Translating Supportability Requirements into Design Reality

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This paper explores some of the principal issues in the integration of supportability into the design process. Roles of the contractor's design, supportability, and management specialists and their government counterparts are discussed as they relate to logistics influence in design. Methods and processes by which weapon system logistics and readiness requirements are established, assessed, allocated to system elements, and translated into specific design features are described. Tradeoff consideration, an approach to effective tradeoff criteria, and the progress of supportability issues through the program phases are identified, with particular emphasis on the necessity for developing and maintaining an effective audit trail.

Introduction

SUPPORTABILITY in system design is the sum of all system characteristics that affect time, effort, skills, and resources required to achieve specified operational rates under specified conditions. For tactical aircraft, it can be directly related to weapons on target and cost per kill through:

1) Sortie rate capabilities (initial and sustained).
2) Mobility factors.
3) Personnel/skills requirements.
4) Support cost.

In essence, tactical aircraft supportability may be viewed as the business of producing the greatest sortie rate for the least resources—aircraft, ground equipment, and personnel.

Great effort has been expended on aircraft programs to make designs supportable—and with a great deal of success. The air forces of the United States are today operating the most complex, high-performance equipment in the world, and doing it with rather modest (by industry standards) personnel requirements for experience and training. Still, there are continuing expressions of dissatisfaction and a growing commitment to do better.

Today, the design world is facing several important challenges. We must develop weapons systems to counter an increasingly sophisticated and capable threat. We must accommodate yet another massive step change in technology, which promises greatly improved performance, and resolution of some support problems, but also brings with it uncertainty about the level and nature of support problems that may be caused by technological advances. Finally, we must continue to struggle with problems of weapons cost escalation and affordability issues.

The best opportunity for gaining on the affordability problem lies on the supportability side of the weapons system. The principal driver of weapons system cost has been complexity. This same factor has also driven support cost, but some headway has been made in using technology to reduce the supportability cost escalation rate. There is an almost universal consensus that we have only just begun and that there are opportunities to cut support burdens still further and produce better, more self-sufficient weapons systems in the process.

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Supportability Roles

Opportunities for improving supportability exist in both weapons system design and support system development. It is the design side, however, that attracts the most attention and is the focus of today's renewed activity based on new technology options.

Design program roles in the government and contractor organization are different. The government acquisition program organization is responsible for defining needs and requirements and for conducting an orderly, competitive acquisition program. The contractor's organization must create and produce a system that satisfies the need.

There was a time when a single individual could design an entire aircraft. With the complexity of current aircraft weapons systems today, well over a hundred different technical disciplines are required to support the design effort. The specialists in each of these disciplines are responsible for the application of the technology of each discipline to the design. Specialists develop design requirements and design features that satisfy the concerns of their disciplines. They propose design solutions in the course of the design process. This design team process is well established and accommodates technologies from aerodynamics to electromagnetic compatibility.

Efforts to incorporate supportability into design must work within the program organization and must adhere to the design process. To that end, supportability specialists (reliability, maintainability, and logistics) must interpret and develop supportability needs and requirements and translate these into terms the design organization can accommodate. The supportability specialists must develop specific design recommendations and must produce the analyses necessary to support those recommendations in design tradeoff studies.

The degree to which the government emphasizes supportability will largely determine the ultimate supportability characteristics of the system. Specifically, the government program organization dictates the amount of emphasis to be afforded supportability, defines requirements and objectives, assures consistency among competitive contractors and, after contract award, maintains surveillance and support.

The emphasis placed on supportability, particularly the evaluation weighting factors for proposals, will strongly influence the number and quality of supportability specialists assigned to the program and, equally important, will be reflected in the basic design tradeoffs. Recent requests for proposals (RFP's) from the government agencies have been excellent in this regard.

A definition of supportability requirements and objectives is also a measure of the mandated emphasis. Requirements must be both significant and attainable. They must be significant in terms of being effective in improving supportability and attainable in the sense that they are affordable, do not impose excessive risks, and do not unduly compromise other valid measures of effectiveness.

Requirements Analysis

Requirements dictate the necessary degree of departure from current designs and the corresponding level of inherent risk that must be assumed. They must be established from three standpoints: technical feasibility, risk, and effectiveness.

Supportability requirements are established by the government Acquisition Program Office and are developed with inputs from the operating forces, and usually in consultation with industry on technical issues.

Under ideal circumstances, technical studies provide the foundation for early definition of prospective requirements by examination of the technical feasibility and logistics effectiveness of the underlying supportability-related ideas. First-cut definitions of prospective requirements are ordinarily refined and solidified early in the program. Some requirements become firm by the end of concept definition; most become firm by the end of the demonstration/validation phase, with some additional modification made in early full-scale development.

Technical Feasibility

Feasibility is, essentially, a function of two factors: the amount of improvement required relative to current systems and the inherent potential for improvement. Where the potential for improvement exceeds the amount of improvement required, we have a feasible requirement. For the opposite case, the degree to which the potential for improvement falls short of the required improvement is a measure of nonfeasibility.

The starting point for feasibility assessment is the determination of the amount of improvement required relative to current systems. This analysis should be conducted at the end-item level and should encompass all current systems that are reasonably similar. Allowances should be made for differences in operational usage that have a measurable effect on the supportability parameters. For example, flight hours per month per aircraft and average flight hours per flight have a very substantial impact on readiness and mean time between maintenance (MTBM), respectively, and each has a strong impact on maintenance man-hours per flying hour (MMH/FH). While such relationships involve many nuances and are often difficult to define, experience has shown that substituting the number of flights for the number of flight hours goes a long way toward normalizing many parameters. Comparisons based on flights per month, maintenance man-hours/flight (MMH/FLT), and mean flights between corrective maintenance actions (MFBM), for example, provide better measures of relative supportability than their flight hour-based counterparts. Comparing these end-item requirements/objectives with operational data for current, comparable systems provides a measure of the required degree of improvement.

Given a measure of the required degree of improvement, we must next address the potential for improvement. This analysis is considerably facilitated if the end item is broken down into elements; for military aircraft—airframe, avionics, and propulsion. Each of these elements is then examined from three aspects: lessons learned, emerging technology, and RFP emphasis on supportability. These factors define the potential for improvement.

Past experience not only identifies problem areas, it often identifies successful solutions. These "lessons learned" are often as important as new technologies in terms of attaining substantial supportability improvements and are comparatively risk-free. There are times, however, when the required degree of improvement demands drastic changes, not just refinements of existing systems. New and emerging technologies must then be considered. It should be recognized, however, that the introduction of new technologies is nearly synonymous with increased risk. Experience has shown that new technologies seldom live up to expectations and usually require a great deal of time to mature. The learning curve sometimes exceeds the life cycle of the weapon system that introduces the technology. In addition, new technology often introduces new logistic problems. With this in mind, the potential benefits of new technologies should be conservatively assessed with a view toward keeping risks at an acceptable level.

The emphasis on supportability reflected in the RFP must also be taken into account in determining the potential for improvement. This emphasis is generally reflected in the willingness of design and program management personnel to go the extra yard for supportability improvements, and often becomes the decisive factor in marginal tradeoffs, i.e., tradeoffs whose results are not totally conclusive.

The quantitative measure of the degree of improvement required and the corresponding potential for improvement provide a valid basis for defining feasibility. Furthermore, it identifies the necessary design approach in terms of lessons learned and new technology.

Risk

Supportability risks can spring from either weapon system or support system design decisions. Most often, it is the weapon system decisions that impose supportability risks. For this reason, the weapon system risk assessment reduction and control program must include supportability as one of the major risk areas. This involvement entails participation in the development of test and evaluation requirements and in development of logistics contingency planning.

Where costly logistic factors are heavily influenced by the system design approach, appropriate testing should be accomplished early enough in the program to assure that problems and doubts are put to rest before the system is cast in concrete. The amount of testing must be fully commensurate with the degree of risk.

In conjunction with an effective test and evaluation program, logistic contingencies should be considered. Contingency thinking recognizes that not all test and evaluation programs culminate in success. An "escape path" is often necessary. By necessity, contingency plans should present a low-risk alternative technical approach that satisfies the customer's minimum acceptable requirements while limiting cost and schedule overruns to acceptable limits. A good contingency plan not only specifies the action to be taken when test results are unsatisfactory, it also specifies when, how, and by whom it is to be accomplished. This plan should be made a part of the contractor's proposal so that the customer knows ahead of time what to expect if risk turns into reality.

Requirements Effectiveness Assessment

In evaluating the effectiveness of requirements and their associated risks, the adequacy of the requirements should be assessed from two standpoints: Is it the right parameter? and Is it the right value?

The term "right value" is used to describe a requirement that is in balance with all other requirements. This is basically a seat-of-the-pants evaluation designed to assure that appropriate emphasis has been properly allocated to each of the overall system requirements. It is often possible to improve overall system effectiveness by tightening up on one requirement to compensate for a reduction in another.

Where feasibility and risk analyses point to potential problems in meeting a specific requirement, it will be necessary to conduct effectiveness assessment in greater depth. The assessment should quantify the requirement in terms of sensitivities and breakpoints and should be worked in conjunction with feasibility and risk analysis. In some cases, a small relaxation in a requirement can substantially reduce costs, schedule, and technical burdens with a minimal impact on overall system effectiveness.

The term "right parameter" is used to define those parameters that have a real influence on overall system effectiveness and are the prime figures of merit. Requirements specified for lower-tier parameters tend to impose unnecessary and costly constraints and seldom achieve their objective.

From a supportability standpoint, the prime figures of merit are readiness, life cycle cost (LCC), sustainability, mobility, and personnel requirements. Parameters such as MTBM, mean time to repair (MTTR), MMH/FH, etc., are constituent elements that are not themselves considered prime.

As generally used, readiness is an accounting term involved with arbitrarily measuring the ratio of system uptime to total time. We say "arbitrarily" because of ground rules that legislate some downtime as uptime, because maintenance days are seldom 24 h long, and because there is always the question of what constitutes a "ready" aircraft.

Also, readiness values are far more sensitive to operational usage than to system attributes and tend to be misleading. For example, since sorties generate the need for maintenance, increasing sortie rates will increase downtime, and thereby reduce readiness. However, the higher sortie rates themselves are indicative of real readiness. Two closely related parameters that can be used in lieu of uptime ratios to measure readiness are maximum sortie rates and elapsed time per sortie for maintenance, servicing, and inspection.

In a wartime environment, the best single measure of readiness for tactical aircraft is maximum sortie rate; the total number of sorties that can be generated over a specified period of time. This parameter is a vital input into mission effectiveness analyses and directly reflects the combined effectiveness of the prescribed support system and the supportability characteristics of the air vehicle.

In a peacetime environment, average elapsed maintenance time per sortie should be used as a surrogate for maximum sortie rate because it lends itself more readily to cost-effectiveness analyses and because maximum sortie rates are inconsistent with peacetime utilization rates. It should be noted that for a given length of the flight day, a given length of the maintenance day, and a specified average sortie duration, elapsed maintenance time per sortie directly relates to the maximum achievable sortie rate.

Life cycle cost is also an important measure of supportability. Supportability not only directly influences costs associated with training/trainers, maintenance personnel, facilities, support equipment, spares/repair parts, technical publications, and some consumables; to a large degree it also influences a significant portion of each equipment's/system's acquisition cost, including software. The increased testing and screening for reliability, the quick-release, self-contained fasteners for accessibility, and the test points for fault isolation, for example, each exact a price that is chargeable to the aircraft weapons system.

Although readiness and LCC are treated as separate parameters, they should always be viewed as a related pair. Alone, neither tells the whole story. The real measure of effectiveness is how much it costs to achieve a specified level of operating capability or, conversely, the level of operating capability that can be achieved for a given number of dollars. For example, it is possible to attain a very high level of operating capability if maintenance equipment, personnel, and logistic resources are unlimited. In real situations, however, resources are constrained.

Being able to achieve a high level of operating capability in a wartime environment, with limited personnel and support resources, is only half the battle. Sustaining operations is the other half. The question is: "What can be done to improve sustainability?" We can stockpile in-theater logistic resources, we can provide resupply services, and we can divert resources through a priority system that gives highest priority to forces under the gun. These are necessary techniques, but they are limited and costly. "Sustainability" as a design characteristic—a design that minimizes the need for logistics resources—is an important supportability goal.

The inherent sustainability of a system is dependent upon its reliability, survivability, and self-sufficiency characteristics. As used in this context, reliability refers to the maintenance rate (MTBM), not to mission reliability. In a similar vein, survivability is important to the extent that it reduces battle damage, and thereby lessens the demand for logistic resources. Survivability also relates to sustained operating rate by allowing aircraft (and aircrews) to survive to fight another day. Self-sufficiency focuses on the use of onboard capabilities to minimize reliance on external support resources. Built-in-test, auxiliary power units, and integral weapon hoists are examples of self-sufficiency features.

In addition to impact on sustainability, self-sufficiency has a large effect on mobility. Obviously, the more of the support system we can build into the aircraft, the less will be the demand for external support assets that must be transported when systems are deployed.

Given that there is an essential minimum of logistic assets that must be transported, these assets must be designed to enhance mobility. In general, size, form factors, weight, ruggedness, and requirements for support of support resources dictate the portability characteristics of those assets requiring transport. The combination of minimum reliance on external assets and maximum portability of those assets deemed essential defines the inherent mobility of a given system.

Personnel requirements (quantities and skills) are quite important in their own right, over and above their impact on readiness and LCC. The armed forces are faced with the increasingly difficult and expensive task of attracting and retaining capable maintenance personnel. Demographic projections indicate this problem will continue to grow. Therefore, the number of personnel and the skills needed to support a system should be treated as prime measures of supportability.

Design Impact

Allocations

Allocations establish detailed design requirements for the major elements of the end item. For most requirements, it is necessary first to decompose requirements into consitituent elements and allocate at that level. For example, operational requirements or readiness requirements must first be divided into secondary parameters such as MTBM, MTTR, and MLDT (mean logistic delay time). Feasible combinations of these parameters must be selected to determine acceptable ranges of values. The worst-case level for each of these parameters is selected as the target goal.

At this point, there are two ways to proceed. Either the target goals are allocated to each element on the basis of percent contribution of similar equipment, or estimates are derived on the basis of reasonable expectations (i.e., prior experience plus potential for improvement), without regard for target goals. The latter method is preferred since it is less affected by wishful thinking and focuses more attention on the potential for improvement, It does, however, usually require that the target goals be reallocated to achieve a more feasible combination of values. The additional work involved is usually a small price to pay for this refinement of target values.

In quantitative form, these allocations will have little significance to members of the design team, other than the supportability specialists. They should be used initially by the supportability specialists to establish the need for specific design features and characteristics. Subsequently, they should be used as a benchmark for monitoring and projecting the degree to which the design satisfies the established requirements.

Requirements/Translation

Allocations of MMH/FH, MTTR, MTBF, and other supportability parameters cannot be directly incorporated into design. They must be translated into a set of specific design features that will result in the desired supportability characteristics. It is the responsibility of the supportability specialists to translate these allocations for the design engineers. Translation is not nearly as difficult as it sounds. In the course of the feasibility analysis, when assessing the potential for improvement, the analyst converts design characteristics into quantitative estimates. We are now reversing the process to get back to the design features required to meet the quantitative allocations. For example, in this context, a mean time between failures (MTBF) requirement or allocation of 5000 h is not a design feature. Use of Hi Rel components, a 50% derating factor, and redundant power supplies to achieve a 5000-h MTBF are design features.

Design inputs must be timely. The design process is dynamic and evolutionary. If submitted too late, supportability inputs cannot be included in an orderly way in design development and may not be included at all. Submittal too early, before a design reaches the appropriate level of detail, also creates disorder. Supportability inputs must be managed by the supportability specialists to be consistent with the state of the design—neither too early nor too late.

In developing design features required to meet the quantitative allocations, the role of supportability specialists requires that they be active members of the design team. They must know in advance what design features can be utilized and will be effective in attaining supportability goals. They must also be aware of, and sensitive to, the impact of their recommendations relative to other design goals. Success depends on an understanding of both the underlying technologies and the field experience origins of supportability needs and requirements. This understanding and knowledge must be directed toward the development of specific design recommendations for features that advance the design toward supportability goals. Supportability-related design recommendations must be traded off against other design attributes. It should be recognized that these recommendations identify the means of satisfying specified requirements, and it is seldom necessary to implement all features to satisfy a requirement. There are cases, however, where certain features are essential to meeting a specified requirement. In these cases, the recommendations become requirements.

Tradeoffs

When we provide designers with supportability inputs, we are really providing them with specific design recommendations. These recommendations must be subjected to tradeoffs to ensure that supportability benefits outweigh penalties that may be incurred in other areas. Many such tradeoffs are done informally, and where the right choice is quite evident, the recommendation is incorporated without a struggle and can be thought of as an uncontested tradeoff. Where the net worth of the recommendation is questionable or has a major impact on the design, a formal tradeoff is required.

There are two types of supportability tradeoffs: those involving design alternatives and those involving support system alternatives. However, before we can do a tradeoff between design alternates, we must first establish the "best" support system for each design alternate. In theory, this implies support system tradeoffs for each design alternate but, in practice, most such tradeoffs are of the uncontested type.

Given the need to conduct a tradeoff, there are five important considerations: use of the results, measures of effectiveness (MOE's), models methodologies, sensitivities, and timing.

Supportability tradeoff results are usually inputs to higher-level analyses. With respect to tradeoffs involving design alternates, supportability analysis results will be used as inputs to the overall system effectiveness and LCC analyses. In a similar vein, the customer will use supportability analysis results as inputs to total force level effectiveness and LCC analyses and will temper conclusions with an eye toward the anticipated availability of funds—near and far term.

While readiness and readiness-related parameters and LCC are used as MOE's for supportability, penalties incurred to attain supportability benefits are usually expressed in terms of space, weight, power, functional capability, and acquisition costs. A common denominator is required to weigh fairly each ingredient in the tradeoff. Most design teams have adopted a dollar per pound index to be used to determine the maximum amount of money that should be spent to save 1 lb of aircraft weight. Several papers have been presented on the subject, and values for next-generation fighters are about in the $1000/lb category. Similar techniques can be used for space and power.

A dollar per ready-hour index for determining the maximum amount of money to be spent to save 1 h of ready time in the life of an aircraft is a very useful supportability index. It far exceeds most other supportability indices in magnitude and provides a common denominator for design tradeoffs. The dollar per ready-hour index is the ratio of total estimated LCC per aircraft to the required/anticipated number of ready-hours per aircraft life cycle. For the next generation of fighter aircraft, the index should be in the $600/ready-hour mark.

There are two approaches for value change involving functional capability. In some cases, it may be feasible to price out the changes required to restore functional capability to its original level. Where this is not feasible, a less direct approach is needed. We must determine the least-cost change required to compensate for the functional degradation on one system by a functional improvement in a different system(s). For example, we can state that a system MOE is defined by the equation

$$\mathrm{MOE} = P_D \times P_T \times P_K$$

where P_D = probability of detection, P_T = probability of track, and P_K = probability of kill. We can compensate for a reduction in the quality of target detection with a comparable increase in either tracking capability or destructive potential, or a combination of the two. The least-cost method dictates the cost (negative value) of the functional degradation.

LCC is not a single entity for tradeoff purposes. A dollar spent up front for development or production is considerably more important than a dollar saved over the 20-year life of a system. Up-front dollars should be segregated from operation and support costs, and each must be properly weighted in tradeoffs. Guidance should be provided by the customer in developing weighting factors for a given program.

There are a multitude of models and methodologies in use today. While we must certainly recognize the need for different models and methodologies for different programs and different program phases, there is a need for consistency and repeatability in supportability analysis. Meaningful dialogue within and between industry and government groups is dependent upon the use of a common language for deriving and expressing analysis results. Parameter names and definitions, computational ground rules, and operational scenarios should be subjected to some level of standardization to foster meaningful assessments of analysis results. Introduction of new models and methodologies should be carefully considered to avoid disorder in the analysis process.

The nature and extent of tradeoffs are obviously slave to the depth of available design information. Gross tradeoffs are conducted early in the program and more detailed tradeoffs later on in the program. Experience has shown that supportability has a high win rate initially, but tends to have many of these wins converted to losses later on. There is more of a tendency to take an optimistic view during initial development. As an acquisition program gets closer to the production (or prototype) phase, design becomes increasingly conservative, especially as cost and weight estimates start to increase. A safety cushion should be developed early in the program. There must be more supportability in the initial design than is necessary to meet the minimal requirements.

Program Controls

Having identified and justified the necessary supportability attributes, a system of controls is required to assure that these attributes show up in the final product. These controls should encompass a means for communicating supportability recommendations to the designer, a design review system, a test and evaluation program, and a bookkeeping system to track and project supportability expectations.

Where equipment is being procured rather than manufactured in-house, specifications are the prime means of communicating requirements and objectives. To assure that supportability inputs are included, it is important that the specification review and approval loop include sign-off by the supportability manager.

For in-house designs, a chit system can be used for early design control. The chits are prepared by cognizant supportability personnel, signed off by the supportability manager, and forwarded to the aircraft weapons system design manager for inclusion in weapons system tradeoff procedures. Preparation by the supportability specialists should include appropriate supportability impact assessment and justification rationale. Many chits will be processed as uncontested trades. Where significant design impact is involved, the tradeoff should be conducted in detail.

As a design progresses, specifications are developed at various levels of detail. Supportability design requirements and features accepted in tradeoffs must be included in these specifications to assure their incorporation in the final product.

The design review system includes formal and informal reviews of the design and associated analyses. The intent of the formal design review is primarily to assure the customer that he is getting his money's worth and that the design is proceeding on schedule. The informal design reviews, which occasionally include customer personnel, provide a forum for the give-and-take that is the single most important means of getting supportability into the design. It is a continuing process, which begins with an explanation of the supportability recommendations and ends up with supportability sign-off of the drawings, pertinent analyses, and specifications.

The importance of a good test and evaluation program is generally recognized, but such programs can be costly. We must get the most mileage out of essential tests and improvise simple means of validation wherever possible. For example, recommended support equipment might be used early in the program, in lieu of factory test equipment, and in conjunction with established maintenance procedures. This could apply to any necessary repairs of preproduction equipment. Qualification and early acceptance test data may be exploited to verify predicted failure and repair rates, failure modes, and fault detection/isolation capability. Mockups can verify accessibility. Analysis may be used in supportability development to eliminate or reduce test requirements.

"Bookkeeping" is an essential part of supportability controls. It is important to know where we are, how we got there, and where we are going.

Comparing current predictions to current allocations defines supportability progress toward goals and requirements at a given point in time. This implies a continual prediction effort, beginning with initial design. As the design definition develops, predictions evolve from first-cut approximations at the system/subsystem level to detailed estimates at the equipment/component level. This evolution is attributable not only to the increased degree of design definition, but also to the tradeoff process, test results, and program-mandated changes (ECP's).

Although allocations are considerably more stable than predictions, they are periodically updated to reflect program-mandated changes and, when necessary, a better balance between system elements.

At the beginning of the design, the predictions should be slightly more optimistic than the allocations, thereby providing a contingency factor. As the design progresses, the contingency factor tends to wear away, and predictions may fall below allocated values. This requires remedial action and usually demands a reassessment of priorities relative to other design attributes.

An effective alternative to waiting for the problem to develop fully is to project current progress to predict where we will be at the end of the program. An extrapolation of current predictions usually shows a growing divergence from the allocations and tends to place the problem in perspective.

Trending analyses, which are used for extrapolation purposes, rely heavily on engineering judgment and skill. The responsible analyst must look beyond the plot of values leading up to the current predictions and look for the underlying reasons for trends. Has supportability been ineffective in the tradeoff process? Are test results strongly influenced by immature equipment and/or inexperienced operators? Are there approved design improvements awaiting incorporation? These and many other questions need to be addressed to guide interpretation.

If done properly, the extrapolation should include an upper and lower bound to establish the area of uncertainty and the anticipated degree to which future program management decisions and priorities will influence the final results. This provides a decision tool for program management to use in controlling priorities and policies.

Finally, we must maintain an audit trail to show how we got where we are. The audit trail should consist of all pertinent tradeoff documentation (inputs, assumptions, alternatives, and results), chits providing specific design recommendations, status reports, test results, changes to the original predictions and allocations, and the rationale for the changes.

Having a good audit trail performs several important functions. In the event predictions start to fall short of allocations and corrective action is required, it is helpful to have a backlog of completed tradeoffs to review and, selectively, reopen. Audit trails also serve to help justify supportability staffing levels. Documented evidence is more credible than off-the-top-of-the-head recollections.

Summary

In summary, supportability requirements can be translated into design reality. Proven techniques exist for implementing programs that develop and satisfy supportability requirements and objectives without unduly compromising cost and performance requirements and objectives. Large-scale improvements in supportability are entirely feasible and can be achieved in the next generation of aircraft.