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Key Words: Product Development R&M 2000, Systems Engineering

Summary of Conclusions

"Integrated Product Development" is the Air Force Systems Command (AFSC) implementation of Concurrent Engineering, which simultaneously considers product design, manufacturing processes, and support processes. In consonance with Department of Defense (DOD) guidance, AFSC has embarked on a broad program to transition its engineering processes to reflect concurrent engineering. The AFSC approach employs critical process analysis, tailoring to accommodate product differences, pilot programs, and transition to a "way of doing business." Major facets of the program include: near-term education and training; major weapon system development programs; long-range policy, guidance, education, and training; research and development. It requires significant changes to the way the R&M disciplines are implemented and how R&M specialists interact with the system changes. The views expressed in this paper are solely those of the author and do not necessarily represent the views of AFSC, the Department of the Air Force, or the Department of Defense.

Introduction

"Integrated Product Development" (IPD) is the Air Force Systems Command implementation of Concurrent Engineering, which simultaneously considers product design, manufacturing processes, support processes, and test/ testability processes. The name was chosen for two specific reasons: first, it was believed to be more accurate; second, it avoided the adverse connotation associated with "concurrency" in the program management context. Contrary to the most common view of concurrency with respect to program management, concurrent engineering is a very positive approach that prevents the occurrence of most of the technical problems seen in system development.

For AFSC, the current fiscal and political environment make IPD a virtual necessity. The disbanding of the Warsaw Pact and changes within the Soviet Union have removed a major military threat to the security of the United States. Obviously, all military threats have not been eliminated (Ref. 1), but the near-term reductions in threats are sufficient to warrant wide-ranging examinations of AFSC programs and practices. The reductions in threats will result in a reduction of resources available to the AFSC and, consequently, an implicit requirement to improve the acquisition processes within AFSC. In response to this challenge, AFSC has examined many of its critical processes, most notably the RFP process and the system engineering process, and revised them to meet the needs of the new environment. IPD is the revised system engineering process.

There are recent precedents for these critical process examinations in industry. Faced with loss

of markets, increasing costs, increasing product delivery time, and increased customer sensitivity to quality and reliability, segments of the U.S. industry have experimented with development processes that have integrated manufacturing, support, and test processes with basic product design. Companies such as Boeing, Texas Instruments, Westinghouse Electric, General Electric, McDonnell Aircraft, John Deere, and Allen Bradley, have used a variety of approaches that are consistent with IPD. These companies have included the use of integrated teams and specialized tools. An excellent summary of some of the approaches and results is presented by Winner et. al. (Ref. 2). The automotive industry experimented with Concurrent Engineering and found that they could reduce the time to pilot production from six years to four years. The "bottom line" of the industry efforts is that industry has viewed the initial results to be positive. The industry view is that these approaches resulted in reductions in both cost and delivery time and increases in both quality and reliability.

As a follow-up to the Concurrent Engineering Study documented in Ref. 2, the DOD issued guidance in 1989 on Concurrent Engineering to its components. This guidance addressed four areas:

1. Near-Term Education and Training
2. Application to Major Weapon System Development Programs
3. Long-Range Policy, Guidance, Education and Training
4. Research and Development in Enabling and High Leverage Technologies

Near-term education and training was requested for the purpose of establishing multidisciplinary cadres at each major system contracting activity. The second area was identified to insure the application of Concurrent Engineering to major weapons systems. It identified the features of Requests For Proposal (RFP), specifications, and contractual tasking that were considered consistent with Concurrent Engineering. The third area addressed efforts to improve technical process military standards, long-term education and training, revising the DOD 4245.7-M templates, integrating Concurrent Engineering with manufacturing and engineering processes, and facilitating the transfer of Concurrent Engineering technology. The last area addressed developing Concurrent Engineering approaches for high-leverage technologies and developing enabling technologies for Concurrent Engineering.

The industry experience and the DOD guidance provided the bases for AFSC to examine its system engineering process. Prior to the advent of Concurrent Engineering, AFSC systems engineering

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was guided by MIL-STD-499, which identified a sequential approach that deferred consideration of manufacturing and support until after characteristics of the product were established. In practice, this process resulted in frequent iterations late in acquisition programs because the design changes were needed to make the product producible, testable, and supportable. It became obvious that the impending resource limitations would necessitate improving the effectiveness of the AFSC system engineering process.

AFSC used a "critical process team" approach to formulate its system engineering process. Briefly, this approach involved identifying a critical process, mapping it, obtaining views on it from customers and suppliers, identifying significant process measurement points and parameters, conducting an in-depth analysis of the process, and then implementing corrective action. The initial team activities were performed by the AFSC Aeronautical Systems Division (ASD), which was joined later by the Electronics Systems Division (ESD) and Space Systems Division (SSD). The end product was the AFSC IPD concept, which is described below.

AFSC has established an IPD Steering Group to guide the implementation of a multi-year IPD plan that addressed the four areas identified by DOD and described above. For example, each product division has identified or is identifying candidate weapon systems for IPD implementation. Also, efforts are underway to examine technical process standards in order to update them to be compatible with IPD. To a large extent, near-term education and training has been completed. In all areas of the plan, industry and academia are being involved as appropriate.

The IPD Process

One of the major departures of IPD from "traditional" system development is the concept of the "system." In the 1950's and 1960's, the "system" generally was considered to be just hardware. Software was only an emerging element and the human was infrequently considered an integral part of the system. As computers increasingly pervaded system functional elements, software gained recognition as a critical player in proper system operation. Therefore, from the late 1960's to the present, the "system" frequently has been defined as "hardware plus software." This is considered a transitional phase as shown in Figure 1. With the advent of the IPD approach, the concept of the "system" is extended to include the human element and to include the manufacturing, support, and test processes. If one were to characterize the system description in terms of parameters for optimization, i.e. optimizing some objective function subject to constraints, one would see the appearance of parameters associated with human performance, manufacturing processes (e.g. Cp or Cpk), support processes (e.g., spares availability, logistic delay time, or maintenance manpower), and test/testability processes (e.g., detection probability) in the objective function and the addition of constraint equations associated with manufacturing, support, and test/testability processes. One sees elements of this view in the semiconductor industry where integrated circuit designs are being analyzed not only in the context of performance characteristics but also in the context on the manufacturing processes that will be used to produce them (Ref. 3).

A second major departure from the current approach to system development is the use of multidisciplinary teams, "Integrated Product Teams" (IPT). These are teams that consist of members with a variety of engineering disciplines (e.g., electronics, structures, "-ilities," manufacturing, support, computer resources). The members jointly participate in the translation of customer requirements into product and process design requirements and the conversion of those requirements into the finished product and its attendant support. Although they possess special areas of expertise, the members of an IPT have a product focus rather than a functional focus. An informal survey by AFSC in 1986 showed only a few aerospace companies had constructed such teams with any rigor and only one third of the surveyed companies had specialty engineering disciplines reasonably well connected to the mainstream design effort. In the majority of companies, product development consisted of each system functional element being designed first and then reviewed by a series of specialists who operated virtually in isolation - "stovepipes." The IPD approach uses teamwork to eliminate the stovepipes and, consequently, eliminate many of the unnecessary iterations that occur. Figure 2 illustrates how the use of teams benefits the system development.

A third departure from tradition occurs with the use of "layouts" and "packages" as shown in Figure 3. In IPD, the basic traditional system engineering functions - analysis of user requirements, trade studies, allocations - are performed during the system engineering segment by an IPT. The product of that team is the system specification (see Figure 3), which in turn is reviewed in the System Requirements Review. After the system specification is approved, it is turned back to the IPT which then effects the design evolution. As Figure 3 shows, design, manufacturing, support, and test functions participate in this process. The first product of the team is the "conceptual layout," which resembles the traditional preliminary design review package except it has a greater balance in terms of manufacturing, support, and test. This layout identifies the general physical characteristics, functions, and locations of the system and its major configuration items. It also defines the candidate materials, tooling and fabrication concepts, design decisions, and interface control documentation. After analysis in the "Development Requirement Review," the conceptual layout is turned back to the IPT for development of the "assembly layout." This product describes the system and its configuration items in detail and associates manufacturing, support, and test characteristics with each item. The assembly layout is reviewed in the "Preliminary Development Review," after which it is turned back to the IPT for development of the "build-to" and support packages. The "build-to" package is the set of process instructions passed to manufacturing for production of the configuration items. The "build-to" package includes the complete 3-D description of the configuration item as data that are transferable to machine tools or automated assembly machines. It also provides a bill of material and verification requirements. Manufacturing instructions in the package include; finish requirements, marking, packaging, handling, storage, and non-destructive inspection requirements. The support package provides specifics for spares definition, diagnostics, support and test equipment, technical data,

training, and software support. Both the build-to and support packages are reviewed in the "Final Development Review," after which the product is manufactured and deployed.

IPD Implications for R&M

In AFSC at the present time, the framework for R&M is described in AFP 800-7, "The R&M 2000 Process." (Ref. 4). This process is summarized in Figure 4. R&M 2000 achieves goals that are meaningful to the Air Force user by means of principles and building blocks that are consistent with IPD. For example, requirements such as simplification and technician transparency and building blocks such as variability reduction, system testing, and stress screening require the early, concurrent participation of manufacturing, testing, and support organizations in the design process. The AFSC product division applications of R&M 2000, such as the integrity programs of ASD, the RISE program of ESD, and the emphasis on both parts control and tailored reliability programs of SSD, require intense interaction between R&M specialists and system designers. Prior to IPD, this usually occurred through an R&M stovepipe. Under IPD, the R&M specialist ceases to be a stovepipe and instead becomes a member of the IPT.

To illustrate how the work of the R&M specialist would change in IPD, consider the impact on the Failure Modes, Effects, and Criticality Analysis (FMECA) or Fault Tree Analysis (FTA) processes. The FMECA determines the effect each potential component failure has on system operation. The follow-on is to take action to reduce the occurrence of each potential failure and to establish diagnostics and planned maintenance. As O'Connor (Ref. 5) notes, the FMECA also can be used to consider the possibility of manufacturing-induced failures, such as incorrect part insertion or faulty soldering process. Under the traditional R&M approach, such failures were not considered with any appreciable consistency. In the IPD environment, identification of such failures, both in terms of design changes and manufacturing process changes, is mandatory, as is the follow-on action. Although it operates from a top-down rather than a bottom-up approach, the FTA similarly can provide important clues regarding the formulation of diagnostics, maintenance, and manufacturing operations.

Under IPD, where manufacturing, support, and test processes are designed concurrently with the product, the R&M specialist has an expanded area to analyze. Not only should the specialist be considering R&M analyses and syntheses of mission elements (hardware, software, human components employed in operational missions) but also he or she should be considering the R&M aspects of the manufacturing process; e.g., machinery and human elements. Downtime or improper performance of manufacturing operations can have a profound effect on mission element operation (as discussed above with respect to the FMECA and FTA) and a profound effect on delivery rates, product quality, unit cost, and unit profit. R&M analyses of manufacturing operations currently are not performed in a consistent manner, if at all. Because of the effect of R&M on manufacturing, the R&M specialist plays an essential role in selecting producible technology for mission elements and structuring manufacturing operations so they are reliable and readily repairable. In selecting producible technology, the R&M specialist must examine the manufacturing base associated with the

technology and make an evaluation regarding sustained delivery of products. Part of the evaluation is the R&M of the manufacturing process. Evaluations of subprocess R&M contribute to the synthesis and validation of new manufacturing processes.

IPD has implications for three major groups of players in the weapon system development process: AFSC, defense contractors, and educational institutions (Figure 5). For AFSC and other Air Force procurement organizations, the implications include the receipt of stable, validated R&M requirements from the operational forces and the translation of those requirements into design-oriented requirements, the formulation of acquisition strategies that facilitate IPD, and the development and implementation of training, tools and research. For industry, the implications include maintenance of trained R&M engineers and managers, the formulation of creative design solutions, and the development of tools and research that supports IPD. The implications for academia are no less significant. They include updating curricula to reflect IPD, R&M providing trained graduates, and developing tools and performing research. For the R&M community, these implications suggest the need for a significant update in R&M analysis and design synthesis tools, R&M aspects of new technologies, organizational relationships, and R&M training.

One readily can observe that a common thread through all of the implications is the development and employment of tools to support the IPD process. This statement is made in recognition of the great strides that have been made to date in computer-aided engineering (CAE). For example, one has seen the development and use of a number of reliability engineering tools for prediction and failure mode analysis. At a higher level of integration, one has seen the development of circuit board design tools that consider physical reliability factors (temperature, vibration, location) as well as statistical ones. A major step forward has been the development of a readily available Sneak Circuit Analysis technique (Ref. 6). Similar developments have occurred in the support and program management areas, including intelligent computer programs that help formulate R&M programs and integrate specialty engineering disciplines into the mainstream of system development. For example, Martin Marietta (Ref. 7) has introduced its System Supportability and Readiness CAD Interface which uses a common database and quantitative analysis hierarchy to integrate traditional supportability disciplines. Similarly, Westinghouse (Ref. 8) has introduced its WISE approach which integrates design, manufacturing, and support. Although several excellent integrating tools have been developed, most commercially available tools tend to reflect the "stovepipes" mentioned earlier, do not communicate well with each other. A excellent survey of the state of computer-aided design, with an emphasis on digital electronics, is provided by Director (Ref. 9).

The success of the IPD approach depends on the use of IPTs and their proper CAE R&M support. Some general capabilities that will be needed for effective IPT function are:

- R&M tools must support a heterogeneous, distributed data base architecture with multiple users;
- The tools must accommodate real-time data changes across multiple users (i.e. IPT members);
- Tools must address design hierarchy considerations and search design options for optimal solutions;
- Design, manufacturing, support, test, and configuration must be supported;
- There must be compatibility with existing CAD/CAM/CAE/CASE tools and CALS requirements.

These are non-trivial capabilities that are only beginning to emerge in commercially available R&M products. The dearth of such products in the past has induced system developers to develop their own internal R&M tools that had only limited versions of the above capabilities. The difficulty in developing industry standards that facilitate compatibility cannot be overstated. The DOD CALS effort offers a major vehicle for completing these standards.

There is a need to develop tools that guide system integration. At the present time, system integration is not taught by our academic institutions. Consequently, graduate engineers are well-versed in highly focused areas but not in R&M and the integration of the complete system. Many "common-sense" system integration principles such as interface control, modularity, testability, operator and maintenance transparency, and use of off-the-shelf products are not considered with sufficient thoroughness. The R&M tool developers should consider how to incorporate these principles into their products and how to develop products that address the R&M in the system integration process.

Perhaps the best recent treatment of significant technologies that will contribute to system R&M in the near future has been provided by the Aerospace Industries Association (AIA) (Ref. 10). Figure 6 shows the technologies addressed by the AIA and details the topics within the Ultra-reliable Electronics Systems technology roadmap. Each major area (technology, product/process integration, manufacturing methodologies, and the U.S. educational system) contributes to IPD implementation and can benefit substantially from attention from the R&M community. For example, the tools that address product and process integration need to address proper characterization of customer requirements, Quality Function Deployment, design of experiments, design for robustness with respect to performance (including reliability) and producibility, and use of benchmarks. Furthermore, design and reliability prediction tools must be updated to drive reliability oriented features into products (Ref. 10). One trend that needs to continue in an expanded mode is rapid prototyping via computer simulation. For each of the technology areas, the physics of failure and design application guidance must be characterized. Also manufacturing processes, testing strategies, and support concepts must be identified and characterized in terms of R&M impact.

The need to educate and train R&M engineers has been addressed many times by other sources (e.g. Ref 11). However, what has been addressed

primarily is the need to initiate such education and training and mechanisms for satisfying that need. The material to be taught has been formulated based on the the traditional view of R&M, perhaps with some lessened emphasis on the statistical aspects of R&M. IPD requires a broadening of the scope of R&M training to include greater emphasis on design and better understanding of manufacturing, support, and test processes. IPD also requires that R&M engineers acquire greater proficiency in system engineering and integration. As part of its IPD implementation program, AFSC is establishing training programs in its product divisions for executive and mid-level management. It is also establishing specific job-related training for engineers involved in the IPD process. AFSC R&M managers and engineers will be attending this training.

Conclusion

AFSC IPD provides a systems engineering approach that will be instrumental in delivering requisite military capability in the anticipated tightly constrained fiscal environments of the near future. It stresses integration of product design with the design of the associated manufacturing, support, and test processes and the use of multidisciplinary teams. It has significant implications for AFSC, industry, and academia in the employment of the R&M disciplines. Widespread adoption of IPD will enhance both the security posture of the U.S. and the competitiveness of its industry.

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Biography

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Mr. LaSala is the Technical Assistant, Systems Engineering and serves as the HQ AFSC focal point for concurrent engineering implementation, systems engineering policy product assurance planning, and international product assurance efforts. Prior to his current assignment, he served as the chief of the R&M division at HQ AFSC, the chief of the product assurance engineering division at HQ Army Materiel Command, a staff R&M engineer with Mr. Willoughby at the former Naval Material Command, and a product assurance section chief and staff R&M engineer in the Naval Sea Systems Command undersea weapons group. Mr. LaSala has served as U.S. representative to the NATO AC/250 Subgroup IX (R&M) and has served as the government resources coordinator in the 1982-3 DOD/IDA R&M study. He has taught basic reliability engineering at the graduate level for the University of Maryland and has published papers on man-machine reliability and other reliability topics. He has coauthored a chapter on man-machine reliability in the McGraw-Hill Handbook of Reliability Engineering and Management. Mr. LaSala has a B.S. in Physics from Rensselaer Polytechnic Institute and a M.S. in Physics from Brown University. He is a member of the IEEE, IES, and SOLE.

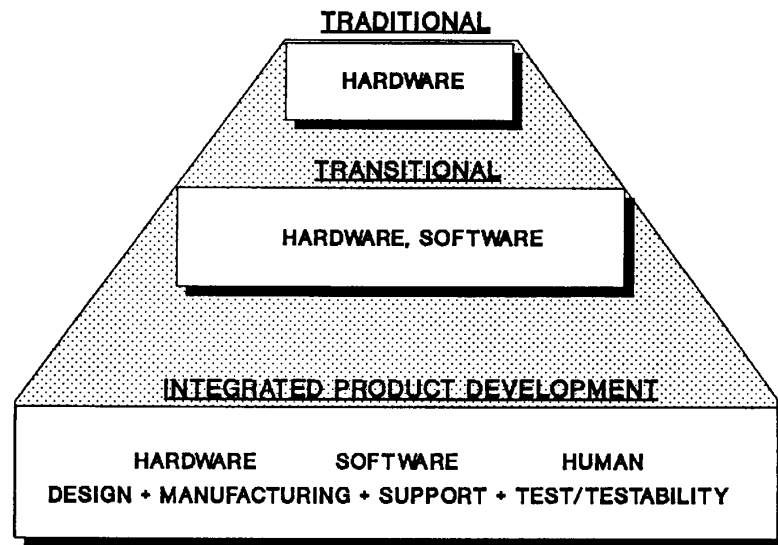


Figure 1. Integrated Product Development System Concept

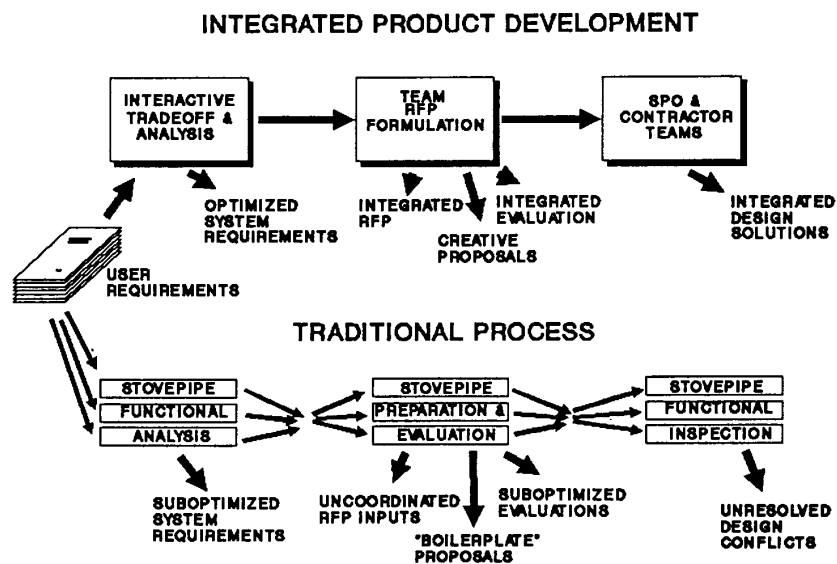


Figure 2. The Development Process

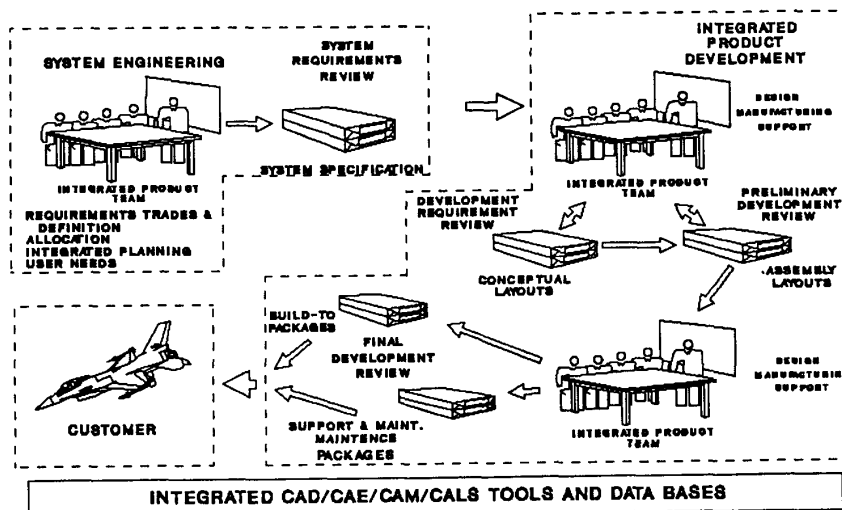


Figure 3. The Integrated Product Development Process

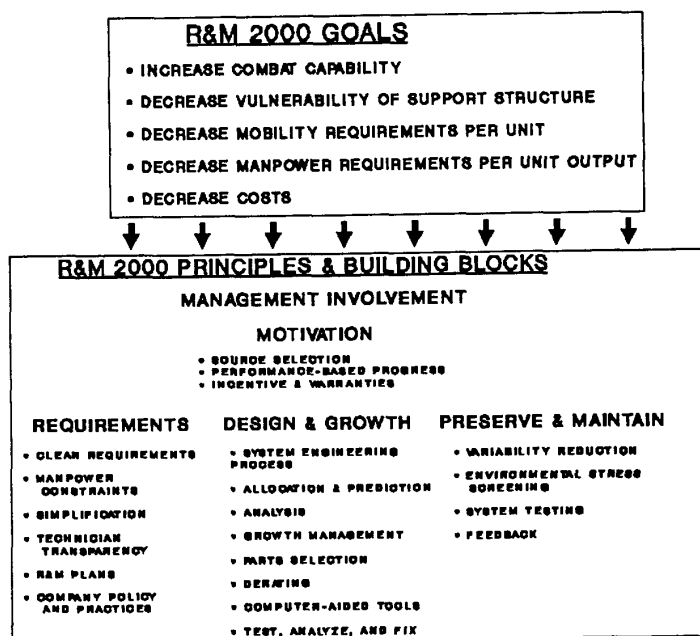


Figure 4. The R&M 2000 Process

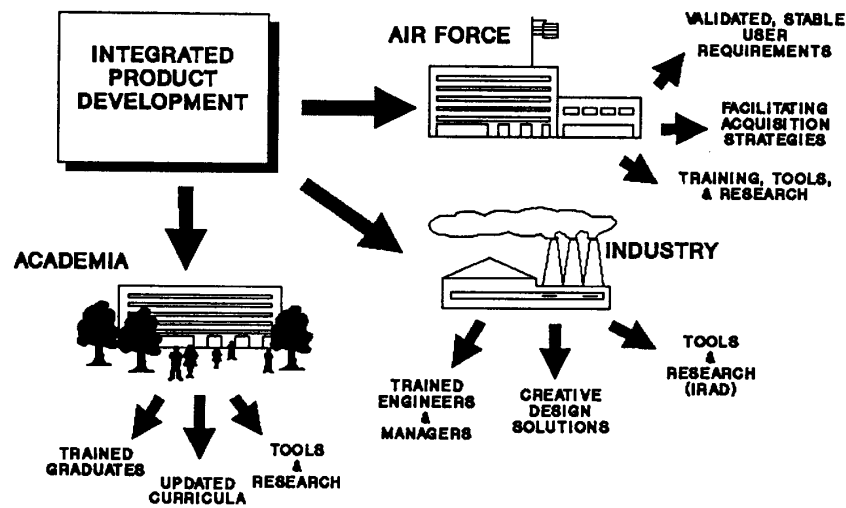


Figure 5. Implications of Integrated Product Development

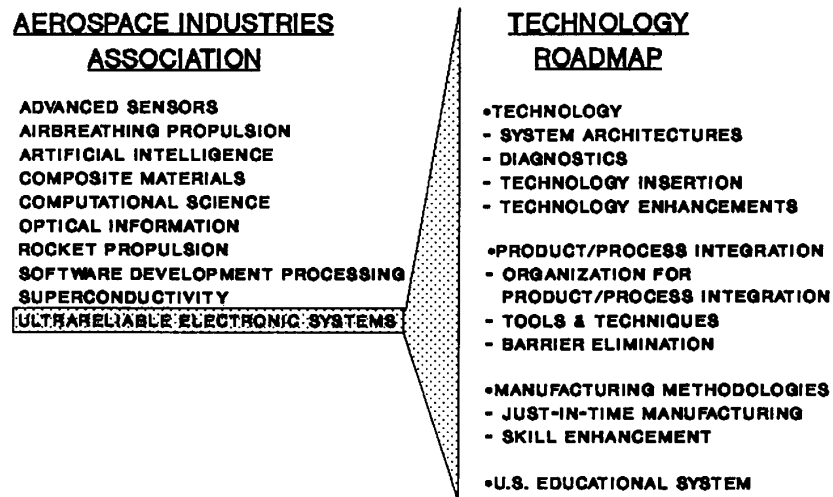


Figure 6. Future Critical Aerospace Technologies