Role of Supportability Engineering in the Design Process

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This paper addresses the impact of supportability on the design process. Four basic questions are addressed in the paper: 1) How can an acceptable level of supportability be achieved? 2) How and why must supportability requirements be translated into design-to requirements? 3) At what point in the design process must supportability be considered? 4) How do the "supportability engineers" prepare themselves to make the most impact on the design process?

Introduction

IN the supportability-conscious environment of today, the contractor's first priority must be to apply new technologies to reduce the operational support costs of the systems being designed and manufactured. Whether the system is an aircraft, satellite, missile, ship, or offensive or defensive electronics, everyone involved in the design decision-making process ultimately impacts the supportability characteristics of the system. Supportability is not the sole responsibility of the "supportability engineers"; it is the responsibility of the entire design team. The level of supportability ultimately achieved in a system is a direct function of the emphasis it receives from the design manager.

In addressing the supportability issue, it is necessary to establish why supportability must be considered as an integral part of the design process. Then, given that supportability has an important place in the design process, the following questions must be considered. What is the impact of supportability on the design process? How can an acceptable level of supportability be achieved? How and why must supportability requirements be translated into design-to requirements that are meaningful to a designer? At what point in the design process should supportability be considered? How do the "supportability engineers" prepare themselves to make the most impact on the design process?

Before these questions are addressed, it is appropriate to establish a common understanding of what supportability really is. The Department of Defense (DOD) defines supportability as "the degree to which system design characteristics and planned logistics resources, including manpower, meet system peacetime operational and wartime ultilization requirements." So what does this mean? Simply stated, this means that the system (in Lockheed-Georgia's case, an airplane) must be designed to assure that its logistics resource requirements have a minimal detrimental impact on accomplishment of the peacetime and wartime mission of the system. Any logistics resource required to support a system is a burden, relative to achievement of mission requirements. Therefore, the objective is to minimize the requirements for system logistics resources, while simultaneously optimizing the "logistics system" required for operational support. At the one extreme, a system that has very low reliability and requires extensive logistics resources to support its mission would have very little probability of successfully completing its mission. At the other extreme, a system that is 100% reliable and requires only replenishment of consumables to meet its mission requirements would have a very high probability of achieving its mission objectives. The real world lies somewhere between these two extremes.

There are many concepts of supportability in the aerospace industry and the DOD. If all these concepts were reduced to their essence, it would be apparent that the supportability of a system is driven by the inherent reliability and maintainability (R&M) characteristics of the system. Everything that directly affects the support of a system, other than consumables (fuel, munitions, etc.), can be directly linked to the inherent R&M characteristics of the system. Therefore, the first step in achieving required levels of supportability is to ensure that R&M is considered early and throughout the design process. For this reason, R&M is used interchangeably with supportability throughout the remainder of this discussion. The R&M link to supportability parameters is shown in Fig. 1.

Supportability Is Equal to Cost, Performance, and Schedule

Why is the aerospace industry placing so much emphasis on the R&M characteristics of the systems they are designing? Because the customer is demanding supportability characteristics that are more stringent than those possessed by in-service systems. The DOD is procuring new systems under a new logistics support policy, which states that *supportability must be considered equal to cost, performance, and schedule*. Supportability now has the same design-driving authority as cost, performance, and schedule.

Why DOD Emphasis on Supportability?

Why has the DOD mandated that supportability be given a more positive position in the design process? There are two major reasons why the DOD has taken this position. First, over the life of a system, operating and support costs far exceed acquisition costs. Second, the DOD is concerned about meeting mission objectives with the ever-increasing complexity of systems. The key issues in meeting mission objectives are readiness and sustainability. Readiness is the ability of the system to perform its mission at any random point in time. Sustainability is the ability of the system to perform its mission repeatedly over a given period of time. Both DOD concerns—excessive operational and support costs and meeting mission objectives—can be cost-effectively influenced only during the design process. Thus, the emphasis being placed by the DOD on supportability.

DOD emphasis on supportability directly impacts the contractor in two ways. The contractor can expect to see more stringent R&M requirements contractually imposed on new systems and stronger penalties for nonachievement of the requirements; DOD emphasis on supportability is readily discernible from the curve shown in Fig. 2 for fighter-type aircraft. This curve graphically depicts the increasing stringency of two

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specific R&M parameters: mean time between maintenance (MTBM) and maintenance man-hours per flying hour (MMH/FH). The upper left portion of the curve reflects MTBM and MMH/FH requirements for the F-4E generation aircraft, whereas the lower right portion of the curve reflects projected requirements for the fighter of the 1990s.

Future procurement contracts may well be won or lost on the supportability characteristics of the system offered. A case in point is the initial competition between General Electric (GE) and Pratt & Whitney (P&W) for the follow-on fighter engine. Sources at Wright-Patterson Air Force Base (WPAFB) have made public the fact that P&W lost the initial contract (75% of the engine buy went to GE) because the GE-proposed engine had superior maintainability characteristics. Obviously, loss of a contract is a severe penalty to pay for inadequate supportability characteristics.

Under the DOD policy of emphasis on supportability, the design problem becomes one of meeting cost, performance, schedule, and supportability requirements, while simultaneously optimizating logistics support costs. This problem is graphically illustrated, from a life-cycle-cost (LCC) standpoint, in Fig. 3. As R&M improvements are made, support costs decrease but, concurrently, acquisition costs increase. The objective is to make R&M improvements up to the point where the cost of the improvement equals the reduction in support costs. This is reflected on the life-cycle-cost curve at the point where the slope of the life-cycle-cost curve is zero. The problem confronting the R&M engineers is quantification of the relationship between R&M improvements and life cycle costs.

In future developmental programs, it may not be possible to optimize R&M from a LCC standpoint. It may be necessary to have LCC costs that are higher than the minimum costs in order to achieve mission objectives, e.g., high sortie generation rates. The objective will be to optimize "operational utility" rather than LCC.

Innovative Design and Support Concepts

How can these stringent R&M requirements be achieved? There are three things that must be done: 1) designers and R&M engineers must be innovative in the design approach, 2) innovative support concepts must be developed, and 3) appropriate emphasis must be placed on the R&M characteristics of the design. "Appropriate emphasis" means that R&M must be given equal consideration with other design parameters. This does not mean that R&M will be incorporated regardless of its impact on cost, performance, and schedule, but that R&M will be given equal consideration in any tradeoff.

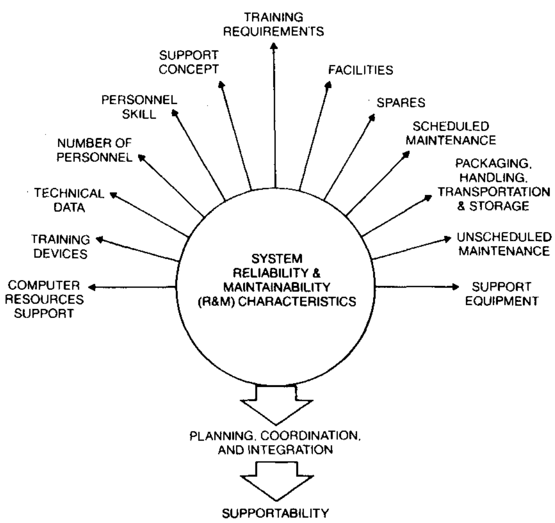

Fig. 1 Reliability and maintainability (R&M) relationship to supportability.

Innovative Design Approach

Being innovative in a design approach is a relative term. Two designers given the same design problem and told to be innovative would probably arrive at two very different solutions to the problem. The cardinal rule in innovative design, from a supportability standpoint, is to find the simplest solution to the problem that will satisfy the performance requirement(s). However, in today's environment, performance, in some cases, may have to be traded for supportability.

Since our technoogy has not advanced to the point that we can economically discard systems when they fail, we must provide a support structure for the system that will permit restoring it to operational status following a failure with minimum downtime and minimum logistics resources. To accomplish this requires six fundamental "resources": 1) trained personnel with the cognitive and physical attributes required to accomplish the repair, 2) capability to isolate the failure to a specific component and verify the repair using built-in-test (BIT) or support equipment (SE), 3) accessibility to the failed component, 4) SE required to troubleshoot/remove and replace/repair the component, 5) spare components, and 6) appropriate technical data. The requirement for these resources directly influences the design of the system, as discussed in the following paragraphs.

Accessibility is one of the basic considerations in designing for supportability. The R&M engineers play the key role in providing the necessary design-to information to the designer to assure that required accessibility is provided. Accessibility must be based not only on a need for maintenance (a maintainability function) but also on the frequency (a reliability function) of the required maintenance. This requires that the R&M engineers predict the scheduled and unscheduled maintenance requirements of the system, based on available design information, historical maintenance requirements data on similar systems, and personal experience, before detail design begins. Once the access requirements are identified by the R&M engineers, the design engineer must design the access to assure achievement of this "supportability" requirement. Providing the required accessibility may entail relocation of critical (from a maintenance standpoint) functional com-

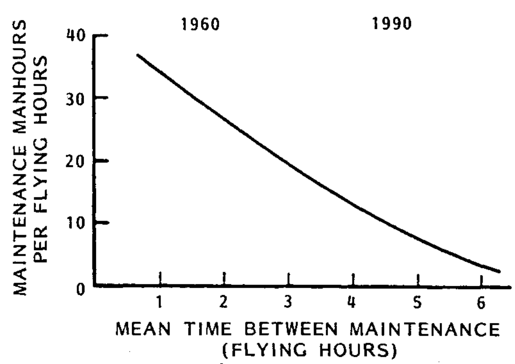

Fig. 2 Increasing stringency of R&M requirements.

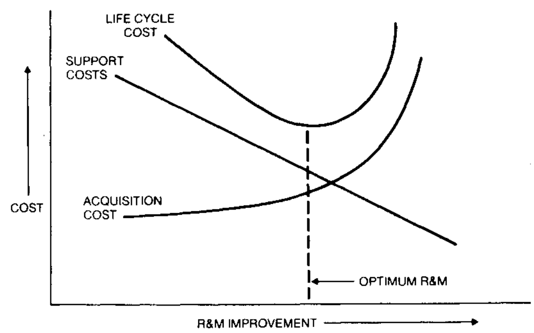

Fig. 3 Optimization of R&M (from ALCC standpoint).

ponents or providing unique accessibility provisions. What can be achieved is limited only by the innovative ability of the designer.

The design-to requirements for both on-system and off-system support equipment is dictated by the mission requirements of the system. This is an area that really needs innovative thinking. If the mission requirements of the system require the system to be self-sufficient, the need for on-system SE must be eliminated. This can be done only through innovative design approaches and attention to the support requirements of the system. To do this, the designer must consider accessibility requirements, handling requirements, troubleshooting requirements, and installation details. SE required for on-system accessibility can be eliminated by providing "ground-level" accessibility for all servicing requirements and built-in ladders and work platforms for all other scheduled and unscheduled maintenance. SE required for handling components installed on the system can be eliminated by providing built-in hoisting provisions and/or modularizing components in order that they can be handled by one person. SE required for troubleshooting can be eliminated by providing BIT that is capable of isolating a malfunction to the replaceable unit on the system and to the shop replaceable unit off the system. Also, simple troubleshooting logic trees can be developed to supplement the BIT, where necessary. Installation of components should be "simplified" in order to preclude the requirement for "special" tools to remove and replace them. Installation details should be such that only common hand tools are required to maintain the component.

Building SE into the system, or designing to eliminate the need for SE, impacts acquisition cost and/or system performance. However, the SE design decision must be based on the ultimate impact on the supportability of the system in relation to acquisition costs and performance requirements. A tradeoff must be made that puts supportability in the proper perspective in relation to cost and performance. In certain unique circumstances, cost and/or performance may have to be degraded in order to meet mission objectives, for example, operating into and out of remote areas for sustained periods of time with no logistics support requirements.

Designing to meet mission requirements in future combat environments and "making it simple" appear to be mutually exclusive. Designing to minimize the mechanical skill and thought processes required to maintain a system presents the greatest challenge to the designer. If the system design cannot be simplified, then the designer must simplify the maintenance required by the system. Simplifying the maintenance required by a complex system can be achieved by: 1) designing components to be economically discardable at failure by appropriate modularization and by designing for high reliability, 2) eliminating the requirement for judgmental decisions to be made by the technician during the maintenance process, 3) designing to assure that components cannot be assembled or installed incorrectly, 4) designing to assure that maintenance can be accomplished in incremental steps that are simple and unambiguous, and 5) designing to eliminate the requirement for alignment or adjustments following the repair or installation. To simplify the design requires that aggressive supportability design decisions be made during the conceptual and preliminary design phases (when system design criteria are being formulated) and followed up during the detailed design phase.

Components must be sized to be handled by a maintenance technician (male or female) without the use of SE. This will require the designer to employ more modularization in mechanical and electronic component design. The designer must assure that the modules are accessible, can be easily and rapidly replaced, and will not require rerigging, alignment, or a system functional check after replacement. This can be achieved if the designer thinks beyond what has been done in the past, considers what must be done to assure achievement of operational performance requirements, and applies imagination to the problem.

The designer must be innovative in designing the BIT for the system. The BIT *must* be a maintenance asset instead of a maintenance burden, as it has been in some instances in the past. The BIT must be independent of the basic function of the system and in no case must the BIT be mission-essential. The BIT can be a maintenance asset or a burden, depending on the attention given to it during the design process. RFP's being issued today require specific levels of BIT reliability and ambiguity.

The requirement for spare components to accomplish repairs and successful completion of mission objectives are functions of the reliability of the system. Therefore, a comprehensive reliability program must be initiated during the conceptual design phase and become progressively more definitized as the design progresses to the preliminary and detailed design phases. Levels of reliability must be achieved that will assure achievement of mission objectives while simultaneously optimizing the logistics support costs for the system. This must be done by identification and resolution of reliability problems early in the design phase. Reliability problems must be identified through accomplishment of reliability analyses on the system and its components and through detailed analysis of developmental test failures.

The reliability engineer must assure that:

1) Design simplicity is achieved.

2) Parts, material, and processes are selected that are compatible with the overall reliability requirements of the system.

3) The stress-strength relationship of components is optimized from a reliability standpoint.

4) Component derating criteria are established and followed.

5) Redundancy is judiciously applied. (Redundancy adversely impacts maintenance requirements.)

6) Durability is designed into line replaceable units (LRU's).

7) Operational and environmental conditions are considered in the design.

8) Appropriate testing is accomplished; e.g., reliability development growth testing (RDGT) and environmental stress screening (ESS).

The complexity of, and requirement for, technical data are driven by the R&M characteristics of the system for which the technical data are being prepared. If the R&M engineers do their job during the design process, the requirement for complex technical data can be eliminated. The less complex the technical data, the higher the probability that the maintenance technician can successfully accomplish the required maintenance function(s).

Innovative Support Concepts

A support concept must be established for the system early in the conceptual design phase to assure that complementary design alternatives are selected.

For example, if an aircraft is to be supported with a two-level (organization and depot) maintenance concept, reliability must assure the selection of components whose removal rates economically justify a two-level maintenance concept. For each component on the aircraft, a design-to reliability requirement must be established and an aggressive reliability program implemented to assure achievement of the two-level maintenance concept. The removal rate of the components must be such that the cost of sparing the complete LRU at base level is less than the cost of providing repair capability. This removal rate will vary for each component, depending upon the cost of spares.

In some cases, mission requirements may dictate that a two-level maintenance concept be established. Mission requirements may override cost considerations and cause LCC to increase. This is a circumstance where operational requirements drive the maintenance concept for the system and

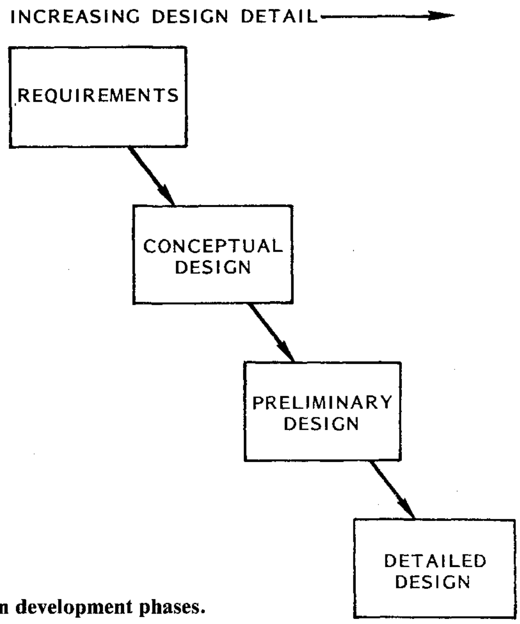

Fig. 4 Design development phases.

may preclude achievement of minimum LCC. In this case, LCC's are "optimized," given specific operational requirements.

Another support concept to be considered is the elimination of airframe depot-level maintenance and the minimization of base-level inspection requirements for the airframe. These requirements drive the structural design approach. The structural design concept for the aircraft must assure durable inspection-free structure and simple visual inspections where inspection cannot be avoided. This decision must be implemented during the conceptual design phase and closely followed up during the preliminary and detailed design phases.

The structural designer must select materials that are fatigue- and corrosion-resistant. He must consider sufficient design margins to instill confidence that major structural inspections of the airframe will not be required during the projected life of the airframe. Attention must be given to corrosion prevention. Interior and exterior finishes and sealants must protect the structure under the most adverse conditions (natural and man-made) in which the aircraft is to be operated. The R&M engineers must identify to the designer those areas of the aircraft that have historically been the most susceptible to corrosion damage.

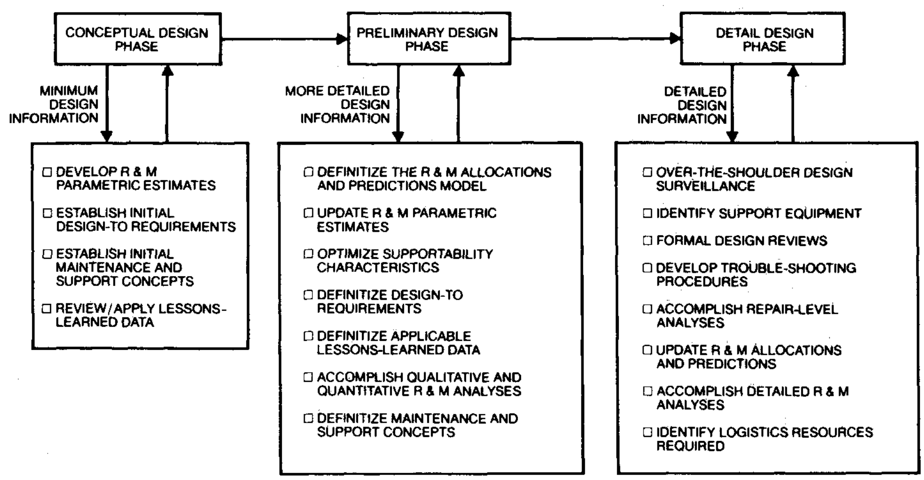

Fig. 5 R&M design relationships.

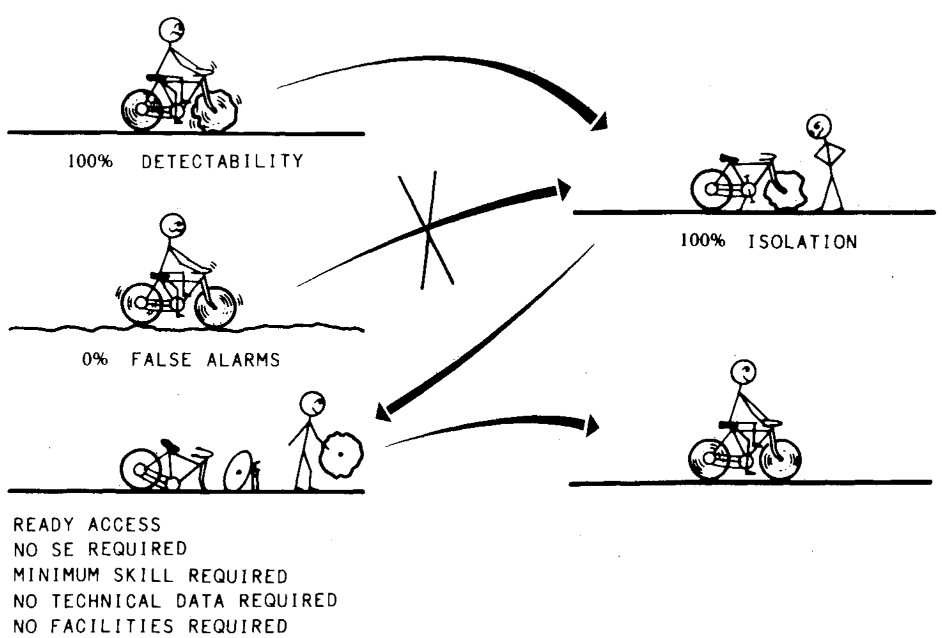

Fig. 6 Optimum supportability.

Designing to eliminate depot maintenance and to minimize base-level inspections of the airframe adds weight to the aircraft which, in turn, degrades performance and increases acquisition costs. However, the added weight must be evaluated against increased supportability and increased airframe availability.

When and How Does R&M Become Involved in the Design Process?

R&M engineers must be involved in the design process from the earliest conceptual design phase through the detailed design phase. Their involvement with the design becomes more detailed as the design progresses, as depicted in Figs. 4 and 5.

Conceptual Design Phase

During the conceptual design phase, initial R&M design-to requirements are established and disseminated to the systems designers. During this phase, R&M engineers provide parametric estimates of the R&M characteristics of proposed designs. The parametric estimating relationships used will have been developed using historical data from systems similar to the one(s) being analyzed. The R&M characteristics quantified using the parametric estimating relationships must be adjusted by the R&M engineers to reflect state-of-the-art improvements in both structures and systems and anticipated support concepts for the proposed system. The adjusted quantified R&M characteristics are used in trade studies to determine the optimum design approach that will meet the customer's stated requirements (supportability, cost, performance, schedule).

Multiple design approaches will be considered during the conceptual design phase, thus requiring rapid response by the R&M engineers. To be effective, the R&M engineers must have the analytical tools readily available to permit rapid evaluation of proposed designs.

Preliminary Design Phase

During the preliminary design phase, R&M engineers coordinate with systems engineers and designers to optimize the supportability characteristics of functional systems and structure. Customer supportability requirements are translated into design-to requirements that are meaningful to the systems engineers and designers, and an R&M allocations and predictions math model is developed.

During this phase, extensive use is made of "lessons-learned" data to assure that in-service problems are not present in the new system design. Lessons-learned data must be translated into design-to requirements that are meaningful to the designer and systems engineer.

As the design evolves and more detailed design information becomes available, the R&M parametric estimates made during the conceptual design phase are updated, and more detailed quantitative and qualitative R&M assessments of the design are made. This information is used in trade studies and to update the R&M predictions and allocation math model in order to further optimize the R&M characteristics of the system. Supportability, cost, performance, and schedule interplay to achieve the best overall design approach that will satisfy all the customer's requirements.

At this point in the development process, a support concept will be definitized. The support concept will be translated into design-to requirements and disseminated to the systems engineers and designers.

Detailed Design Phase

During the detailed design phase, the R&M allocations and predictions math model developed during the preliminary design phase is definitized and updated with detailed design information. This math model will contain all on-system replaceable units in the system. Quantitative R&M requirements at the top level will be allocated to each individual system, subsystem, and on-system replaceable component. Then, as detailed R&M analyses are made, predictions will be input to the model to permit tracking of R&M requirements. R&M allocations are made from the "top" down, and predictions are made from the "bottom" up.

The allocated R&M parameters must be translated into terms to which the designer can relate. For example, an on-equipment maintenance requirement of 0.000005 MMH/FH has no significance to a designer, per se. However, if the designer is told that the installation of the item must be such that the item can be removed and replaced, including access, in 10 min, he readily understands this. This requirement automatically constrains both access provision and the installation details of the item. It is important to realize that quantitative R&M values that have significance to R&M engineers may have little or no significance to a design engineer. Mean-time-between-removal (MTBR), MMH/FH, availability, turnaround times, skill required, and other supportability requirements must be translated into design-to requirements to which the designer can relate. R&M math models are necessary to permit tracking achievement of R&M requirements; however, the type of information they provide contributes little to the designer's understanding of the supportability requirements.

Probably the biggest error made by the R&M engineers during the design process is failure to provide the designer with hard design-to requirements that can readily be translated into hardware. This presents the greatest challenge to the R&M engineers. If this challenge is not effectively met, no one knows about it until the system becomes operational and cannot be supported. It is too late then to solve the problem cost-effectively!

During the detailed design phase, R&M engineers work directly with the designer to assure that the "innovative design approaches" discussed earlier are actually included in the detailed design of the system. The R&M engineers assure that:

1) Accessibility is commensurate with scheduled and unscheduled maintenance requirements.

2) Troubleshooting provisions are incorporated.

3) Handling provisions are incorporated.

4) The equipment operating environment is compatible with the reliability requirements of the components.

5) Components are sized to permit ease of handling.

6) Requirements for support equipment have been minimized.

7) Support equipment is off-the-shelf support equipment or a modification thereof.

8) The design has been simplified in order to minimize the number and skill of maintenance personnel required.

During this phase of the design, a subcontractor/vendor R&M program must be initiated. System-level supportability requirements must be allocated to subcontractors/vendors and translated into design-to requirements. The subcontractor's/vendor's program to achieve the supportability design-to requirements must be very closely monitored to assure achievement of requirements.

Subcontractors/vendors play a key role in assuring that overall system-level supportability requirements are met. With certain exceptions, all functional components that go into Lockheed systems are designed and built by subcontractors/vendors. Consequently, R&M requirements, including appropriate testing, must be imposed that will assure optimization of the supportability characteristics of the item(s) furnished.

R&M Engineers Must Be Prepared to Support the Designer and Systems Engineer

R&M engineers must be systems (functional and structural) oriented in order to be effective in the design process. To be properly prepared to influence the design effort, R&M engineers must be familiar with and understand in-service state-of-the-art systems. They must be aware of the positive and negative attributes of in-service systems and the influence these attributes have upon the supportability of the system. When design characteristics negatively influence the supportability of a system, the R&M engineers must actively participate in the selection of a design approach by providing positive design solutions. It is not enough simply to recognize the problem. Recognition is only part of the task. The task is not complete until a solution to the problem has been recommended.

The R&M engineers must not only stay abreast of state-of-the-art systems, they must look to future requirements. This is accomplished through Independent Research and Development (IR&D) projects that are directed toward development of support concepts and identification of supportability design-to requirements that will enhance achievement of future operational requirements.

Parametric estimating relationships must be continuously updated to reflected state-of-the-art improvements in aircraft functional systems and structure. Without accurate parametric estimating relationships, it would not be possible to react quickly to proposed design approaches during the conceptual and preliminary design phases.

Conclusions

With the emphasis on supportability, we must be innovative in our design approach and the support concept we select for the system. We must have R&M engineers who not only understand logistics problems, they must also be systems (functional and structural) oriented and understand the "why" and "how" of system design.

The key to a successful R&M program is the *active participation* of the R&M engineers in the *design process*. Simply *reacting* to the design process will not get the job done!

R&M engineers must look ahead and prepare for the supportability requirements of the 21st century. In the environment of the 21st century, the effectiveness of a weapon system will be dependent upon its mobility and flexibility, which are directly impacted by the logistics requirements of the system. The challenge is evident. The success of future systems, in terms of meeting mission objectives, will be dependent upon the consideration given to supportability during the design process. Further, a company's success will be dependent upon how well the customer's supportability requirements are satisfied.

Figure 6 concisely summarizes optimum system supportability.