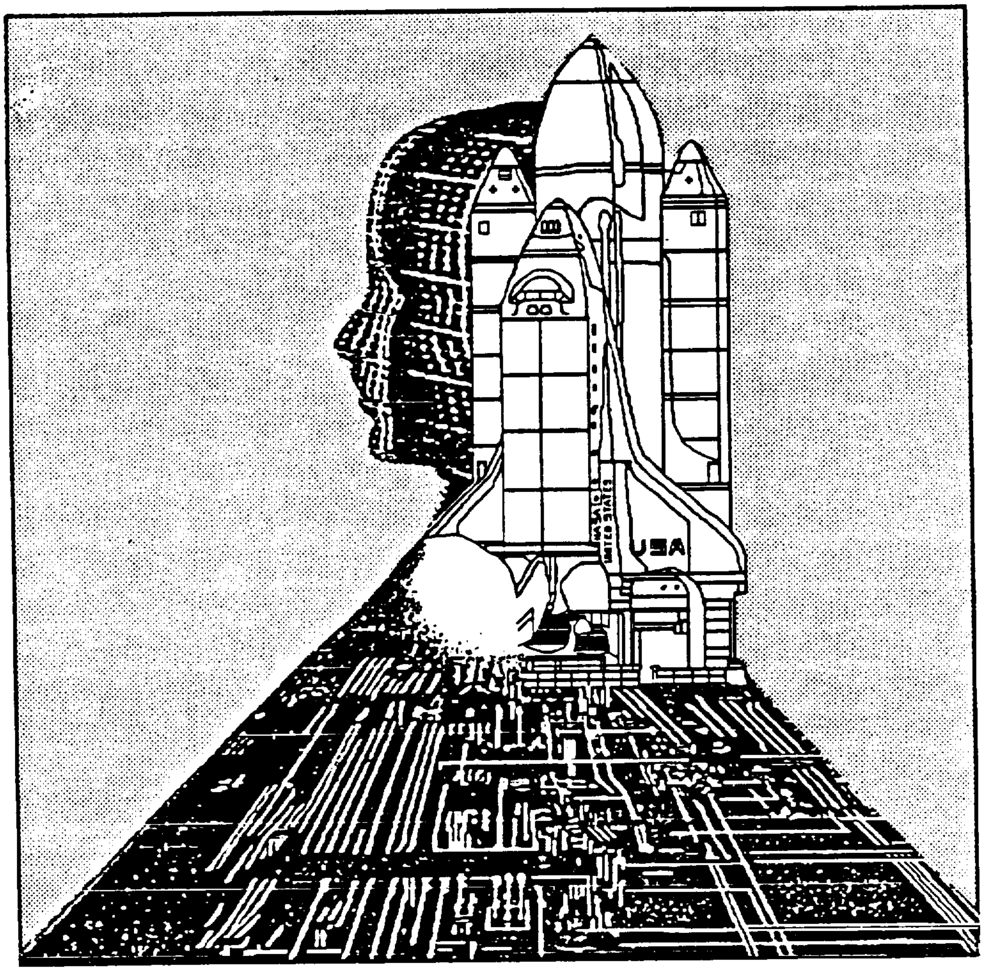
BOEING

Shuttle Ground Operations Efficiencies/Technologies Study

AEROSPACE OPERATIONS



EXECUTIVE SUMMARY

VOLUME 1 of 5

FINAL REPORT - Phase 1

KENNEDY SPACE CENTER

NAS10-11344

May 4, 1987

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SHUTTLE GROUND OPERATIONS EFFICIENCIES/TECHNOLOGIES STUDY

EXECUTIVE SUMMARY

FINAL REPORT - VOL 1
- PHASE 1 -

MAY 4, 1987

KENNEDY SPACE CENTER
NAS10-11344

BOEING

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SPACE SHUTTLE GROUND OPERATIONS EFFICIENCIES/TECHNOLOGIES STUDY
PHASE 1 FINAL REPORT

This executive summary of the Shuttle Ground Operations Efficiencies/Technologies Study provides a brief overview of the study.

Study Objectives

The objective of this study is to define methods and technology to reduce the overall operations cost of a major space program. Space Shuttle processing at KSC was designated as the working model that would be the source of the operational information used in the study. The study addresses methods of improving efficiency of ground operations and identifies new technology elements that could reduce cost. Study emphasis is on specific technology items and management approaches required to develop and support operationally efficient ground operations. Prime study results are to be: 1) recommendations on "how to achieve" more efficient operations; and, 2) identification of existing, or new technology that would make vehicle processing in both the current program and future programs more efficient; and therefore, less costly.

Overall Study Conclusions

MANAGEMENT ISSUES: A major issue stressed during the Study was the need to accept new management concepts and practices. The increasing demand by both NASA and DoD to drastically reduce the cost of operations can only be met if the designed and fabricated hardware, as delivered to the operational site, has had supportability and maintainability designed into it from the beginning of the conceptual study development.

Advanced management techniques are an essential part of the "new look" required for future vehicles. The use of Design/Build Teams and Build-to-Cost concepts, along with the use of new design tools like ULCE (Unified Life Cycle Engineering) systems, will be required if one is to stay in business.

It may require a change in mindset about what constitutes "good management" but cost figures for new programs are getting so huge that inefficiencies, of any nature, can no longer be tolerated. This subject is discussed in more detail in Sect. 1.4.12, Volume 2. The subject of ULCE and new management concepts was also presented in both the Final Phase 1 Oral presentation at KSC on April 3, 1987 and to the STAS (Space Transportation Architecture Study) contractors at IPR-5 (In-Progress Review) at MSFC on April 8, 1987 (see pages 111 through 149, Volume 3).

SHUTTLE: The ongoing Shuttle processing activities at KSC was used as a working model of existing ground processing management, techniques, and capabilities.

Analysis of the massive amount of ground processing related information; documented information and reports generated after the Challenger (51-L) loss; and management of those activities provided the basis for the conclusions reached during this Study. As shown in Vol 2, all issues and problems reviewed were determined to be related to either a "design" or a "management" cause.

There is no easy answer for streamlining Shuttle ground operations. The Shuttle was not designed for economical operations. Limiting front-end design costs resulted in the vehicle being a proof-of-concept vehicle where operational efficiency was not a mandatory design requirement. This is a fact that is generally conceded by most everyone at this time..

Analysis shows that major block modifications to make the three Orbiters operationally efficient does not appear to be cost effective. Selected mods to provide for operational efficiency improvements or for flight demonstration of "future vehicle systems" could be incorporated in parallel with mandatory safety mods.

Implementation of the IMIS (Integrated Maintenance Information System), a portion of the ULCE (Unified Life Cycle Engineering) system, should be considered as a viable candidate to improve the paperwork processing systems used to control Shuttle processing. While this system would require a significant up-front investment, the system would pay for itself in approximately four years at a flight rate of 10 flights per year. Profits, in the out-years, to future programs would be significant.

NEW VEHICLES: The operations and management lessons learned from the Shuttle Program, if used in conjunction with technology advances, can significantly reduce the operational portion of life cycle costs for new vehicles. Maximum use of these three elements (operational lessons, technology applications, and new management techniques) will be required to keep Program costs under control so that this Country can regaining the space leadership it once held.

A big step forward in that direction can be made by NASA requiring the use of the Unified Life Cycle Engineering (ULCE) system. It incorporates the DoD standard (MIL-STD-1840A) for data interchange. All major contractors will be working to this standard so it can easily be specified for future NASA contracts. Individual Centers must not be allowed to develop data interchange formats unique to a particular Center. Formats must provide for full data interchange with other NASA Centers, Air Force, or Contractors. Full use of ULCE in future programs can bring about a VERY large reduction in total life cycle costs; e.g., as shown in Cost Trade Summary, Sect. 1.6.3, Volume 2, to be approximately six percent of $28.6B for 100 Orbiter flights or $1.72B per vehicle. These recommendations have been presented in Midterm and Final Phase 1 Oral presentations to both NASA and DoD communities.

FACILITIES: While the subject of facilities was not addressed in Phase 1 of the Study, they provide a significant contribution to the "operational" portion of the overall life cycle costs for a program. Facilities are one of the significant "tools" provided to the workforce at the launch site.

Initial facility costs may be kept low by modifications to old facilities; however, any inefficiencies forced on the operators is not a "one time thing". It is repetitive in every flow for the entire life of the program so even a relatively small item can become large from an LCC standpoint. The Shuttle program, for example, has had to modify available facilities at KSC. Only recently has solid rocket booster processing been moved from the VAB so that those hazardous operating conditions do not have to be imposed on other VAB located operations. Many of the Shuttle workers remain in improvised office facilities (boxcars) located a considerable distance from the VAB. Workers located in close proximity to their work stations are happier and more productive than workers that have to "check in" at one location and then go some distance to get to their work station.

Facilities involved with the various operations at KSC are widely separated so any joint operations require that at least management personnel have to travel between facilities. Operationally efficient facilities, designed to provide the right support capabilities at the right location for the processing crews, must be provided if processing costs are to be lowered.

STUDY REPORT

Volume 1	Executive Summary
Volume 2	Ground Operations Evaluation
Volume 3	Final Presentation Material
Volume 4	Preliminary Issues Database (PIDB)
Volume 5	Technology Information Sheets (TIS)

Volume 1

The Executive Summary provides an overview of major elements of the Study, reviews the findings, and reflects development of recommendations resulting from the Study.

Volume 2

The Ground Operations Evaluation volume describes the breath and depth of various Study elements selected as a result of an operational analysis conducted early in the Study. Analysis techniques used for the evaluation are described in detail. Elements selected for further evaluation are identified, results of the analysis documented, and a follow-up course of action recommended. The background and rationale for developing recommendations for the current Shuttle or for future programs is presented.

Volume 3

The Final Presentation Material volume contains the final version of charts used in Phase 1 Oral Briefings at KSC on April 6, 1987, and at the STAS (Space Transportation Architecture Study) IPR-5 (In-Progress Review) held at MSFC on April 8, 1987.

Volume 4

The Preliminary Issues Database (PIDB) was assembled very early in the Study as one of the fundamental tools to be used throughout the Study. Data were acquired from a variety of sources and compiled in such a way that the data could be easily sorted in accordance with a number of different analytical objectives. The computerized database system significantly expedited sorting and flexibility as well as providing a user-friendly tool for the analyst. Volume 4 summarizes information contained in the PIDB and provides the reader with the capability to manually find items of interest. How that information was used in this Study is explained in greater detail in Volumes 2 and 3.

Volume 5

The Technology Information Sheets (TIS) volume was assembled in database format during Phase 1 of the Study. This document was designed to provide a repository for information pertaining to 144 major, OMI-controlled (Operations and Maintenance Instructions) operations in the OPF, VAB and PAD. It provides a way to accumulate, for each task, information about required crew sizes, operations task time duration, identification of where that time is considered serial or parallel, special GSE required, and identification of potential application of currently existing technology, or the need for the development of new technology items. Manhour data by OMI (procedure) is incomplete because the Shuttle Processing Contractor was not required to accummulate the data to that level of detail.

NOTE: Volumes 1 and 2 are being widely distributed. Volume 3 is a copy of presentation material already distributed and Volumes 4 and 5 are database material that will not be distributed unless requested. Copies of the report will be placed in libraries at NASA HQ., JSC, KSC, MSFC and

NASA RECON. Individual volume copies may be obtained by forwarding a request to W. J. Dickinson, KSC PT-FPO, (305) 867-2780.

Study Schedule

The schedule, presented in Figure 1 below, shows the activities conducted during the eleven month, Phase 1 study effort (June 1986 to May 1987) and how those various activities related to each other.

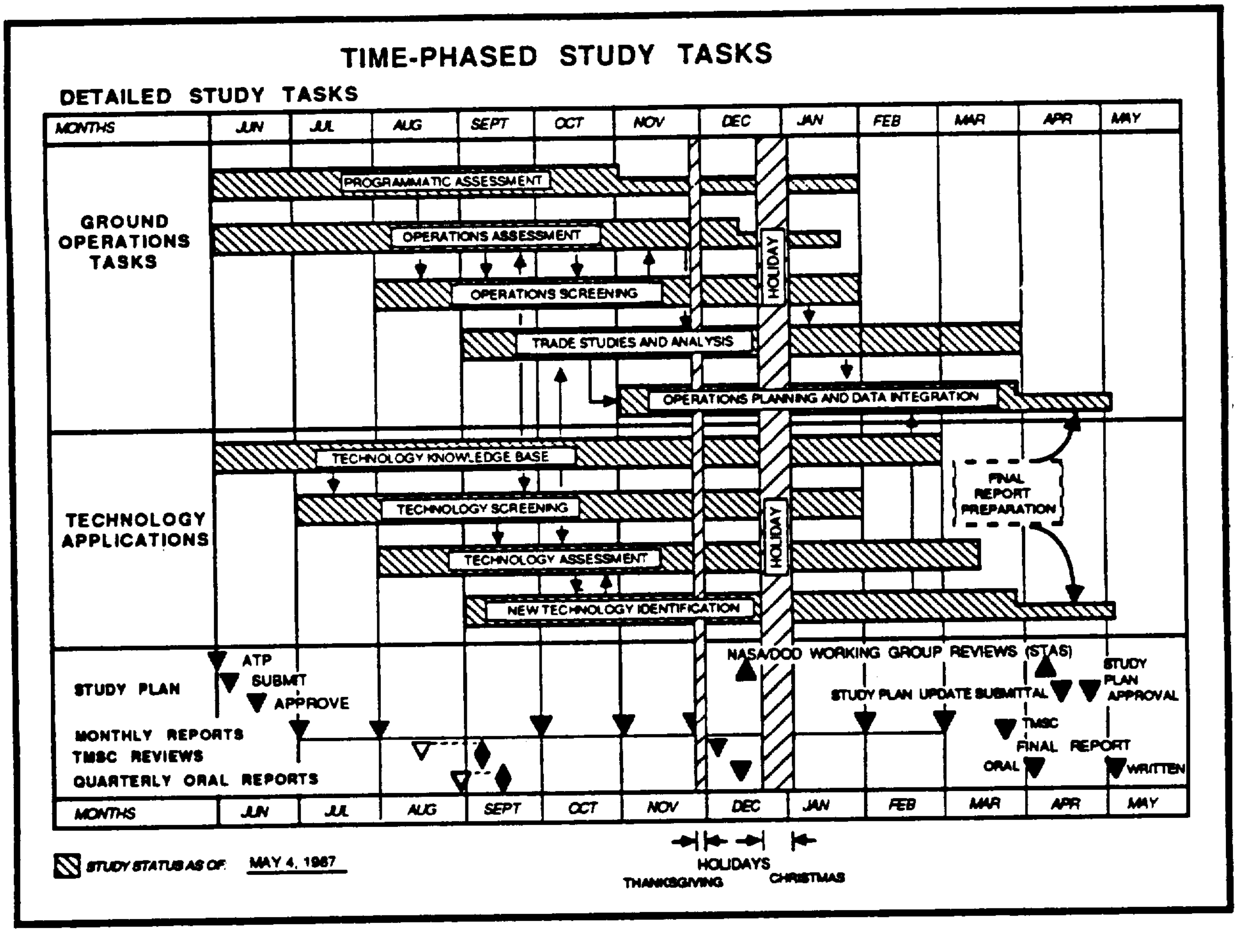

Figure 1

Study Flow

Study management techniques are pictorially described in Figure 2 on the next page. Initial activities of the study were to find a method to define the issues involved and develop a way to handle the vast amount of data to be reviewed.

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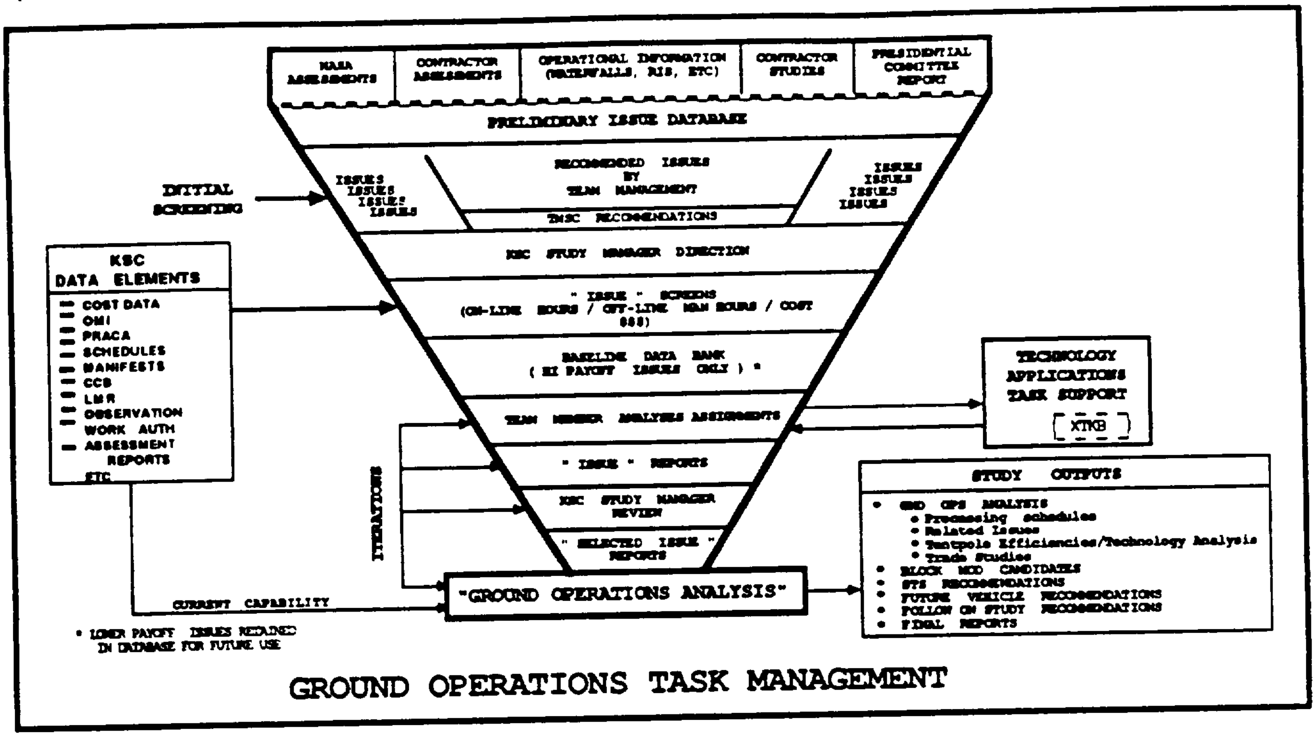

Figure 2

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Input data were taken from many sources including hardcopy review, electronic data transfer from other databases, survey trips, and interviews. A Technology Information Sheet (TIS) format was developed for orderly and standard extraction of data from the 144 major OMI's that control Shuttle operations in the OPF, the VAB, and the PAD. These data covered such items as required crew sizes, operations task timeline (serial or parallel), special equipment, and any hazards involved. The TIS data was assembled in database format to allow its use in conjunction with the PIDB (Preliminary Issues Database).

The PIDB was developed as a fundamental tool early in the study and used throughout the study. It was assembled from a wide variety of sources, see Figure 3 on the next page. The over 2000 issues collected in the PIDB were sorted into 40 topics. An analysis of these topics along with a detailed analysis of the current Shuttle processing flow, identified 12

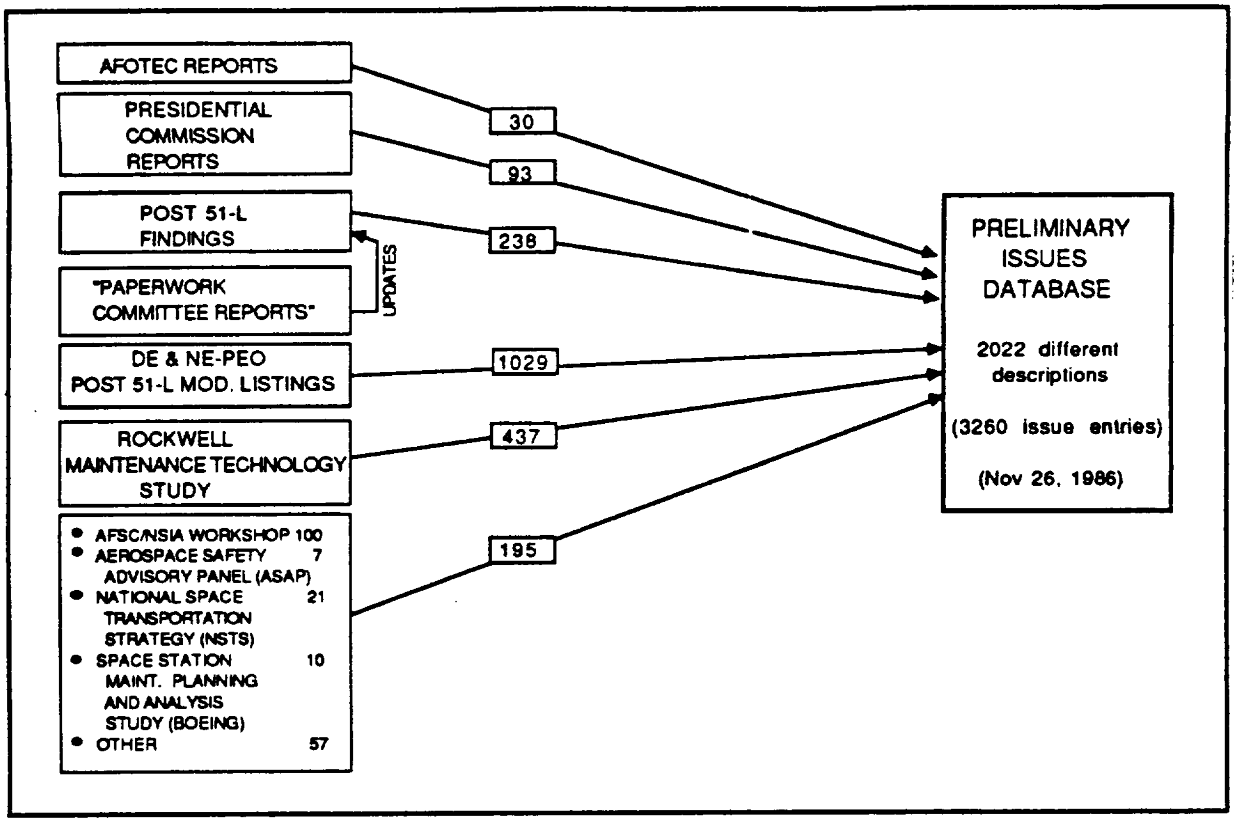

Figure 3

"tentpoles" (refer to Volume 2, Sect. 1.4.1 for details) that could be grouped into two categories: 1) timeline improvements, and, 2) technology applications. When all problems are studied, they can be assigned to one of three categories with different potential solutions:

1. A simple solution that can be accomplished within time and budget constraints, can be thought of as a short term " bandaid".
2. Solutions that require time and budget considerations are considered block changes or major surgery.
3. Solutions that cannot offer a payback within the remaining portion of the current program are categorized as Future Program Problem Avoidance.

All twelve tentpoles identified in the current program should be considered demonstrations of elements to be remembered as "lessons learned" and avoided in future programs. A summary of these tentpoles is shown in Figure 4 below.

	TENTPOLE	ISSUES: Design	Access.	Maintain.	Cost	SHIFTS ①	TECH MHRS ②③	ENGR/QA/ETC MHRS
TIMELINE IMPROVEMENTS	1. SSME Processing	X	X	X	X	47	3792	N/A
	2. AFD/PLB Reconfiguration	X	X		X	30	1680	↑
	3. Cabin Air Recirc.	X	X	X	X	12	384	
	4. Weight & CG	X			X	1	128	
	5. PayLoad Bay Cleaning	X			X	3.5	112	
TECHNOLOGY APPLICATIONS	A. Anomaly Resolution	X	X	X	X	48	964	
	B. WCCS Functional Checks	X	X	X	X	23	920	
	C. Window Polishing			X	X	24	384	
	D. TPS Inspection ④			X	X	7	632	
	E. Fuel Cell Operation	X		X	X	21.5	N/A	
	F. Ordnance Operations	X	X	X	X	N/A	N/A	↓
	G. Paperwork	X		X	X	N/A	N/A	N/A

① OTHER OPERATIONS MAY BE BEING WORKED IN PARALLEL ② DOES NOT INCLUDE TROUBLESHOOTING OR RETEST NOT ASSOCIATED WITH AN OMI ③ MANHOUR DATA NOT COMPLETE
SHORT-TERM BANDAID; BLOCK CHANGES; FUTURE PROGRAM PROBLEM AVOIDANCE ④ NOT VEHICLE DEPENDENT, DEPENDS ON GSE AVAILABILITY

Figure 4

The ATKB (Automation Technology Knowledge Base) was developed earlier, used on another study (Orbit Transfer Vehicle Launch Operations Study, Contract NAS10-11165), and brought to this study. The ATKB has been expanded during this study to form the XTKB (Expanded Automation Technology Knowledge Base), which provided a computer-aided technology search tool.

Several methods were used to search for solutions or fixes to issues identified by the Ground Operations Analysis. These methods included an extensive literature search utilizing the XTKB, interviews, and four technical survey trips. These trips were made to:

1. Boeing - Seattle
2. Human Resources Laboratory - Wright Patterson AFB
3. Rome Air Development Center
4. Naval Surface Weapons Center

These trips provided the most current information available on several topics directly applicable to the study:

- 7J7 Program Development Management concepts
- Non-Destructive Evaluation (NDE) technology
- Integrated Fault Tolerant Avionic Suite (IFTAS)- a layered architecture that provides for equipment changout without system shutdown
- 767/747 built-in-test (BIT) and its use in integrated testing
- Manipulative robotic systems
- Optical sensors and processors
- Life-cycle cost reduction through Unified Life-Cycle Engineering (ULCE)
- Automated anomoly resolution (fault detection, fault isolation and fault resolution)
- NiTiNOL development/application as a substitute for ordinance devices

All issues and analyses were iterated several times to identify high payoff items and to properly categorize recommendations. The operations and technology analysis were scheduled so adequate time could be spent on each issue and still have time to determine interdependence of issues. All operations analyses used at least four basic inputs: 1) original 14 day (160 hour) assumptions, 2) KSC operations schedule history, 3) KSC operations issues history, and 4) consultants. These inputs were analyzed to: a) identify technology needs, b) accomplish a technology search, c) develop technical definition, d) define technical feasibilty, and e) identify non-technical efficiencies. Trade studies were then made involving costs, schedule, weight, safety, etc. and appropriate recommendations made for the current or future space programs. <u>All</u> tentpoles are discussed in detail in Volume 2, Ground Operations Evaluation. For those of you interested only in a detailed "tentpole summary", see Section 1.4, Volume 2.

Findings

The operational analysis surfaced five tentpoles, see Figure 4, in the area of timeline improvements for Shuttle that required application of existing technology to implement. We have included these timeline improvments, not related to new technology, that need special management attention. Because this type of item has been vigorously pursued by both NASA and the Shuttle Processing Contractor since the Challenger accident (with literally hundreds of people participating), we directed our prime study effort to the identification of potential, new technology applications to provide additional efficiencies in vehicle processing..

The operations analysis developed seven "tentpoles" that are excellent candidates for new technology applications. These new technology requirements range from a new chemical coating for the Orbiter windows to a series of expert systems programs for anomaly resolution. The analysis has shown that a need exists for the implementation of program design and program management techniques that will support emphasis of design for maintainablilty/supportability.

A developmental program at WPAFB was found, using the XTKB, that deals with the methodology of "Unified Life Cycle Engineering" (ULCE). This program comes very close to having a computerized, all encompassing system that integrates design criteria, system design, software development, hardware manufacturing, QA, operations, logistics, and the other involved disciplines.

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While selected block modifications may provide some operational efficiencies to the current Shuttle Program, they do not appear to support major life cycle cost reductions because the cost of modifications and extended loss of flights outweigh net gains in the life cycle cost. If desired mods can be packaged with mandatory safety mods; or if early proof of some individual future vehicle system is desired, some processing efficiencies could result. For future programs the use of ULCE is an excellent program management and program design technique to control life cycle cost. The ULCE provided a multi-discipline management and design capability to get key, critical decisions early in the program and thus gain early control over life cycle costs. Figure 5, below, shows ULCE and its related components.

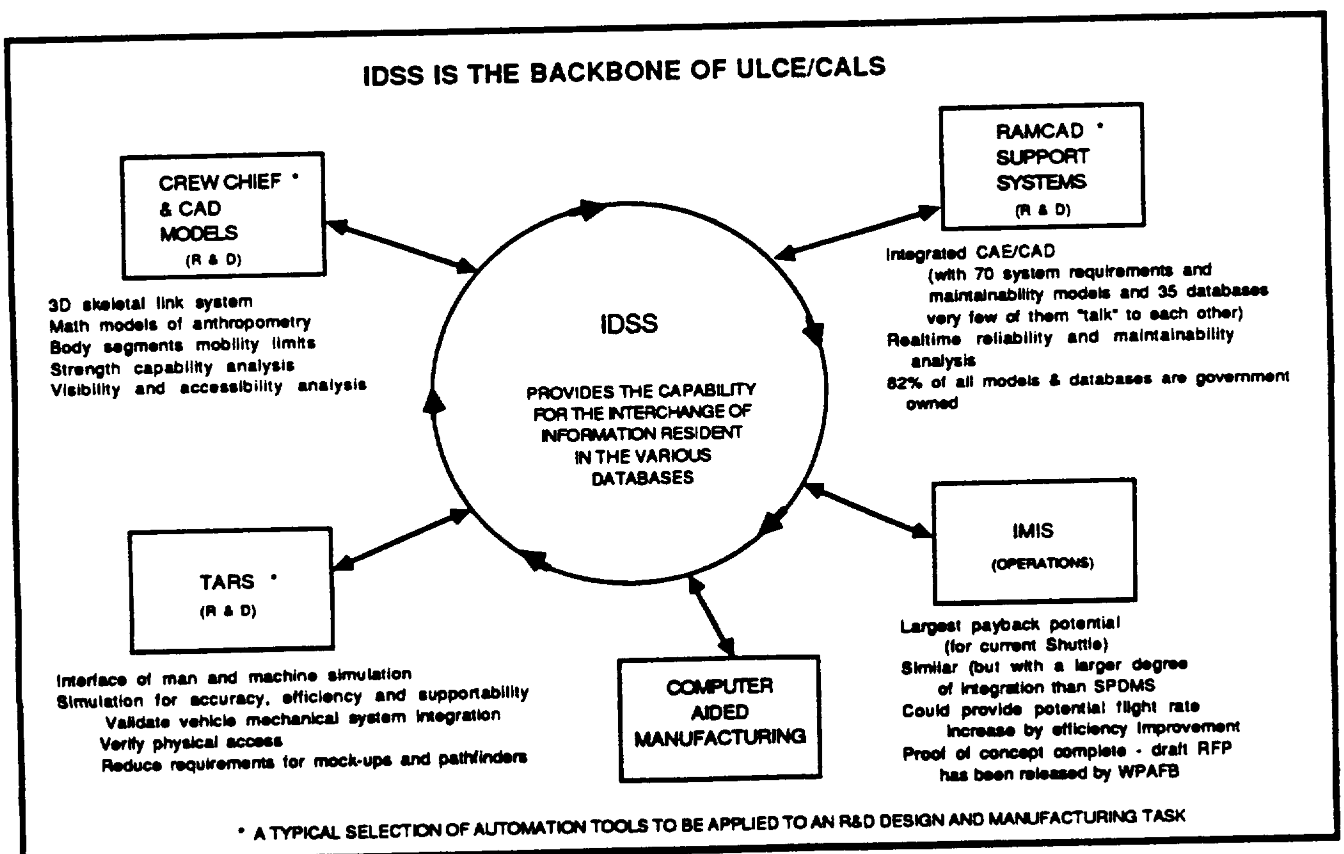

Figure 5

A program management and design technique identified during the study was the design/build team (DBT) concept, see Figure 6.

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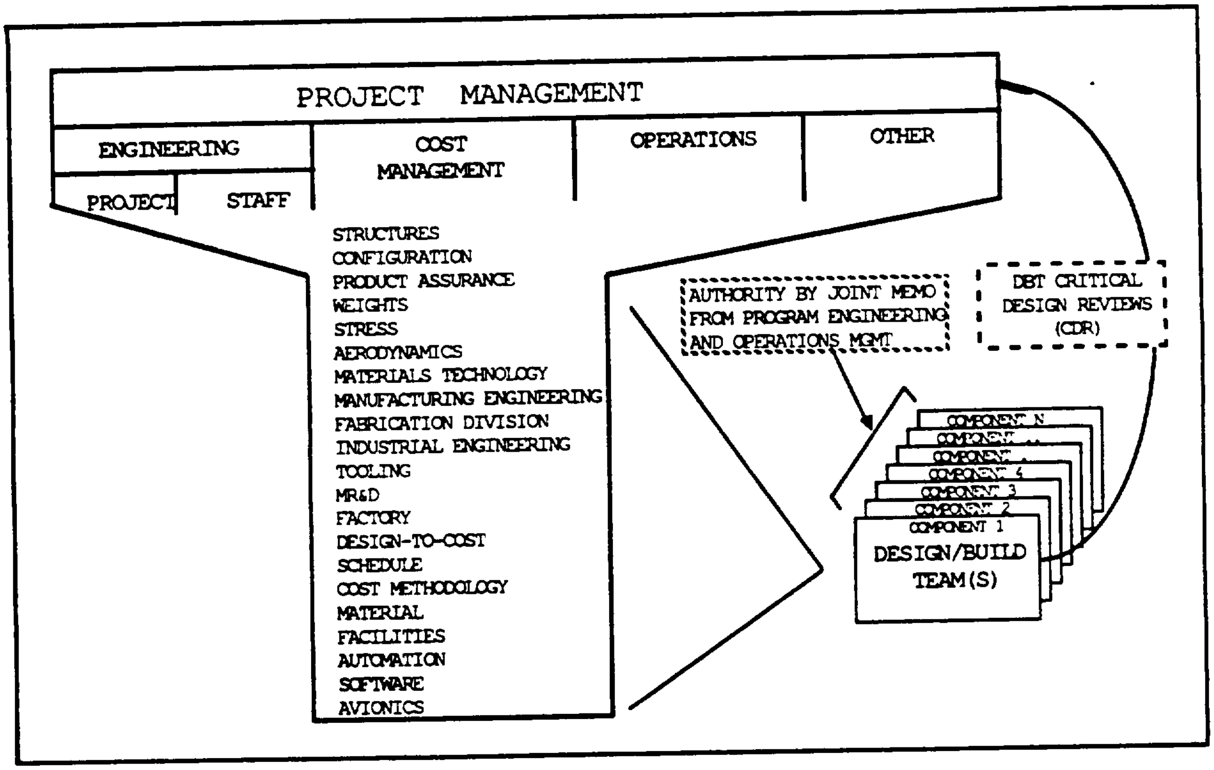

Figure 6

New management technology is required to achieve maximum effect from the new computer aided design tools. A new, participating management system is the hardest part to establish, but without it the new design/build team methods will not work. Under this concept Design/Build Teams report administratively to their line managers but are responsible to the DBT co-chairmen for their assigned product. The DBT has complete design responsibility, within the team, for their specific product assignment. The DBT co-chairmen conduct design reviews for project management concurrence and approval. This technique requires a large effort on the part of systems engineering to establish firm, operational performance and cost criteria down to the level required to define the DBT package, see Figure 7.

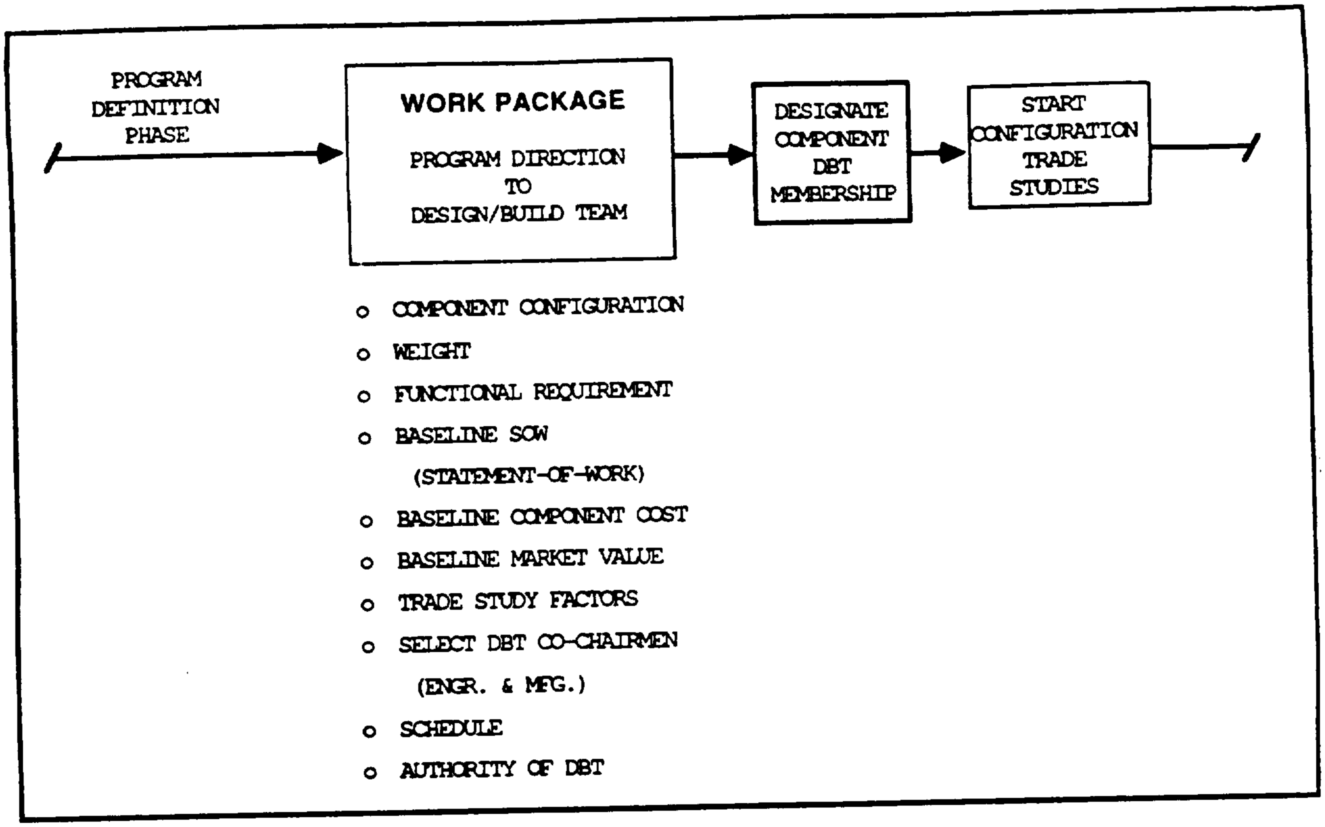

Figure 7

The DBT is given authority commensurate with responsibility and is directly responsible to develop the technical product while meeting performance, risk, and cost goals approved by the program manager. Figure 8, on the next page, compares old and new concepts.

The study also shows that life cycle costs (LCC) are significantly affected by the program definition and system design phase for the product. The current Shuttle design is such that operational costs are 86% of the LCC while DoD / commercial programs are experiencing 60% / 50% respectively for the operational portion of LCC. Future programs **must** use ULCE to acquire early control over LCC forecasts and thereby establish control of the resulting operational costs in the out-years of the program.

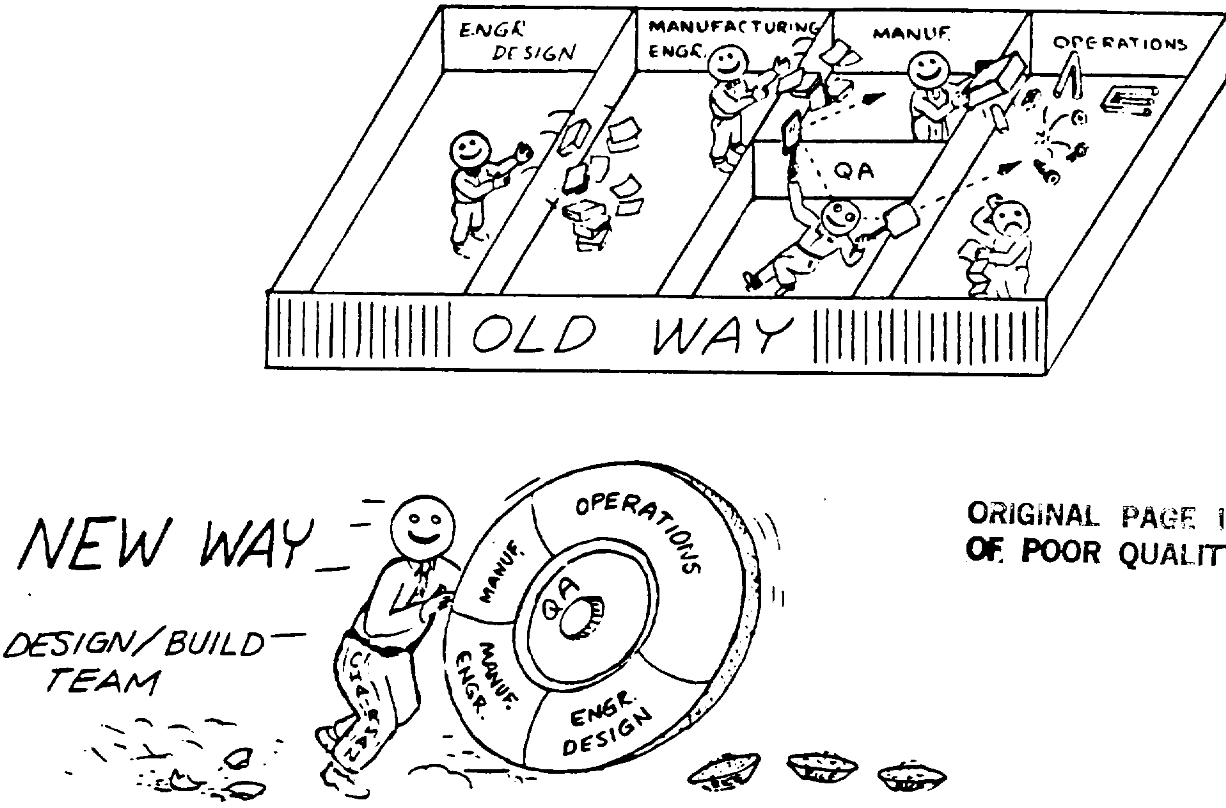

Figure 8

Report Distribution

Monthly Study reports and interim progress reviews developed during the study have been widely distributed. The Study distribution listing was, and is, a dynamic listing with changes made periodically to accommodate individual agency/contractor needs. This same distribution listing system will be used for Phase 2 of the Study. See Figure 9, on the next page, for the distribution listing at the end of Phase 1 of the Study.

SHUTTLE GROUND OPERATIONS EFFICIENCIES/TECHNOLOGIES STUDY

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Figure 9

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Report Documentation Page

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These additional benefits include items such as: a smaller chance for "human error" through automation, reduced number of people required for operations, smaller number of documentation changes, and an increase in test-to-test consistency. Document these findings and capabilities for use as guidelines for use on STAS and other future programs for both manned and unmanned vehicles.

16. Abstract Using the current STS as a working model: identify existing, or new technologies, changes to flight hardware, or changes to processing methodologies that would reduce the processing time and program manpower costs of space vehicle processing. Document methods of improving efficiency of ground operations and identify tehcnology elements that could reduce cost. Study emphasis is on:
1) Identification of specific technology items.
2) Management approaches required to develop, operate, support and control operationally efficient ground processing activities.
Prime study results are:
1) Identification of existing, or new technology that would make vehicle processing less costly. 2) Recommendations for the use of selected technology items in the current STS program. 3) Recommendations for the research and/or development of specific technology items for use on future programs to make their processing (and operation more efficient. 4) Identification of new management techniques necessary to achieve and control these more efficient operations.
Increased use of automation to provide current and more comprehensive managements reports, operational analysis support, evaluation of systems, conduct of operations and other ways to cut costs and provide additional benefits. *see 15

17. Key Words (Suggested by Author(s))
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