Apr 1st, 8:00 AM

Regaining Space Leadership Through Control of Life Cycle Costs

David J. Lowry
Boeing Aerospace Co.

Thomas A. Feaster
NASA, KSC Future Projects Office

Regaining Space Leadership Through Control of Life Cycle Costs

by

David J.Lowry — Boeing Aerospace Co.
Thomas A. Feaster — NASA, KSC Future Projects Office

ABSTRACT

This paper covers the concept of Unified Life Cycle Engineering (ULCE) and how it could be used to avoid the types of problems that have been identified in the operation of the current configuration of the Shuttle.

Presents the concept of incorporating reliability and maintainability factors in the early phases of new system design. Describes plans for research and development of computerized tools in this area. The concept includes the role that CAE/CAD/CAM should play in improving design for supportability. The products that are needed to integrate these factors into database structures supporting the entire life cycle of the new system will also be discussed.

Advanced management techniques (Design-Build-Team and Build-To-Cost) used in conjunction with the new design tools will be detailed. Also discussed will be the characteristics of these new management techniques designed to achieve the maximum benefits from the new computerized aides.

INTRODUCTION

Design for performance has been the priority goal for new systems for decades. Consequently, many analytical procedures and data bases have been developed to accomplish these design activities. In contrast, design for support has had much lower priority; consequently, few analytical procedures and databases have been developed which allow the support factors to be included in the design process.

However, the opportunity exists today to significantly, and dramatically, improve the capability to design for supportability. The opportunity exists now because of the convergence of four historical trends.

The first trend is the steadily increasing demand by the Department of Defense to drastically improve the maintenance and support of systems while reducing manpower and costs.

The second trend is the accumulation of evidence from recent research performed by the Human Resources Laboratory at Wright-Patterson Air Force Base which indicates that maintenance and logistics support characteristics must begin with early concept studies. This research indicates, also, that one of best ways to improve design for support is to put the maintenance and logistics data and factors directly into the daily working procedures used by the design engineering personnel. (reference 1)

The third trend is the "explosive" emergence of computer aided design (CAD) as the daily working procedure within American industry for design of products. One of the main reasons for this rapid growth is that CAD greatly reduces the time and engineering labor hours required to produce a new design. The opportunity, therefore, is to link these trends and develop the technical capability to put maintenance factors, logistics factors and operational requirements directly into the CAD process being used by the aerospace industry. This technical capability does not exist today except in limited scope and then only in isolated cases. The current status of design for support is primarily that of analyses being performed "off-line" from the main performance engineering design activities, and then being performed "after the fact" without input to major design decisions. The development of the technical capability to put maintenance and logistics factors directly into the main CAD process can change this picture. Design for supportability can become an on-line design activity.

The fourth trend is one that will tie together the first three and maximize their combined effect on the development of the next generation systems. As costs have risen , the competitive position of the aerospace industry in the world market has been further weakened by the inequity of foreign governments subsidizing manufacturing and operating costs. To meet this challenge the Boeing Commercial Airplane Company has developed the Design/Build Team (DBT) concept as a dramatic approach to cost reduction and product improvement.

ISSUES

The Shuttle Ground Operations Efficiencies/Technologies Study used the STS 51-L(the last Challenger flight) launch operations data and the post 51-L reports as a point of departure. This data was then used to analyze the launch operations characteristics and place documented problems into one or more of several categories called "ISSUES".

A total of 41 different categories were identified, 18 of which will be discussed here. The following list contains those Issues that have a potential for avoidance in the future by incorporation of techniques within ULCE.

ACCESSABILITY	MAINTAINABILITY
CHANGE CONTROL	MANAGEMENT
CONSTRAINTS	PAPERWORK
DESIGN	PROCEDURE
DESIGN CRITERIA	QA
DISCIPLINE	RELIABILITY
DRAWING SYSTEM	REQUIREMENTS
INTEGRATION	STANDARDS
LOGISTICS/SPARES	TRAINING/CERTIFICATION

ULCE RELATED ISSUES

Each of the issues described above is listed in the following section with a brief description of the general nature of the problem. The source of these quotes is the Issues Database from the Shuttle Ground Operations Efficiencies/Technologies Study. The number of occurrences of the issue in the database will give the reader a relative feeling of its severity. (reference 2)

Accessability: (104) "...Contract specifications need to stress LRU maintainability/accessability...Fund maintainability and accessibility up front to significantly reduce unnecessary support costs in the operational area...include a logistics representative on the design team to continually address the problems of standardization, ease of maintenance, and accessability..."

Change Control: (30) "...The qualification of the test article was not in all cases representative of the flight configuration...Work accomplished on Flight 10 was formally approved for Flight 11...This OMI was deviated to change the configuration of the holddown post-blast shields for launch, formal engineering was not available for the operations, verbal agreements were reached and four of the blast shields were modified, post launch inspection revealed that the items incorporated for the mod were blown away at launch..."

Constraints: (18) "...Events associated with the STS 51-L mishap identified SRM flight safety issues not addressed in the FRR process...Manpower limitations due to high workload created scheduling difficulties and contributed to operational problems...MSFC is not part of the formal IFA (Inflight Anomaly) tracking system...Team members identified several problems with the constraint system which hampered effective traceability of open work items...Limited visibility of the constraints status make it difficult to identify and schedule work to support the test flow..."

Design: (750) "...Designers of black boxes should position PCBS so they will be vertical when the black box is installed in the system. Locate electrical feed through connectors on the side or back, not on the bottom...Design specs would require simplicity of design/accessability to facilitate maintenance, maintainability verification should be conducted to identify & correct maintenance deficiencies before design is "frozen"..."

Design Criteria: (298) "...Perform fit checks of mission equipment hardware on a high fidelity mock-up at the design agency to preclude field problems...Provide a defined maintainability design criteria at the inception of the program and a design review board to monitor adherence to these criteria..."

Discipline: (125) "...Five weeks after the 51-L accident, the criticality of the solid rocket motor field joint was still not properly documented in the problem reporting system at Marshall...Work authorization documentation audit, the review has found that the ability of the work control documentation system to guarantee proper real time execution of tasks and their subsequent traceability is inhibited by factors that must be identified and corrected by KSC management..."

Drawing System: (30) "...Incremental delivery of orbiter/payload mod kits is a problem. A system must be devised to I.D. problems/delays before becoming constraints to the field...Reference designators should be of a constant format across all program elements: Orbiter, External Tank (ET), Solid Rocket Booster (SRBS), develop a uniform system...Enforce a standardized drawing and part number system on all contractor and government furnished equipment..."

Integration: (11) "... Provide a full fidelity model for sub-system maintainability testing, to be used early in the design phase to verify design requirement compliance..."

Logistics: (81) "...Use standard industry hardware rather than unique hardware, unique limits the availability of spares and drives up the cost..."

Maintainability: (226) "...Maintenance requirements should be: Identified prior to design; Imposed at the sub contractor level, design requirements must address maintenance..."

Management: (82) "....Methods should be developed which assure more direct design contractor involvement in the processing and testing effort at the launch sites...Signature requirements on 'Real Time' work paper (deviations,TPS' IPR'S etc.) are lengthy and required personnel are geographically scattered ..."

Paperwork: (104) "...The OMRSD system is very difficult to paper track with respect to auditing requirements. The OMP and PSP which are often incorrect in the deviations and revisions are incorporated between the publication of one document and another. The OMP is not a closed loop system and is sufficiently complex such that cognizant systems engineer is the only person who knows the full status of OMRSD requirements..."

Procedure: (94) "...Of the 51 work documents generated by the MCR's, 96% were found to have errors of an administrative or format type as defined by the SPI (Standard Practice Instructions)...Task deviation log does not indicate effectivity of temporary deviations. Therefore, there is no fool proof way to determine if a temporary deviation is effective on a given run..."

QA: (107) "...OMRSD V41BG0.010 which checks the redundancy of individual regulators was not verified under flow conditions...The leak check steps for test port #4 were inadvertently omitted from OMI V1009.04. This is a violation of OMRSD V41AZ0.070..."

Reliability: (51) "...Design is a compromise between performance, reliability, maintainability, weight, space restrictions, safety, etc. Management must re-prioritize these factors so maintainability receives it's deserved attention..."

Requirements: (167) "...The processing support plan is a KSC document that lists all work that may be performed on a specific STS flow and lists OMRSD requirements and OMI's that will be released. The PSP is published about 50 days prior to OPF roll-in and is continually updated by system engineers. There is NO feedback into the OMP..."

Standards: (33) "...Problem reporting requirements are not concise and fail to get critical information to the proper levels of management..."

Training/Certif: (31) "...Training must be adequate to ensure that all workers are able to comply with the regulations which govern the paperwork system, ...The OMRSD requirement of 1 psid in the manifold was violated in that 6 psid were present causing the valve to slam..."

This multiplicity of problems is astonishing! It is imperative that a system be developed to control these interrelated problems. ULCE can provide the core solution !!

Today's Methods

The problems identified in the previous Issues section all have a common denominator, lack of SUPPORTABILITY. Each of the issues discussed in the previous section are the result of vehicle supportability being de-emphasized early in the design phase. This problem can be seen in almost all vehicle sub-systems as well as ground support systems.

The emphasis on performance has resulted in many tools being developed to support the evaluation of a given design for performance. The evaluation of supportability is primarily performed off-line, after the fact and if it is performed at all, too late for initial design influence.

It is clearly defined that the life cycle cost (LCC) of a system can be divided into four primary phases.

1. The **Mission Definition** phase involves conceptualizing the system; defining the problem to be resolved and considering initial architectures.

2. The **Design** phase in which the system is designed and the prototype is constructed and tested.

3. The **Production** phase entails manufacturing the product.

4. The **Operations** phase involves repair, operations, spares, training, product improvements, maintenance testing etc.

The distribution of the LCC for a DOD or commercial system is given in Figure 1.;

LCC Phase	LCC %
1. Definition	<1 %
2. Design	<10 %
3. Production	30 %
4. Operations	60 %

Figure 1.
DOD LCC Distribution (reference 3)

The current STS LCC has a distribution as shown in Figure 2.;

LCC Phase	LCC %
1. Definition	<1 %
2. Design	6 %
3. Production	8 %
4. Operations	86 %

Figure 2.
Shuttle LCC Distribution (reference 4)

In the past, <u>up front costs</u> and <u>performance</u> has been given the priority at the expense of <u>reliability and maintainability</u>. The design of future systems will have to consider **Operational** requirements including reliability and maintainability at the same level as performance, if our designs are to provide life cycle costs competitive in the market place.

The prime reason for this trend has been political economics. If inadequate funds are allocated for the initial design and manufacturing, then proof of concept (initial flight) take all the allocated funds leaving none for maintainability, and reasonable life cycle costs factors.

New Technical Requirements

The previous sections have identified the urgent need for a radical shift in design techniques. The methods used to design systems in the past, although adequate in their time are no longer suitable for systems of the future where low cost operations are paramount.

There are several CAD (Computer Aided Design) technologies currently available or in development that can alleviate many of the operational problems associated with today's Shuttle.

In order to define the nature of the work required to provide the CAD capability it is necessary first to understand the relevant characteristics of such a system: (reference 1)

1. Quickness of reaction time is probably the characteristic of CAD that will most effect the future design for supportability. Entire vehicle system design must be established within days or weeks. Support analyses for proposed designs cannot exist off-line. Support analyses will need to respond rapidly or they will be disregarded.

2. Computer-based automated analysis models are an essential part of the CAD process. Presently these models are used to assess performance characteristics or weight and balance. These automated analysis models are one of the reasons for the quick reaction time of the CAD process. Automated maintenance and logistics analyses models will also be required.

3. The ability to view objects in three dimensions is now resident within many CAD systems. Color representation of objects is now possible. These characteristics will afford opportunities to use CAD to perform mockup maintainabilty evaluations of equipment during early design.

4. The design and drawing data generated by CAD are being bridged to the databases that operate the numerical controlled machines within the manufacturing facility. The data flows from CAD to CAM and eventually to field and service engineering. Unfortunately, the databases that are used in maintenance and logistics analysis models are not linked with the CAD/CAM engineering databases. Design tasks for future systems will have to provide for supportability analysis data interchange with CAD/CAM.

5. Design systems of the future will be required to provide an integrated data path, providing a birth-to-death documentation tracking capability. Data generated during the design and manufacturing phase will have to be compatible with the data structures and processing systems used in the field and vice versa.

6. To achieve the maximum benefit from new computer aided design techniques will require new management techniques that can instill within the project four basic steps; (William E. Conway, Conway Quality Inc.)

   A. **Desire** to change
   B. **Belief** that change can be accomplished
   C. **Wherewithal** to change
   D. **Doing**

TECHNICAL EVALUATION

The Air Force Human Resources Laboratory, Wright-Patterson AFB (AFHRL) is involved in the development of future aerospace systems design techniques to reduce LCC (Life Cycle Costs) and increase supportability, this project is known as ULCE (Unified Life Cycle Engineering).

There are four primary components in ULCE;

1. **IDSS** (Integrated Design Support System)

2. **IMIS** (Integrated Maintenance Information System)

3. **RAMCAD** (Reliability and Maintainability through Computer Aided Design)

4. **CREW CHIEF** and **TARS** (Turnaround and Reconfiguration Simulation).

IDSS

The integration of dissimilar CAE/CAD/CAM and operational data sources on local and geographically distributed networks is the major problem faced in the development of ULCE. The development of the IDSS by the Air Force will provide a means to accomplish this integration. The goal of IDSS is to develop a computer software methodology for the acquisition, storage, retrieval and coordination of technical information between design engineering efforts and operational activities to support such developments as Operations and Maintenance Instructions (OMI), training programs, and operations problems analyses. The IDSS will provide for the reduction and duplication of data while also providing for the rapid distribution and increase in the quality of the data. (see Figure 3.)

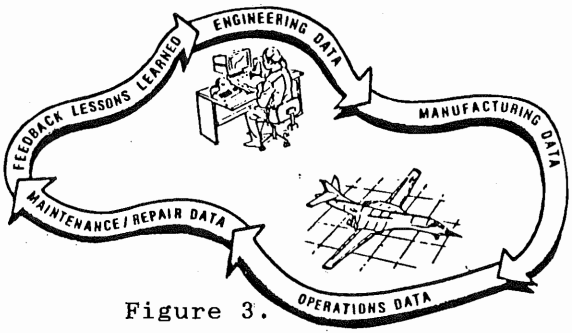

Figure 3.

The architecture of the IDSS is comprised of two main areas the Executive Control System (ECS) and the Data Acquisition System. (see Figure 4.)

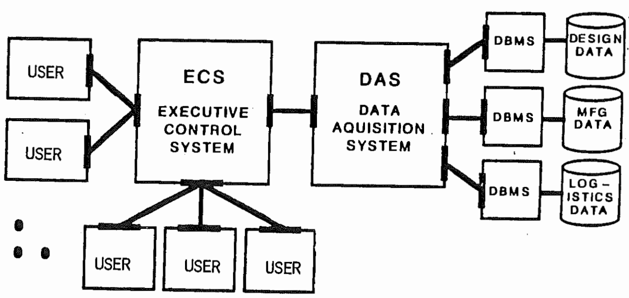

Figure 4.

The ECS will provide for:

1. User interface
2. Application software (e.g Data query,Data Edit, etc)
3. Data coordination and distribution
4. Configuration Control
5. Project Management
6. Data Security (i.e Data access control)

The DAS portion will provide for;

1. Heterogeneous H/W and S/W systems
2. Distributed Database Management
3. Network Communications Protocol
4. Data Integrity

IMIS

The modern operational environment is being increasingly inundated with additional information systems. Each new "operational aid" is an operations hindrance because it forces technicians to learn yet another "system". To utilize the valuable information that these new systems offer, while eliminating the specialization required for each, AFHRL is developing IMIS.

IMIS will utilize a very small portable computer/display to interface with on-board systems and ground computer systems to provide a single, integrated source of the information needed to perform required tasks on the line and in the shop. IMIS will consist of a workstation for use in the shop, a portable computer for flight line use, and a vehicle interface panel. (see Figure 5.)

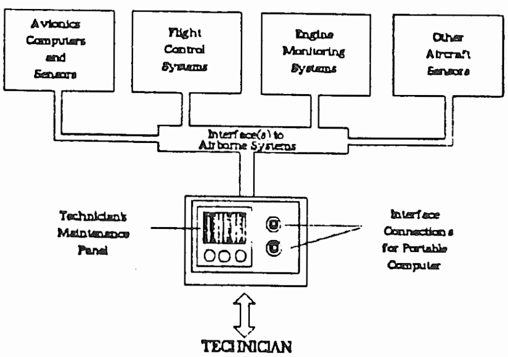

Figure 5.

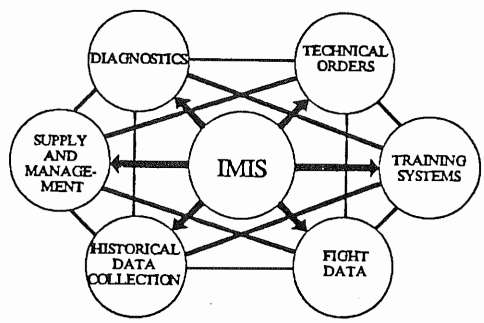

Figure 6.

The system will provide the technician with direct access to several information systems and databases compatable with IDSS. IMIS will process, integrate, and display maintenance information to the technician. The system will display graphic and/or technical instructions, provide intelligent diagnostic advice, analyze in-flight performance and failure data, and access and interrogate on-board built-in-test capabilities. It will assure that all of the Operational and Maintenance requirements are satisfied by directly interrogating the requirements database. (see Figure 6.)

It will also provide the technician with easy, efficient methods to receive work orders, report maintenance actions, order parts from supply, and computer-aided training lessons complete with a simulation capability.

RAMCAD

RAMCAD is a joint Air Force in-house and contractor study to develop an analysis model and database structure for assessing the location of line replaceable units (LRUs) within a vehicle with regard to failure rate of the components and accessability for maintenance actions. The goal is to develop an automated assessment model which will yield a quantitative index of the "goodness" of a given arrangement of LRUs within a housing.

CREW CHIEF and TARS

Crew Chief is a computer-based model of the technician which can be used to assist in the evaluation of equipment designs. The early design was based on the COMBIMAN model which was an earlier product of Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base. The Crew Chief model can be used to provide mockup-type evaluations of equipment on 3-D interactive graphic displays.

Crew Chief can be utilized to evaluate such maintenance operations as component testing, component removal and replacement, vehicle servicing and turnaround activities, engine removals, fuel and ordnance loading. The operations may be performed with the model wearing various types of clothing, such as warm weather, cold weather, and chemical defense gear(SCAPE). Exploded view enlargements of hand and arm activities to include manipulation of tools are included. It is also possible to evaluate human strength capabilities for various lifting and pulling tasks. (see Figure 7.)

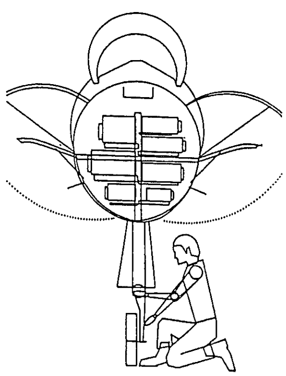

Figure 7.

TARS is a tool similar to Crew Chief except the emphasis is on the interaction of the entire operations team with the vehicle. Provisions are also made for placing the vehicle within a processing facility. This system will provide for the same level of detail as Crew Chief including 3-D interactive graphics while also allowing the designer to evaluate the operations team accessability to the vehicle, such as the process of engine removal, placement of work stands , positioning and access for robotics, payload bay reconfiguration, and assorted OMI development.

MANAGEMENT TECHNOLOGY

Without management acceptance,implementation and followup, no successful system can be installed. The discussion of new management technology is a topic deserving of a paper of its own. The topic is so important to the success of any project that it must be mentioned here in an attempt to convey its meaning.

The first two management steps **Desire** and **Belief**, of the four basic requirements to instill a change, represent about 80% of the effort required to accomplish a change. The aforementioned computer aided techniques are the **Wherewithal** to accomplish the change and will only be of use if the first two steps are completed. For example the Boeing Commercial Airplane Company is placing new management techniques "on-line" that will provide the means to accomplish the first two steps. Boeing believes this is necessary to survive in tomorrows marketplace.

Productivity improvement planning requires the same kind of systematic approach as financial planning. <u>Every manager from the highest level (i.e. Presidential and Congressional) down</u> must establish a plan to instill the **Desire** and **Belief** that change is required and possible, this must be a continuous process requiring frequent follow-up reinforcement.

The manager's greatest responsibility is to work on the system itself; this requires making changes in the ways in which work is performed at all levels of the project. These types of changes are usually highly effective at producing both increased quality and reduced costs. Experts in productivity improvement estimate that 80% or more of the opportunities for change are the result of management's improvement of the system to allow change. The workers accomplish the remaining 20%.

If a problem is shared among several groups, it is important for these groups to share the accountability for it and to work together to solve it. Design Build Teams (DBT) are an effective way to do this. The DBT has members from all of the effected functional areas; design engineering, manufacturing, materials, operations, etc. <u>All team members participate directly</u> in the design process, each assuring that the initial design meets all of the operational and performance requirements.

A quote from W. Edwards Demming (of Japanese industry fame) may be best to close this brief discussion of new management techniques;

> "Eliminate targets, slogans, pictures, posters for the work force, urging them to increase productivity, ...<u>What is needed is not exhortations but a road map to improvement, management's obligation.</u>"

Pressure to work harder or better does not achieve productivity improvement. Most workers already believe they are doing the best they can in the current enviroment. Evaluating them by the quality of their work places the entire responsibility for improvement on them alone.

Conclusion

Design for Performance has been the priority goal for new systems for decades. The result when supportability takes a back seat to performance is exemplified in the overwhelming Life Cycle Cost and schedule delays evident in the operation of the current Shuttle.

The Shuttle Ground Operations Efficiencies/Technologies Study, using data made available primarly as a result of the 51-L incident has been able to document a host of problems that are relatable to the lack of supportability considerations in the design of the Shuttle.

The current CAD design tools utilized are all related to performance with little or no consideration being given to reliability and maintainability requirements. The USAF has a major effort underway to improve supportability for new systems, by developing design tools to provide on-line analysis of supportability for a proposed design. These tools will include maintenance and reliability factors within CAD.

It is realized that improved design for support is not the only means to an end. Improved training of maintenance personnel, better job performance through new management techniques, and better automated maintenance aids and concepts will also contribute. However, improved design for support will make a significant contribution, and including reliability and maintainability factors in CAD will make a significant contribution to improving the design.

For the U.S. Space Program to thrive once again requires **drastic changes in management** and **technology innovation** to control Life Cycle Costs. Business as usual is **suicidal**.

Leadership that can instill the "desire and belief" to change is the key.

References

1. Askern, William B. Maintenance and Logistics Factors in Computer Aided Design Air Force Human Resources Laboratory, Wright-Patterson AFB. NASA RECON 84A16548.

2. Thomas A. Feaster. Shuttle Ground Operations Efficiencies/Technologies Study, Future Projects Office Kennedy Space Center.

3. Al Lowenstein & Greg Winter. VHDL's Impact on Test, IEEE Design & Test April 1986. NASA RECON 86A35709.

4. Fiscal Year 1985 Congressional Budget Cost Per Flight Operations Costs, Office of Management and Budget.