structure and organization.

[59] These include: type of I & W motivating flight control diagnosis/repair; source of I & W; channels and protocols for I & W reporting

[60] These include: metrics/measures of adequate control performance; criteria for mandatory diagnosis/maintenance; criteria employed in evaluating maintenance outcomes.

[61] We need to lay out a representative set of actions, positions, postures, etc., that maintainers adopt or execute during a typical flight control maintenance procedure. This entails factors such as: on-floor vs. on-aircraft positions; use of assistive devices (ladders, lights); moving around, etc.

[62] In other words, we need to take special note of time and/or effort that must be applied to "get ready to do the next step," as contrasted with actually doing the next step. Such digressions include (e.g.): going to get a tool/instrument; moving to another location; contacting someone else; doing paperwork, checking a reference aid, etc.

[63] These include any states or conditions in which a procedural constraint or obstacle interferes with efficient and/or effective execution of the maintenance task. Probes for breakdown conditions include (e.g.): persistent "time sinks," things that "make me want to pull my hair out," "worst-case scenarios," "worst incidents," etc.

[64] Improvements include specific items, events, innovations, etc., which the maintainer(s) cite as having improved flight control maintenance functions in the historical past. Detriments are the opposite - things that can be specified as having made things worse.

- Identification of tools and instruments[65]
- Categorization of the tools and instruments employed[66]
- Correlations among personnel and particular tools/instruments[67]
- Correlation of tools/instruments with flight control systems/subsystems[68]
- Correlation of tools/instruments with flight control maintenance procedure/process[69]
- Availability/accessibility for the tools /instruments[70]
- Functional features for each of the tools/instruments (relative to the task)[71]
- Interface/usability features for each of the tools/instruments (relative to the user(s))[72]
- Criteria for selecting/employing tools/instruments[73]
- Breakdown conditions[74]
- Demonstrable improvements/detriments[75]

II.D. ASPECT 3: Flight Control Maintenance Information Requirements

Obtain an overview of the information requirements pertaining to flight controls maintenance for the 3 classes of aircraft. Such overview info will need to be obtained for both individual maintainers and flight control diagnostic teams. With any luck, there will be a leverageable level of "generality" at which the information requirements are similar across the 3 aircraft types. Primary attention should be paid to factors including:

- Identification of specific features, factors, and factoids critical to flight control performance (general)[76]

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[65] We need to inventory the range of tools and instruments employed by the flight control maintenance personnel (individually and/or collectively) in the course of the flight control maintenance functions. *NOTE: For this purpose informational resources count as a "tool/instrument." For example: A reference aid is a tool just like a wrench.*

[66] We'll need to lay out a reasonable taxonomy for the types of tools employed (e.g., hand tools vs. documents vs. electronic modules vs. computers/software).

[67] This means we need to correlate specific personnel and specific tools/instruments wherever possible. It will be important to both identify tools used solely by one or another role and tools employed by all roles involved in the maintenance team.

[68] To the maximum extent possible, we need to be able to correlate tools/instruments with the aircraft components/subsystems to which they are applied. This is necessary to establish a basis for correlating tools with steps or aspects of the flight control maintenance function (as that function itself correlates with components/subsystems).

[69] Given a basic procedural/process schema for the flight control maintenance function, we need to be able to correlate tools/instruments with steps or options or phases represented in that schema.

[70] We'll need to know (for each listed tool/instrument) where it's located, how the maintainer accesses it, how far he/she goes and how long he/she takes to get/return it, etc.

[71] We'll need to know how the tool is employed in the course of flight control diagnosis/maintenance activity. Examples include: plugged into the aircraft for measurement; applied to physically modify an aircraft component; kept at hand for reference, etc.

[72] This covers those features or factors pertaining to how someone uses the given tool/instrument. Such features include (e.g.): size/weight; portability; sensory modalities employed in interaction, etc.

[73] This includes any info on why someone decides to employ a given tool/instrument. In particular, we need to pay attention to any selection criteria applied in selecting among two or more tools/instruments that would suffice for a single task

[74] These are conditions, states, or situations in which a given tool becomes problematical or useless to the task at hand. Phrased another way, a "breakdown" (vis a vis tools/instruments) pertains to that item not being as usable or useful as one would hope.

[75] Specific changes or innovations that have improved (or degraded) the applicability/utility of a given tool/instrument.

[76] This means we need to compile a set of key features and factors used for reference in addressing the flight control systems/subsystems by the target SMEs.

- Identification of specific features, factors, and factoids critical to flight control troubleshooting[77]
- Identification of those features, etc., which serve as criteria for assessing flight control performance/functionality[78]
- Identification (where possible) of the scalar or relative values used for such assessments[79]
- Correlation of information elements with tools/instruments[80]
- Correlation of information elements with specific systems/subsystems[81]
- Correlation of information elements with the course of the maintenance process/procedure[82]
- Correlation of information elements with specific personnel[83]

III. KA Strategy

The end goal is to generate a set of data about tools and instruments employed in flight control maintenance. However, one cannot reasonably focus on the tools from the beginning. Something has the status of "tool" on the basis of it being employed in the course of a task - otherwise, it's basically just a "box on the shelf." In other words, interest here is only in what qualifies as a flight control maintenance tool, not any old thing that is sitting around available for use. This demands need to operate with primary regard to a model for a typical/representative flight control maintenance task, then correlate data on tools with steps, requirements, and procedures delineated within that model.

III.A. Developing a Schema for the Flight Control Maintenance Process (General)

This is the single most important thing we have to do. It must be done early, and it must be done to a degree of specificity/detail that permits us to leverage the model to categorize, sort, and correlate the other data.

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[77] We want to pay special attention to reference elements used to address "what's wrong." There is no necessary correlation between referential elements used to address a system and those used in addressing a sick system." While the former are obviously important to outlining maintenance info needs, the latter are more likely to be critical to understanding info requirements during the course of diagnosis and repair activities.

[78] In other words, out of those key features/elements identified in accordance with the preceding items, we need to flag those that are themselves highlighted in evaluating system/subsystem performance (both for assessing faults and for evaluating maintenance quality).

[79] In other words, for each of the features/elements employed as criteria, we need to probe on the range of values applied in the measurement/evaluation of that element's state. These may be quantitative or qualitative. *NOTE: For qualitative criteria, we shall always attempt to identify a 2-, 3-, or 5-point rating scale.* A 2-point scale is for simply binary conditionals ("on/off;" "good/bad"), a 3-point is for a median or nominal range with critical extrema ("high-OK-low"), and a 5-point is a finer-grained elaboration on a 3-point. For the 3- and 5-point scales, the center value will always be "nominal/normal."

[80] We'll need to specify (wherever possible) which tool(s)/instrument(s) serve as the source for a given information element. If it's available to the maintainer by directed unaided inspection, we need to note that as well.

[81] To the extent it is reasonable, we need to correlate the information elements with the flight control systems/subsystems with the maximum possible specificity. For example: Hydraulic pressure might correlate with the hydraulic subsystem and not the electrical.

[82] This means we need to identify any necessary relationships between information elements (including I & W, measures, etc.) and steps in the maintenance procedure. Phrased another way, we need to lay out a map for what needs to be known when.

[83] This means we need to identify how information elements map onto the set of personnel (either singly or collectively). Phrased another way, we need to lay out a map for who needs to know what.

The recommended starting point will be to offer a process or sequence schema to the SMEs for their inspection and review. This will be an illustrative "map" for a generalized maintenance task. The notional initial such "map" is as follows:

- Problem Identification
- Problem Reporting/Documentation
- Unit Coordination of maintenance Status for Aircraft
- Maintenance Setup/Preparation (for Handling the Problem)
- Diagnosis
- Prognosis (Decision on Reparability of Aircraft; Whether to Proceed)
- Solution Specification (Decisions on What to Do)
- Repair Actions/Activities
- Supply/Requisition Activities
- Completion Decision (i.e., deciding when it's finished)
- Testing/Evaluation of Solution
- Certification/Validation of Outcomes
- Solution Reporting/Documentation
- Maintenance Stand-Down (Cleaning up; clearing out)
- Unit Coordination of Aircraft Return to Duty

First, we need to run this "map" past the SMEs to see if they believe it's representative of a single pass through a maintenance solution path. If not, it must be modified until they're comfortable with it.

Criteria for Completion:

This phase is reasonably complete at the point we have obtained a consensus on the basic steps or phases for a representative process map

Things to Watch out for (General):

We need to pay special attention to the following things (if and when they pop up):

- Specific references to procedural breakdowns (situations or conditions when the process flow is disrupted or blocked, etc.).
- Specific references to breakdowns in team coordination, administrative requirements, etc. (i.e., overhead obstacles to getting the job done).
- Specific differences in opinion (or mention of multiple options) in the general process schema.

Things to Watch out for (for RADSS):

With regard to the RADSS-based "back end" to this project, we need to pay special attention to the following things (if and when they pop up):

- Alternatives/options in procedures
- Selection criteria for choosing among alternative procedures
- Any mention of amounts, numbers, relative rankings, value judgments, etc., which indicate qualitative/quantitative metrics relevant to tool and procedural assessment

III.B. Populating the Process Schema with Data on the Four Aspects

Second, we then need to "drill down" into each of the steps outlined in the notional process map. For each step, we need to identify and capture data pertaining to the 4 topical aspects outlined earlier.

Criteria for Completion:

This phase is reasonably complete at the point we have obtained:

1. At least one pass through the schema or map capturing data on functions
2. At least one pass through this map capturing data on tools/instruments
3. At least one pass through this map capturing data on information requirements

Things to Watch out for (General):

We need to pay special attention to the following things (if and when they pop up):

- Specific references to procedural breakdowns (situations or conditions when the process flow is disrupted or blocked, etc.).
- Specific references to informational breakdowns or deficiencies (misinterpretations; gaps in data; time lost learning something, etc.).
- Specific references to breakdowns in tool usage (problems, constraints, time sinks, etc.).
- Specific references to breakdowns in team coordination, administrative requirements, etc. (i.e., overhead obstacles to getting the job done).

Things to Watch out for (for RADSS):

With regard to the RADSS-based "back end" to this project, we need to pay special attention to the following things (if and when they pop up):

- Specific references to tools and instruments in use
- Specific references to tools and instruments available, but not used

- Specific references to tools and instruments formerly used
- Alternatives/options in procedures
- Selection criteria for choosing among alternative procedures
- Alternatives/options in tools/instruments and their application
- Selection criteria for choosing among alternative tools
- Distinctions between hardware and software tools
- Distinctions between tools used for (e.g.) manipulating materials versus those used for measurement, etc.
- Correlation of particular tools with particular phases or steps in the process map
- Correlation of particular tools with particular roles or individuals
- Any mention of amounts, numbers, relative rankings, value judgments, etc., which indicate qualitative/quantitative metrics relevant to tool and procedural assessment

The above-cited steps are the basic cores of the on-site SME KA effort. They are the minimum that we must do to proceed toward RADSS evaluation of tools. I'm not saying this is all we can aspire to do out at Nellis. I am, however, saying this is the minimum we need to accomplish for each of the 3 maintenance teams/units with whom we'll be visiting.

III.C. Auxiliary On-Site Data Gathering Activities

There is a variety of other data, which might be accessible while we're on-site. If we can, we should make a point to gather any data (no matter how general) on the following topics:

- Maintenance operations statistics (overall for the unit)
- Maintenance functions statistics (overall, and especially for flight control issues)
- Incidence statistics for flight control problems (e.g., how often, how long it takes, etc.)
- Data on specific tools (especially those employed automation, programming, and/or resident software)
- Inventory of information resources available to the maintenance team
- Data on the maintenance team's supply chain and supply procedures
- Data on any recent changes/innovations in flight control maintenance ops
- Data on any pending changes/innovations in flight control maintenance ops

Appendix D: SME Sign-in Sheet with Privacy/Disclosure Statement

Table 34: Subject Matter Expert Sign-in

NAME/RANK/UNIT	ROLE (Check all that apply)	Maintenance/TECH SPECIALIZATION if applicable - hydraulics, avionics, etc.
	◆ Fault Diagnosis ◆ Repair ◆ Test/Evaluation ◆ Maintenance Oversight/Mgmt ◆ Other(___________)	
	◆ Fault Diagnosis ◆ Repair ◆ Test/Evaluation ◆ Maintenance Oversight/Mgmt ◆ Other(___________)	
	◆ Fault Diagnosis ◆ Repair ◆ Test/Evaluation ◆ Maintenance Oversight/Mgmt ◆ Other(___________)	
	◆ Fault Diagnosis ◆ Repair ◆ Test/Evaluation ◆ Maintenance Oversight/Mgmt ◆ Other(___________)	

	◆ Fault Diagnosis ◆ Repair ◆ Test/Evaluation ◆ Maintenance Oversight/Mgmt ◆ Other(___________)	
	◆ Fault Diagnosis ◆ Repair ◆ Test/Evaluation ◆ Maintenance Oversight/Mgmt ◆ Other(___________)	

PRIVACY/DISCLOSURE STATEMENT: Your participation in this knowledge acquisition effort has been solicited to help us understand flight control maintenance functions and to compile criteria for evaluating potential innovations and aids for these functions. The solicitation of personal identification information above is only for the use of the TRS DO24 researchers (for compiling and organizing our results). You will not be personally identified in any reports or other products of this TRS DO 24 research effort. The TRS DO 24 research staff will not disseminate any personally-identifiable data we collect. *Thank you for your participation.*

Appendix E: MXM Tool/Instrument Survey Form

Table 35: Tool/Instrument Summary Sheet

NAME			
DESCRIPTION (Size, weight, etc.)			
TYPE of device	♦ Physical Hardware ♦ Electrical Hardware ♦ Electronic instrument	♦ Programmable device (PC; calculator, etc.) ♦ Software Application	♦ Built-in (to A/C) ♦ Read-only paper ♦ Read-/Write-Device
WHAT it's used for:	♦ Physical Action ♦ Measurement ♦ Work environment (e.g., stands, lights)	♦ General Reference (e.g., manual) ♦ Decision Aid (e.g., diagnostic guide)	♦ Documentation ♦ Communications ♦ Other: ♦ ____________
WHEN is it needed: (During what phase/task/ activity)	♦ Fault Discovery ♦ Fault Reporting ♦ Fault Diagnosis (Testing/ Exploration) ♦ Fault Diagnosis (Troubleshooting/ Decision Aid)	♦ Solution Specification ♦ Repair ♦ Test/Evaluation of Repair Outcomes ♦ Maintenance Management (Documentation; Coordination)	♦ Communication (within team; across shift, etc.) ♦ Supply/Requisition ♦ ♦ Other: ♦ ____________
AVAILABILITY (Access to Tool)	Readily/On-hand	♦ Go get it (within area) ♦ Go get it (elsewhere)	♦ Send out for it nearby ♦ Send for it (Distant)
ACCESSIBILITY (Access to Tool)	I have one anytime	Must share it within unit:	Must share it with other:

AVAILABILITY (Measures for what it takes to get tool)	**TIME** (min/max)	**DISTANCE** (min/max)	**HOW OFTEN?**
PORTABILITY (Deploy; maneuver)	Hands-Free (can carry it on belt, in pocket...)	♦ One-handed carry ♦ Two-handed carry	♦ Roll around (Manual) ♦ Roll around (Driven)
ENGAGEMENT (Deploy; bring to bear)	♦ No setup required ♦ Must set up tool/instrument	♦ Must connect to A/C ♦ Must connect to other unit:__________ ______________	♦ Must connect to power ♦ Must connect to other: ______________ ______________
ENGAGEMENT (Physical Use)	♦ Hands-Free (don't have to manipulate it) ♦ (Someone else does)	♦ One-handed interaction ♦ Two-handed interaction	♦ Must read/check setting ♦ Must make setting(s)
ENGAGEMENT (Informational Use)	♦ Attention-Free ♦ Must select setting	♦ Must read data ♦ Must enter data	♦ Must navigate ♦ Must translate data
ENGAGEMENT (Configuration)	♦ Unchanging/"As Is" ♦ Must reconfigure/ reset (once) to use	♦ MUST reconfigure/ reset during use ♦ MAY do so during use	Repair on breakdown
HOW OFTEN EMPLOYED:	♦ 0 - 20% of incidents ♦ 20-40% of incidents	♦ 40 - 60% of incidents ♦ 60 - 80% of incidents	100% of incidents
LONGEVITY:	Dispose after 1 use	Dispose on breakdown	Repair on breakdown
EASE OF USE:	DIFFICULT	NOMINAL	EASY
WHO USES IT: (flight control maintenance team) PLEASE SPECIFY:	One person only	Some team members	All team members

ALTERNATIVES? (To this Tool)	Yes ------→ No	What?
OTHER TOOLS THAT MUST BE USED ALONG WITH THIS ONE?	Yes ------→ No	What?
SPECIFIC GRIPES?	Yes ------→ No	What?
SPECIFIC IMPROVEMENTS?	Yes ------→ No	What?

GENERAL QUESTIONS:

When (in what circumstances) do you **expect** to use this tool/instrument?

When do you **not expect** to use it (but you've used it anyway)?

Are there any tools/instruments you expect to use **before** using/needing to use this one? If so, what:

Are there any tools/instruments you expect to use **after** using/needing to use this one? If so, what:

What indications cue you that you'll be needing to employ this tool/instrument?

Do you know of a **specific** tool/instrument (single one; category; type) that's better for the given function than this one? If so, why?

Appendix F: Flight Control Maintenance Tool Inventory: F-15 Shops

This appendix presents the results obtained from the tool survey with the F-15 shops at Nellis AFB. Table 36 lists the tools and instruments identified in the F-15E support section. Table 37 lists the tools and instruments identified in the F-15C support section.

Table 36: Strike Shop (F-15E)--Tool Inventory Data

TTU-205 Tester (a.k.a.: "TT-205," "205")	
Description	**Notes/Comments**
♦ Model Designation: TTU-205F ♦ Title: "Test Set, Pressure - Temperature" ♦ Kit volume: 3 cubic feet ♦ Kit weight: 116 lbs. ♦ Listed Cost: $35,000.00 ♦ Stock Number: 4920-01-214-2410 or 4920-00-731-1457 ♦ Part Number: 189 104 80001	♦ Very commonly employed by impound team for flight control problems. ♦ There are supposed to be 2 available ♦ Typically, 1 is functional and 1 is in the shop at any given time. ♦ "By the book" procedure requires 205 usage anytime lines are connected/disconnected. ♦ A 205 is typically checked out for usage 1 or 2 times per week. ♦ In a "worst case" scenario, tracing a leak may require using the 205 for circa 2 workdays.
Connection Set forTTU-205 Tester (a.k.a.: "hose set," "connector set/kit")	
Description	**Notes/Comments**
♦ Model Designation: None ♦ Title: "Pitot Connection Set" ♦ Kit size: Housed in an aluminum case approximately the size of a 24" suitcase ♦ Kit weight: ca. 25 lbs. ♦ Listed Cost: Unknown	♦ Connectors and hoses are problematical ♦ It often seems that the connection kit is the main constraint in using the 205

Digital Multimeter	
Description	**Notes/Comments**
◆ Model Designation: None ◆ (Commercial multimeter unit)	◆ Employed in troubleshooting wiring ◆ Used to check for continuity, grounding, and resistance in wiring circuits

Heat Guns	
Description	**Notes/Comments**
◆ Hapco HT900 "All Purpose Heat Gun" ◆ (Commercial unit)	None

Wire Repair Kit (Commercial)	
Description	**Notes/Comments**
◆ Daniels Mfg. Corp. (DMC) is the typical supplier ◆ Title: "DMC 712 Maintenance/Repair Kit for F-15"	◆ 2 such kits were on the shelf. ◆ Each kit includes circa 40 special dies for wire connection work.

Wire Repair Kit (Locally-Devised)	
Description	**Notes/Comments**
◆ Locally developed and assembled. ◆ Formally listed among inventory items. ◆ Title: "57th AGS Strike AMF NJSS00822 Wire Repair Kit"	◆ Total constituent components = 74 ◆ These components are stored in 5 trays plus general storage within the case.

Table 37: F-15C Shop Tool Inventory Data

FLTS Tester	
Description	**Notes/Comments**
♦ Model Designation: AN/ASM-497 ♦ Title: "Test Set, Automated Flight Control System" ♦ Manufacturer: GE ♦ Listed Cost: $143,546.00	♦ 2 FLTS test units are in stock. ♦ At the time of our visit, one of these units had just returned from being serviced. ♦ Each FLTS test set includes a connector kit (a sizeable satchel containing cables). ♦ There are (4) cables (W2, W3, power, ground) which must be connected to use the FLTS tester.
Time Domain Reflectometer (a.k.a.: "TDR")	
Description	**Notes/Comments**
♦ Model Designation: Tektronix 1502B TDR ♦ Listed Cost: Unknown	TDR is employed to evaluating the distance along a conductive cable or wire to an apparent break or gap.
TDR Adapter Kit[84] (Locally Assembled)	
Description	**Notes/Comments**
♦ Designation: "TDR Adapter Kit" ♦ ID: NJSE8O102	♦ Used to attach and use the Tektronix TDR. ♦ Consists of a collection of cables and adapters housed in a circa 18"- long hip roof toolbox.
Mach Number Simulator	
Description	**Notes/Comments**
♦ Manufacturer: Pratt & Whitney/Howell Instruments ♦ Weight: 51.9 lbs. ♦ Size: circa 14" X 18" X 18" ♦ Listed Cost: $7416.00	♦ Octal data output ♦ Used to check pitch and roll channel assembly (an electromechanical valve system). ♦ Last checked out 27 months ago.

[84] The kit consists of a total of 24 components (all lead cables or adapters). This is one of only 2 locally devised tools encountered at Nellis.

AFCS Breakout Box	
Description	**Notes/Comments**
◆ Manufacturer: McDonnell Douglas ◆ Title: "Automated Flight Control System Breakout Box - F-15" ◆ Listed Cost: $7714.00	◆ Was last checked out on 17 July 2002. ◆ This was the only recorded usage since 1998.

Miscellaneous Stands/Supports	
Description	**Notes/Comments**
◆ Stepladders ◆ Stands ◆ Boarding ladder	Miscellaneous equipment used to access the A/C during maintenance.

Wire Repair Kit (Locally-Devised)	
Description	**Notes/Comments**
◆ Locally developed and assembled. ◆ Formally listed among inventory items. ◆ Title: "57th AGS Strike AMF NJSS00822 Wire Repair Kit"	◆ Total constituent components = 74 ◆ These components are stored in 5 trays plus general storage within the case.

Appendix G: Flight Control Maintenance Tool Inventory: F-16

This appendix presents the results obtained from F-16 tool inventory at Nellis AFB.

Table 38: F-16 Shop: Tool Inventory Data

TTU-205 Tester (a.k.a.: "TT-205," "205")	
Description	**Notes/Comments**
♦ Model Designation: TTU-205F ♦ Title: "Test Set, Pressure - Temperature"	♦ No additional data or facts obtained relative to what we'd already gathered from the F-15 support sections. ♦ Refer to the F-15 tool survey data for more details on the TT-205
Connection Set forTTU-205 Tester (a.k.a.: "hose set," "connector set/kit")	
Description	**Notes/Comments**
♦ Model Designation: None ♦ Title: "Pitot Connection Set"	♦ No additional data or facts obtained relative to what we'd already gathered from the F-15 support sections. ♦ Refer to the F-15 tool survey data for more details on the TT-205 connector kit
Digital Multimeter (a.k.a.: "fluke meter")	
Description	**Notes/Comments**
♦ Model Designation: None ♦ (Commercial multimeter unit) ♦ Stock number: 6625 01 147 6182	♦ Employed in troubleshooting wiring ♦ Used to check for continuity, grounding, and resistance in wiring circuits ♦ Three in stock in the support section

EDNA (Enhanced Diagnostic Aid)	
Description	**Notes/Comments**
♦ Manufacturer: Lockheed Martin/ Ft. Worth ♦ Form: Specialized laptop-style hardware with associated cables. The EDNA package includes a ruggedized removable hard drive, keyboard, and an internal power source. ♦ Listed Cost: $63,463.00	♦ Some cables are included in the basic EDNA kit ♦ A second/larger box associated with the EDNA contained an estimated 15 - 20 cables of various types for connecting EDNA ♦ Because most data can be obtained (as Hex codes) from the onboard systems, EDNA isn't used all the time. ♦ EDNA is typically brought in for a "brain bender" (i.e., a particularly difficult diagnostic problem). ♦ EDNA allows the maintainer to read BIT codes as one proceeds with the troubleshooting

Wire Repair Kit (Commercial)	
Description	**Notes/Comments**
♦ Daniels Mfg. Corp. (DMC) is the supplier ♦ Title: "DMC 716 Maintenance/Repair Kit for F-16"	♦ One kit on the shelf ♦ This DMC kit appeared to be pretty much the same general set as the 712 kit tailored to the F-15s. ♦ The DMC kit is not often checked out/used.

Time Domain Reflectometer (a.k.a.: "TDR")	
Description	**Notes/Comments**
♦ Model Designation: Tektronix 1502B TDR ♦ Stock Number: 6625 01 0035561 ♦ Listed Cost: Unknown	♦ TDR is employed to evaluating the distance along a conductive cable or wire to an apparent break or gap. ♦ This unit appeared identical to the TDRs employed at the F-15 unit. ♦ No adapter kit had been locally developed/assembled, as had occurred over at the F-15 unit.

Crossover Cable Sets	
Description	**Notes/Comments**
Designation: None - just "crossover cables" or "crossover cable sets"	♦ These cables allow maintainers to temporarily patch flight control circuits over to the other side of the A/C. ♦ Running diagnostic tests double-checking similar behavior on the other side of the A/C allows maintainers to validate apparent fault conditions and help figure out fault locations. ♦ One crossover cable set observed on the shelf.

Gyro Polarity Cable Set	
Description	**Notes/Comments**
♦ Designation: None found ♦ Stock number: 16U14558LI-1	♦ This is a cross-connector kit used to troubleshoot the gyros on the F-16. ♦ One such cable set observed on the shelf.

Appendix H: Flight Control maintenance Tool Inventory: C-17

This appendix presents the results obtained from the C-17 tool inventory at Charleston AFB.

Table 39: C-17 Tool Inventory Data

TTU-205 Tester (a.k.a.: "TT-205," "205")	
Description	**Notes/Comments**
♦ Model Designation: TTU-205F ♦ Title: "Test Set, Pressure - Temperature"	♦ No additional data or facts obtained relative to what we'd already gathered from the F-15 support sections. ♦ Refer to the F-15 tool survey data for more details on the TT-205 ♦ A total of three in stock
♦ Model Designation: TTU-205D ♦ Title: "Test Set, Pressure - Temperature"	♦ No additional data or facts obtained relative to what we'd already gathered from the F-15 support sections. ♦ Refer to the F-15 tool survey data for more details on the TT-205 ♦ A total of two in stock
Connection Set forTTU-205 Tester[85] (a.k.a.: "hose set," "connector set/kit")	
Description	**Notes/Comments**
♦ Model Designation: None ♦ Title: "Pitot Connection Set"	♦ Refer to the F-15 tool survey data for more details on the TT-205 connector kit ♦ Six in stock

[85] Several issues relating to the TT-205 connector set were mentioned. As was stated at Nellis, the connector sets are more often problematical than the testers themselves. The hose sets have to be ordered from Canada. In use, there are 2 hoses that have to be attached to the TT-205 tester. The most common failure point is not the hose, but the seals in the connectors. These seals have a tendency to warp or "roll up" within the connector bodies. Another problem specific to the C-17 is hose length. It was noted that new hoses recently requisitioned could not be used on the C-17 because they were too short to permit the required connections between the aircraft and the tester unit.

Inclinometers[86]	
Description	**Notes/Comments**
Model Designation: Hilger & Watts T8108-1	◆ Employed in checking flight surfaces' and other components' alignment/orientation ◆ Analog type ◆ 3 in stock
Model Designation: Hilger & Watts Model A TB107	◆ Employed in checking flight surfaces' and other components' alignment/orientation ◆ Analog type - larger than the T8108-1 ◆ 1 in stock
Digital Multimeter (a.k.a.: "fluke meter")	
Description	**Notes/Comments**
◆ Model Designation: Fluke 77III ◆ (Commercial multimeter unit)	◆ Employed in troubleshooting wiring ◆ Used to check for continuity, grounding, and resistance in wiring circuits ◆ One found in the support section
◆ Model Designation: Fluke 8025B ◆ (Commercial multimeter unit)	◆ Usage same as noted above for 77III ◆ One found in the support section
DTOS	
Description	**Notes/Comments**
◆ Computer-based reference and diagnostic aid for C-17 ◆ Platform: Panasonic "Toughbook" (ruggedized laptop), which costs circa $6500.00. ◆ Listed Cost: $63,463.00	◆ CD-based software package providing wide-ranging technical documentation on C-17 maintenance issues.[87] ◆ Main features noted were Job Guide documentation and wiring diagrams. ◆ For both text and diagrams, on-screen legibility required zoom factor of at least 125%. ◆ At 100% and 125% zoom factors, neither text nor diagram displays could be shown within the bounds of the available display screen.

[86] Only "analog" inclinometers were on hand, but newer digital inclinometers were on order.
[87] The variety of reference materials available is indicated in the main index entries, which include: Fault Isolation; Flight Manual Supplements; FMs; General Reference Manuals; General Systems; Inspection Manuals and Workcards; Interface Test Adapters; Intermediate Maintenance Instructions; IPBs; Job Guides, Maintenance Manual Supplements; Schematic Diagrams; Structures; Support Equipment; TCTOs; and Wiring Diagrams.

Wire Repair Kits/Equipment[88]	
Description	**Notes/Comments**
♦ Daniels Mfg. Corp. (DMC) is the supplier ♦ Title: "DMC 31 C-141/CHS8/H003	One kit on the shelf
♦ "Pin Kit - Install" ♦ Supplier: Astro Tool Co. ♦ Part Number: M83521/6-01	One kit on the shelf
♦ "Flap Pigtail" ♦ Stock Number: 1680 PO2147 24418 ♦ Part Number: 17P6E 4150-502	♦ One on the shelf ♦ Used in troubleshooting flaps
Time Domain Reflectometer (a.k.a.: "TDR")	
Description	**Notes/Comments**
Model Designation: Tektronix 1502B TDR	♦ TDR is employed to evaluating the distance along a conductive cable or wire to an apparent break or gap. ♦ Two units in stock at the support section ♦ No adapter kit had been locally developed/assembled, as had occurred at the Nellis AFB F-15 unit.
Cable Breakout Boxes	
Description	**Notes/Comments**
♦ Designation: "Cable Breakout Box" ♦ Part Number: 17G410523 1	Two in stock
Rigging Equipment/Implements	
Description	**Notes/Comments**
♦ "Protractor Set - Rigging" ♦ Part Number: 176-140307-23	One in stock
♦ "Protractor Set - Rigging" ♦ Part Number: 170-141554-1	One in stock

[88] The support section staff stated that most individual wire repair implements (e.g., crimpers, etc.) were separately binned and inventoried.

◆ "Rigging Equipment - Cable Mechanical" ◆ Supplier: McDonnell Douglas ◆ Part Number: 176-140015-1A	◆ Rigging implements for fixing mechanical controls on C-17 ◆ Two in stock
◆ "Rigging Equipment - Cable Mechanical" ◆ Supplier: McDonnell Douglas ◆ Part Number: 176-140015-1	◆ Rigging implements for fixing mechanical controls on C-17 ◆ One in stock ◆ Part number differs from previous item by one letter ("A" at the end). Unable to find out what differentiates the 2 sets.
Miscellaneous Rigs and Fixtures	
Description	**Notes/Comments**
Stands and structural rigs	Miscellaneous equipment used to access the A/C during maintenance and/or support items

Appendix I: Logistics Quality Performance Measures: Fighters - FY1993 through FY2002

One of the KA goals was to obtain general data on maintenance operations. In the course of the KA visits a point was made to solicit statistical data on maintenance performance for those aircraft included in the KA. Among the data collected were a series of ten-year summaries for maintenance on the operational fighters covered in the KA efforts and a month-by-month summary of 8-hour fix rates for the period April 2002 through March 2003. This data was obtained and provided to the contractor team by AFRL/HESR.

The ten-year summary data has been transcribed into illustrative tables (Tables 40 – 46) for five categories of aircraft (all operational fighters; A/OA-10A; F-15C/D; F-15E; and F-16C/D). Each table offers a year-by-year inventory of relevant 4-hour and 8-hour performance standards and actual recorded fix rates. For each of these metrics the composite ten-year average is computed. The deviations between average standard and average fix rate metrics are computed for both the 4-hour and 8-hour metrics. Finally, the overall trend (first year to last year) is computed for illustration. Finally, the monthly summary for CY02 - CY03 is compiled into another table.

Table 40: Ten-year Summary: Fix Rates for A/OA-10A Fighters (Total)

Fiscal Year	4-Hr Fix Rate (Standard)	4-Hr Fix Rate (Actual)	8-Hr Fix Rate (Standard)	8-Hr Fix Rate (Actual)
1993	66	70.8	85	85.6
1994	66	70.1	85	87.2
1995	65	74.4	80	88.6
1996	65	73.4	80	86.1
1997	65	69.8	80	84.9
1998	65	64.7	80	80.0
1999	65	61.9	80	78.8
2000	65	63.1	80	77.8
2001	65	61.8	80	76.6
2002	65	65.2	80	80.1
10-Yr Average	**65.2**	**67.5**	**81**	**82.57**
Deviation from Standard (Decade Avg.)		**+3.5% (better than standard)**		**+1.9% (better than standard)**
10-Year Trend (First vs. Last)	**Nominally Unchanged**	**-7.9%**	**-5.88%**	**-6.4%**

Table 41: Ten-year Summary: Fix Rates for F-15C/D Fighters (Total)

Fiscal Year	4-Hr Fix Rate (Standard)	4-Hr Fix Rate (Actual)	8-Hr Fix Rate (Standard)	8-Hr Fix Rate (Actual)
1993	57	61.8	75/72	80.2
1994	57	63.4	75/72	81.4
1995	57	62	75	80.6
1996	57	60	75	77.8
1997	57	52.9	75	72.9
1998	57	53.7	75	71.3
1999	57	48.9	75	67.9
2000	57	49.3	75	67.8
2001	57	44.6	75	65.3
2002	57	42.6	75	63.8
10-Yr Average	**57**	**53.92**	**75 (approx.)**	**72.9**
Deviation from Standard (Decade Avg.)		**-5.4% (short of standard)**		**-2.8% (short of standard)**
10-Year Trend (First vs. Last)	**Unchanged**	**-31.1%**	**Unchanged**	**-20.4%**

Table 42: Ten-year Summary: Fix Rates for F-15E Fighters (Total)

Fiscal Year	4-Hr Fix Rate (Standard)	4-Hr Fix Rate (Actual)	8-Hr Fix Rate (Standard)	8-Hr Fix Rate (Actual)
1993	57	63.6	75/72	82.1
1994	57	58.7	75/72	78.5
1995	60	60.5	75	79.2
1996	60	57.9	75	77.2
1997	60	50.0	75	70.8
1998	60	48.8	75	68.0
1999	60	50.1	75	69.7
2000	60	51.1	75	71.4
2001	60	48.2	75	68.3
2002	60	47.2	75	66.9
10-Yr Average	**59.4**	**53.6**	**75 (approx.)**	**73.2**
Deviation from Standard (Decade Avg.)		**-9.75% (short of standard)**		**-2.24% (short of standard)**
10-Year Trend (First vs. Last)	**+5.3%**	**-25.8%**	**Nominally Unchanged**	**-18.5%**

Table 43: Ten-year Summary: Fix Rates for F-16C/D Fighters (Total)

Fiscal Year	4-Hr Fix Rate (Standard)	4-Hr Fix Rate (Actual)	8-Hr Fix Rate (Standard)	8-Hr Fix Rate (Actual)
1993	66	71.7	85	89.2
1994	66	71.5	85	88.6
1995	66	67.9	85	84.7
1996	66	64.8	85	81.2
1997	66	61.8	85	80.2
1998	66	59.6	85	78.2
1999	66	60.6	85	78.1
2000	66	58.2	85	77.3
2001	66	61.1	85	78.7
2002	66	57.3	85	76.6
10-Yr Average	**66**	**63.45**	**85**	**81.28**
Deviation from Standard (Decade Avg.)		**-3.86% (short of standard)**		**-4.38% (short of standard)**
10-Year Trend (First vs. Last)	**Unchanged**	**-20.1%**	**Unchanged**	**-14.13%**

Table 44: Ten-year Summary: Fix Rates for All Operational Fighters

Fiscal Year	4 Hr Fix Rate (Actual)	8 Hr Fix Rate (Actual)
1993	63.9	82.8
1994	63.7	82.9
1995	63.0	80.9
1996	61.9	79.3
1997	57.6	76.7
1998	55.7	74.1
1999	54.6	73.0
2000	54.0	72.5
2001	52.7	71.2
2002	51.4	70.9
10-Yr Average	**57.85**	**76.43**
10-Year Trend (First vs. Last)	**-19.6%**	**-14.37%**

Table 45: Eight-hour Fix Rates for A/OA-10s & F-15C/D & Es: CY02 - CY03[89]

Month (CY2002 - CY2003)	A/Oa-10 Fleet Standard = 80	F-15c/D Fleet Standard = 75	F-15e Fleet Standard = 75
April	85.3	66.8	64.2
May	80.6	68.2	66.7
June	80.7	65.1	69.7
July	78.9	54.5	66.5
August	79.8	54.0	60.9
September	80.1	58.4	65.7
October	78.1	61.4	66.1
November	81.0	63.0	63.4
December	80.7	62.1	62.6
January	81.2	58.6	68.8
February	85.9	59.5	75.0
March	85.9	63.1	72.4
Cumulative	**81.6**	**61.2**	**67.1**
Cumulative versus Standard	**+1.6%** **(above standard)**	**-18.4%** **(short of standard)**	**-10.5%** **(short of standard)**

[89] **SOURCE:** Headquarters ACC Briefing: *Logistics Maintenance Performance Indicators - Fighters - March 03* (Unclassified)

Table 46: Eight-hour Fix Rates for F-16C/D, Blocks 30, 40 & 50: CY02 - CY03[90]

MONTH (CY2002 - CY2003)	F-16C/D FLEET (Block 30) Standard = 85	F-16C/D FLEET (Block 40) Standard = 85	F-16C/D FLEET (Block 50) Standard = 85
April	76.6	67.9	87.2
May	72.2	68.2	87.2
June	66.1	70.6	81.6
July	67.9	62.3	80.4
August	60.2	68.2	86.3
September	75.0	72.4	82.4
October	74.0	71.3	85.6
November	82.1	70.7	87.9
December	84.5	68.1	77.9
January	76.1	71.2	77.9
February	86.9	67.5	72.1
March	80.9	71.6	87.8
Cumulative:	**74.9**	**69.3**	**83.2**
Cumulative versus Standard	**-11.9% (short of standard)**	**-18.5% (short of standard)**	**-2.1% (short of standard)**

[90] **SOURCE:** Headquarters ACC Briefing: *Logistics Maintenance Performance Indicators - Fighters - March 03* (Unclassified)

Appendix J: Guidelines for Subsystem Selection

Tables 47 – 54 depict the specific data supporting the subsystem selection decision process.

Table 47: Fuel

FUEL	A-10	B-1	B-52	F-15	F-16	EC/HC-130
Top 5 Man-hour consumer (1-No 5-Yes)	5	5	5	5	5	5
Ease of troubleshooting (1-Easy 5-Tough)	2	5	5	3	3	4
Relevance to MX Mentor project (1-Not much 5-Significant)	1	1	1	1	2	1
Potential Integration Challenges (1-Huge 5-Manageable)	1	2	1	1	2	1
Potential Improvement for Maintainer (1-Little 5-Major)	2	5	3	3	3	3
TOTAL–86	**11**	**18**	**15**	**13**	**15**	**14**

Table 48: Hydraulic

HYDRAULIC	A-10	B-1	B-52	F-15	F-16	EC/HC-130
Top 5 Man-hour consumer (1-No 5-Yes)	1	1	1	1	1	1
Ease of troubleshooting (1-Easy 5-Tough)	2	4	3	3	1	3
Relevance to MX Mentor project (1-Not much 5-Significant)	1	1	1	1	1	1
Potential Integration Challenges (1-Huge 5-Manageable)	2	1	1	2	3	1
Potential Improvement for Maintainer (1-Little 5-Major)	1	3	3	2	1	3
TOTAL--51	**7**	**10**	**9**	**9**	**7**	**9**

Table 49: Propulsion

PROPULSION	A-10	B-1	B-52	F-15	F-16	EC/HC-130
Top 5 Man-hour consumer (1-No 5-Yes)	5	5	1	5	5	5
Ease of troubleshooting (1-Easy 5-Tough)	1	5	3	4	4	2
Relevance to MX Mentor project (1-Not much 5-Significant)	3	5	1	4	4	3
Potential Integration Challenges (1-Huge 5-Manageable)	3	1	1	2	2	3
Potential Improvement for Maintainer (1-Little 5-Major)	2	4	1	3	4	3
TOTAL--94	**14**	**20**	**7**	**18**	**19**	**16**

Table 50: Landing Gear

LANDING GEAR	A-10	B-1	B-52	F-15	F-16	EC/HC-130
Top 5 Man-hour consumer (1-No 5-Yes)	5	1	5	5	1	5
Ease of troubleshooting (1-Easy 5-Tough)	1	5	5	3	2	3
Relevance to MX Mentor project (1-Not much 5-Significant)	1	2	3	3	1	3
Potential Integration Challenges (1-Huge 5-Manageable)	5	1	1	3	4	1
Potential Improvement for Maintainer (1-Little 5-Major)	3	2	3	3	1	3
TOTAL--84	**15**	**11**	**17**	**17**	**9**	**15**

Table 51: Flight Controls

FLIGHT CONTROLS	A-10	B-1	B-52	F-15	F-16	EC/HC-130
Top 5 Man-hour consumer (1-No 5-Yes)	5	5	1	5	5	1
Ease of troubleshooting (1-Easy 5-Tough)	1	5	2	5	3	4
Relevance to MX Mentor project (1-Not much 5-Significant)	2	4	1	5	5	3
Potential Integration Challenges (1-Huge 5-Manageable)	5	2	2	4	5	3
Potential Improvement for Maintainer (1-Little 5-Major)	2	4	1	5	5	3
TOTAL--103	**15**	**20**	**7**	**24**	**23**	**14**

Table 52: Radar

RADAR	A-10	B-1	B-52	F-15	F-16	EC/HC-130
Top 5 Man-hour consumer (1-No 5-Yes)	1	1	1	1	1	1
Ease of troubleshooting (1-Easy 5-Tough)	1	3	1	3	2	1
Relevance to MX Mentor project (1-Not much 5-Significant)	1	3	1	2	1	1
Potential Integration Challenges (1-Huge 5-Manageable)	5	1	3	3	4	5
Potential Improvement for Maintainer (1-Little 5-Major)	1	2	1	3	3	2
TOTAL--59	**9**	**10**	**7**	**12**	**11**	**10**

Table 53: Electronic Countermeasures

ELECTRONIC COUNTERMEASURES (ECM)	A-10	B-1	B-52	F-15	F-16	EC/HC-130
Top 5 Man-hour consumer (1-No 5-Yes)	1	1	5	1	5	1
Ease of troubleshooting (1-Easy 5-Tough)	2	3	4	2	3	2
Relevance to MX Mentor project (1-Not much 5-Significant)	1	2	4	1	4	1
Potential Integration Challenges (1-Huge 5-Manageable)	5	1	2	3	3	3
Potential Improvement for Maintainer (1-Little 5-Major)	1	2	3	1	3	1
TOTAL--71	**10**	**9**	**18**	**8**	**18**	**8**

Table 54: Electrical

ELECTRICAL	A-10	B-1	B-52	F-15	F-16	EC/HC-130
Top 5 Man-hour consumer (1-No 5-Yes)	1	5	5	1	1	5
Ease of troubleshooting (1-Easy 5-Tough)	2	5	5	3	2	4
Relevance to MX Mentor project (1-Not much 5-Significant)	1	3	3	1	1	3
Potential Integration Challenges (1-Huge 5-Manageable)	5	1	1	2	4	2
Potential Improvement for Maintainer (1-Little 5-Major)	1	5	5	1	1	3
TOTAL--82	**10**	**19**	**19**	**8**	**9**	**17**