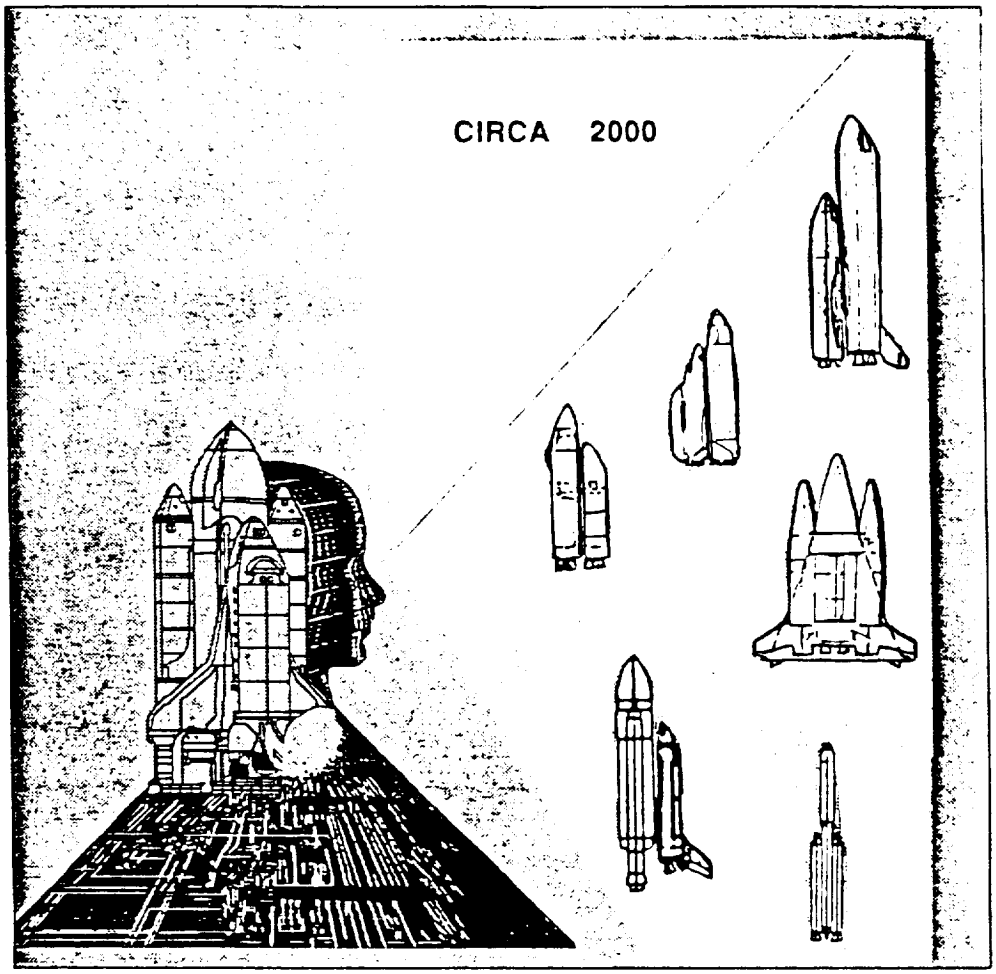
Shuttle Ground Operations Efficiencies/Technologies Study

BOEING

AEROSPACE OPERATIONS



FINAL REPORT PHASE 2
Volume 1 of 6

EXECUTIVE SUMMARY

W. J. Dickinson
KSC Study Manager
(407)867-2780

KENNEDY SPACE CENTER
NAS10-11344
May 5, 1988

A. L. Scholz
Boeing Study Manager
(407) 867-2334

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SPACE SHUTTLE GROUND OPERATIONS EFFICIENCIES/TECHNOLOGIES STUDY

PHASE 2 FINAL REPORT

This executive summary primarily covers Phase 2 of the Shuttle Ground Operations Efficiencies/Technologies Study. It briefly reviews Phase I activities and Phase 3 forecasts. The Phase 1 products were released in the Phase 1 Final Report (5 volumes) on May 4, 1987. A third phase is in the planning stage with completion scheduled for May 1989.

STUDY OBJECTIVES

PHASE 1 (30 May '86 -- 4 May '87)

Objective of Phase 1 was to define methods and technology to reduce overall operations cost of a major space program. Space Shuttle processing at KSC was designated as the working model source of operational information. The study addressed methods of improving efficiency of ground operations and identified new technology elements that could reduce cost. Study emphasis was on specific technology items and management approaches required to develop and support operationally efficient ground operations. Prime study results were: 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.

PHASE 2 (5 May '87 -- 4 May '88)

Objective of Phase 2 was to expand Phase 1 data and analyses, and apply those elements to the next generation of launch vehicles. Inclusive to that objective were: 1) identification of significant operations cost drivers or requirements that affect efficiency of ground support operations, 2) highlighting new and developing technologies that apply to subjects of the study, and 3) conceptual application of the technologies and cost drivers identified in the study to ALS program requirements, resulting in SLSOC (Simplified Launch Systems Operational Criteria) Operations Criteria.

PHASE 3 (scheduled completion 4 May '89)

Objective of Phase 3 is to apply the data developed and "lessons learned" during Phases 1 and 2. Application will consist of development and conduct of ground operations cost driver workshops for down-selected ALS contractors. Objective of the workshops s to make sure that down-selected ALS contractors understand the data available to them in SGOE/T databases to support their various trade studies and analyses. The workshops will review design concepts from operational cost driver aspects. Results of the workshops will be documented. Later, preliminary ALS designs will be critiqued from an operational cost driver viewpoint.

OVERALL STUDY CONCLUSIONS

PHASE 1

Conclusions of the Phase 1 study centered on management issues, shuttle operations analysis, technologies applications, new vehicles, and facilities. The following are paraphrased from those conclusions presented in the Phase 1 Executive Summary.

Management Issues - A major issue was the need to accept new management concepts and practices. In particular the need for up-front supportability and maintainability analyses was stressed. The use of design/build teams and Unified Life Cycle Engineering (ULCE) were cited as prominent examples of improved management.

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Shuttle - Processing activities were examined in some detail by the study. Related issues and problems were found to be caused by "design" or "management" deficiencies. Significant improvement in STS processing turn-around time requires major block modifications and would not be cost effective when lost launch opportunities and lower payload weight deliveries to orbit are taken into account. Specific tentpoles were identified and potential solutions described. Implementation of the Integrated Maintenance Information System (IMIS) segment of the ULCE system was noted as a viable candidate to improve the Shuttle paperwork processing system. This would not incur any flight hardware modification costs, but would require a significant upfront investment in an automated paperless system.

New Vehicles - Operations and management lessons learned from Shuttle, if used in conjunction with technology advances and system design simplification, can significantly reduce operational life cycle costs for new vehicles. A cost trade summary in the study showed full application of ULCE can reduce the LCC of a new 100-flight vehicle by 6% of Life Cycle Cycle.

Facilities - Initial facility costs may be kept low by modification of existing facilities and thereby influence basic vehicle configuration. However, inefficiencies can be forced on the operators, resulting in large, unexpected increases in LCC. Scattered facilities, operations, and personnel office/work locations were cited as serious contributors to operational inefficiency and increased LCC on Shuttle and other, earlier programs.

PHASE 2

Circa 2000 (C2K)

During this study phase, but prior to ALS redirection and our development of an unmanned, expendable system concept, a fully reusable vehicle concept was envisioned and assessed in a moderately detailed comparison with STS/KSC. This assessment, the Circa 2000 System (C2K), provided the foundation for later derivations. C2K and its LCC development from comparison with STS/KSC is included in Volume 6 of this Phase 2 report.

Figure 1 shows the four principal C2K areas of operations assessment:

Management and System Engineering
Test and Checkout
Orbital Access Vehicle
Launcher/Pad

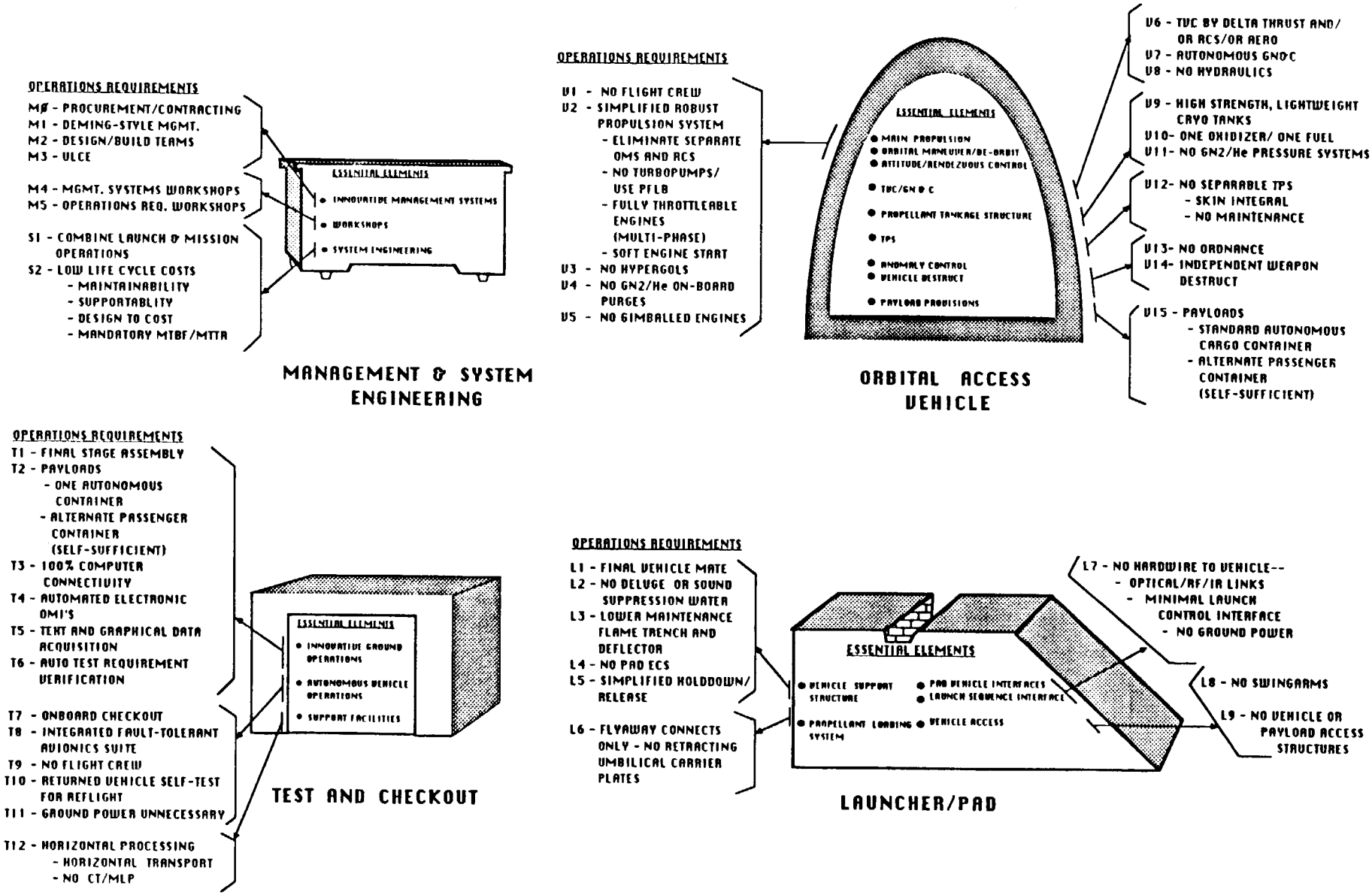
The alpha-numeric numbers refer to the initial Technology Checklists developed for the four principal operations areas noted above. They are also included in Volume 6.

Phase 2 conclusions relative to C2K are:

1. For a robust, reusable vehicle (booster and orbiter), reduction in flight systems quantities and complexities (with attendant reduction in GSO and facilities) produces exponential LCC reduction.

2. Cargo cost of $600/lb. to LEO (FY-85 $) appear possible with a launch rate of 24/yr. This cost is 11 percent of STS.

CIRCA 2000 SYSTEM
Executive Summary
Figure 1



Simplified Launch System Operational Criteria (SLSOC)

A conceptual expendable vehicle, perceived to meet available ALS criteria, was envisioned and assessed with the goal of identifying processing handicaps and inefficiencies. The concept was further assessed for design cost driver items which should be eliminated or greatly simplified from an operations viewpoint to approach the ALS desired payload cost-to-orbit of $300/lb. **Figure 2** shows the six major operational/design areas identified. Items targeted for elimination or simplification to effect a dramatic cost reduction compared to STS are also identified. The alpha-numeric numbers refer to a family of Operational Criteria pages in the Volume 4 of this Phase 2 Final Report that provide expanded details including:

Operational Requirement

Rationale

Sample Concept

Technology Requirement

Technology References (NASA/RECON database)

Figure 3 is a sample page from those Operational Criteria pages.

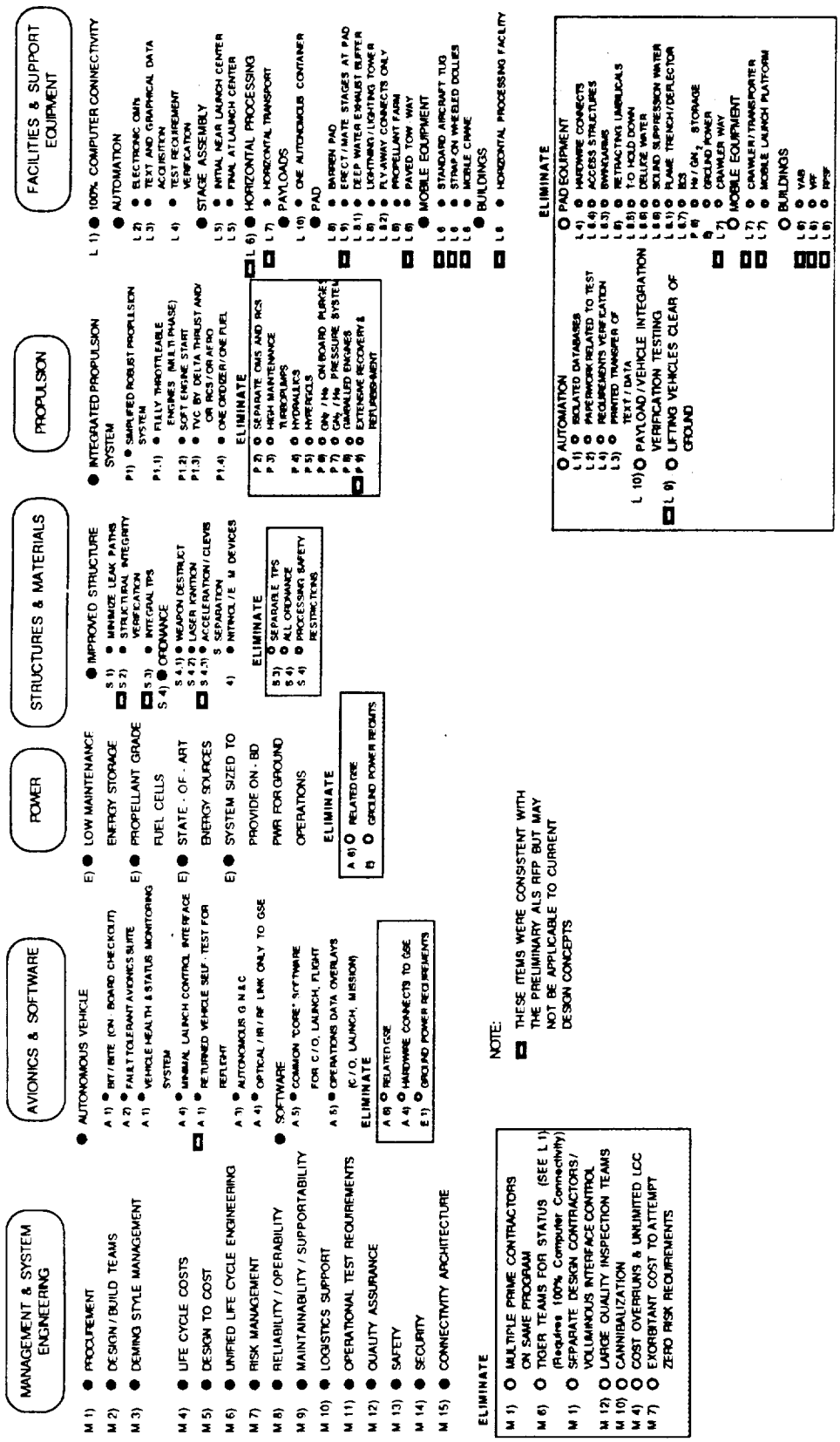
Phase 2 conclusions relative to the SLSOC are:

1. Simplified, expendable, unmanned vehicles of conventional technology, do not show promise of meeting $300/lb. LEO ALS goal even with highly simplified ground operations; $750 (in FY-86 dollars is more likely).

2. Expendable booster cost can equal a significant portion of total expendable flight hardware costs. An easily maintained reusable booster provides a way to reduce costs and approach the ALS goal.

3. Addition of a P/A module to an expendable core stage or use of a series of recoverable engine pods may reduce life cycle costs but will require additional launch site facilities and ground support operations.

SIMPLIFIED LAUNCH SYSTEM OPERATIONAL CRITERIA (SLSOC)
Executive Summary
Figure 2



OPERATIONAL CRITERIA EXAMPLE
Executive Summary
Figure 3

No.: M4 **Title:** Life Cycle Costs (LCC)

Operations Requirement:

Operations efficiency must be considered during concept development and design.

Rationale:

Operations requirements have been disregarded in the past because they are brought up too late in the design cycle to be implemented in a cost-effective manner.

FOR EXAMPLE (FY-85 STS OPERATIONS COSTS FOR 8 FLIGHTS):

SRB	$464.2M	FLIGHT OPS	$345.3M
ET	415.8M	ORBITER HDWRE	162.6M
LAUNCH OPS	347.5M	CREW EQUIP.	36.3M
PROPELLANTS	30.3M	SSME	51.6M
GSE	24.1M	CONTRACT ADMIN.	17.1M

SUBTOTAL $1894.8M

PLUS NETWORK SUPPORT	$ 20.4M
R & PM	274.2M
FY-85 TOTAL COST	$2189.4M (in '85 dollars for 8 flights)
	or $ 273.5M per flight

Minimizing upfront program costs multiplies Life Cycle Cost.

Sample Concept:

Do not sacrifice operational efficiency for vehicle performance. Build a truck - not a Ferrari.

Prepare thorough and realistic life cycle cost analysis for Congress. Emphasize Life Cycle Cost - not start-up costs.

Implement tools listed below.

Technology Requirement:

No new technology required, only further development and implementation of the proper concepts and tools:

DEMING MANAGEMENT AND QUALITY TECHNIQUE
ULCE (Unified Life Cycle Engineering)
DESIGN/BUILD TEAMS
MAINTAINABILITY
SUPPORTABILITY
DESIGN-TO-COST
MANDATORY MTBF/MTTR

Technology References:

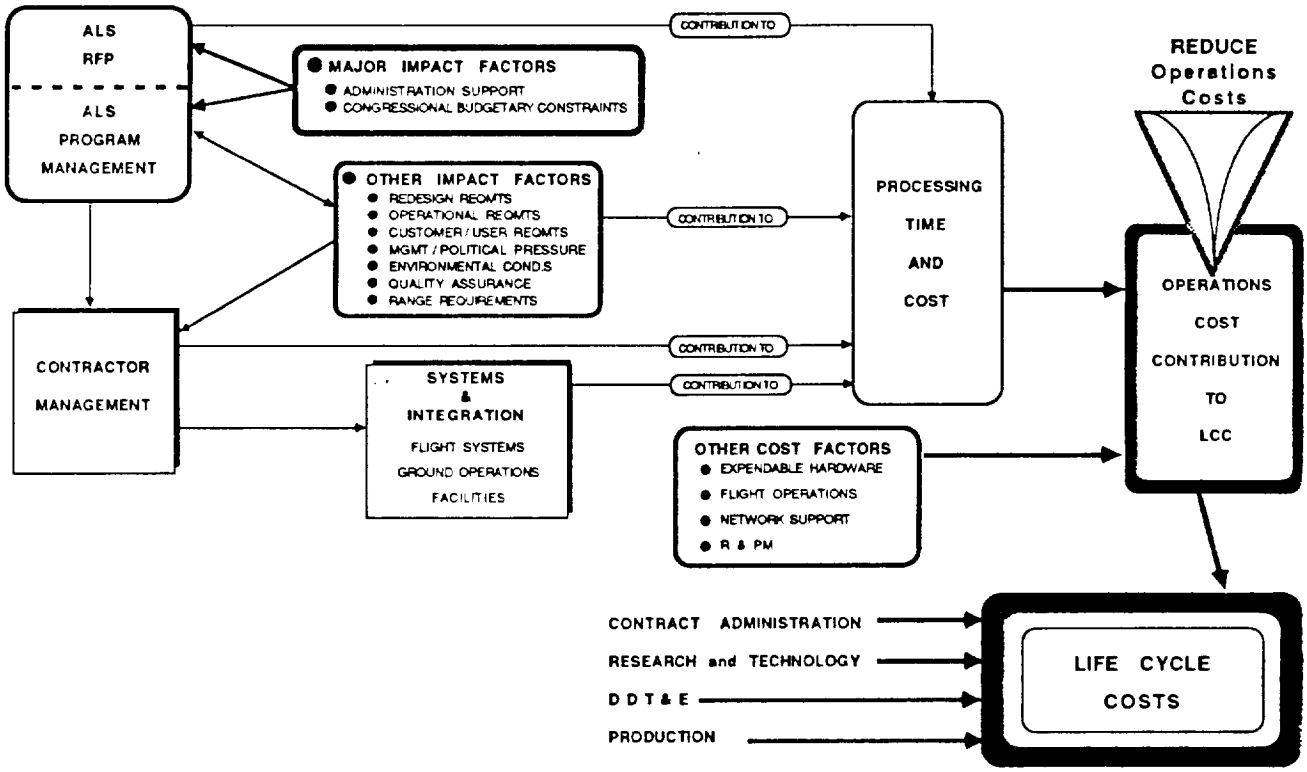
NASA/RECON (See Volume 5): 86X75319, 86N28011, 86A42678, 86A42618, 86A21872, 86A10929, 85A45150, 85N30966, 85A42678, 84X78919, 84N31062, 84N26962, 84N24495, 84N23330, 84A15212, 83A43748, 84A30608, 83A49578, 83A48334, 82A14787, 81N11907, 81A30295

Cost Contributors

Figure 4 shows major impacts and other factors affecting Life Cycle Costs. The following list presents "cost driver mindsets" that must be attacked and changed as a prerequisite to major LCC reduction.

- o PROJECT (OR ACCEPT) LOW FRONT-END PROGRAM COSTS TO SELL PROGRAM.
  (Require life cycle cost data be presented in initial proposals)
- o "NOT MY PROBLEM"
  (Design-build teams)
- o "FIRST THINGS FIRST"
  (Design-build teams/ULCE/multi-year funding)
- o REQUIREMENT FOR ARMY OF QUALITY INSPECTORS
  (Deming-type management)

COST CONTRIBUTORS
Executive Summary
Figure 4



Cost Contributors (Cont'd)

- o COST TRADES DONE AT LOWEST HARDWARE LEVELS (i.e. CIRCUITS)
  (Cost trades justification at concept level)

- o MAXIMUM ENGINE SPECIFIC IMPULSE
  (Robust engines)

- o RANGE SAFETY REQUIREMENTS AND HARDWARE ARE NOT NEGOTIABLE
  (Substitutes for vehicle ordnance)

- o CANNIBALIZATION IS AN ACCEPTABLE SUBSTITUTE FOR ADEQUATE SPARES FUNDING
  (Adequate spares provisioning from beginning)

- o ALL INCLUSIVE READINESS REVIEW MEETINGS REQUIRED TO EVALUATE PROGRESS
  (Disciplined automated review process)

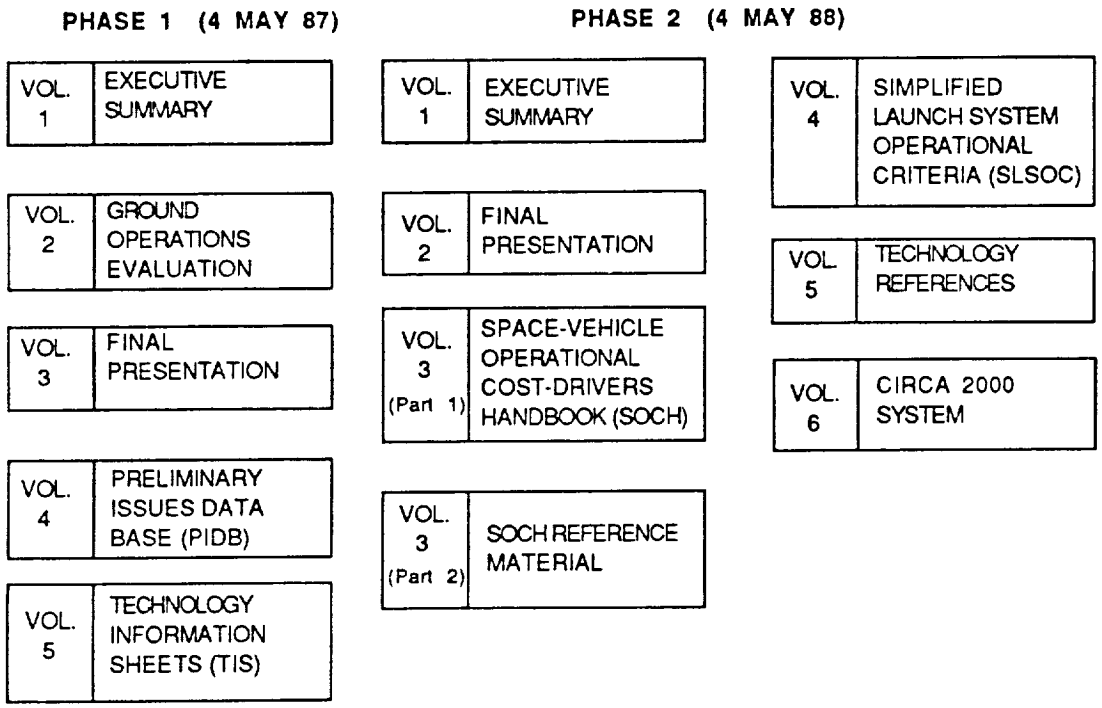
- o RESTRICTIVE LAUNCH SITE LABOR AGREEMENTS ARE INEVITABLE.
  (Negotiate strong cross-utilization agreements)
  (Standardize work time/break and paid holidays)

- o ABSOLUTE SAFETY REGARDLESS OF COSTS
  (Cost effective risk management thru adequate redundancy, robustness, comprehensive vehicle health monitoring.)

FINAL PHASE 2 SYNOPSIS

A diagram of the various study report documents for Phases 1 and 2 are shown in **Figure 5.**

SGOE/T STUDY DOCUMENTATION AVAILABLE
Executive Summary
Figure 5



The following is a brief synopsis of the contents of each of the Phase 2 products.

STUDY REPORT

Volume 1	Executive Summary
Volume 2	Final Presentation Material
Volume 3	Space-vehicle Operational Cost-drivers Handbook (SOCH)
	Part 1 Cost Driver Checklists
	Part 2 SOCH Reference Information
Volume 4	Simplified Launch System Operational Criteria (SLSOC)
Volume 5	Technology References
Volume 6	Circa 2000 System

Volume 1 EXECUTIVE SUMMARY

The Executive Summary provides an overview of major elements of the Study. It summarizes the Study analytic efforts, the documentation developed, and reviews the recommendations resulting from the analyses conducted during Phase 2 of the Study.

Volume 2 PHASE 2 FINAL ORAL PRESENTATION

The Final Presentation Material volume contains the charts used in the Final Oral Presentations for Phase 2, at KSC on April 6, 1988. A brief, overall review of the Study accomplishments is provided. An indepth review of the documentation developed during the last quarter of Phase 2 of the Study is presented. How that information was used in this Study is explained in greater detail in Vols. 3 and 4. An initial look at the topics planned for the upcoming Workshops for Government/Industry is presented along with a cursory look at the results expected from those Workshops.

Volume 3 SPACE-VEHICLE OPERATIONAL COST DRIVERS HANDBOOK (SOCH)

The Space-vehicle Operational Cost drivers Handbook (SOCH) was assembled early in Phase 2 of the Study as one of the fundamental tools to be used during the rest of the Phase. The document is made up of two parts -- packaged separately because of their size.

Part 1 Presents, in checklist format, the lessons learned from STS and other programs. The checklist items were compiled so that the information would be easily usable for a number of different analytical objectives, and then grouped by disciplines or gross organizational, and/or functional responsibilities. Content of the checklists range from 27 management; 11 system engineering; 8 technology; and 19 design topics -- with a total of 793 individual checklist items. Use of this Handbook to identify and reduce Cost Drivers is recommended for designers, Project and Program managers, HQ Staff, and Congressional Staffs.

Part 2 Contains a compilation of related reference information about a wide variety of subjects including ULCE, Deming, Design/Build Team concepts as well as current and previous space launch vehicle programs. Information has been accumulated from programs that range from, Saturn/Apollo, Delta, Titan, and STS to NASP and Energia.

Volume 4 SIMPLIFIED LAUNCH SYSTEM OPERATIONAL CRITERIA (SLSOC)

The SLSOC document was developed from the generic Circa 2000 System document, Vol. 6; is similar in content; and also indicates the manpower effect of the elimination of many STS-type cost drivers. The primary difference between the two documents is the elimination of all generic Circa 2000 requirements (and support) for manned-flight considerations for the ALS vehicle. The data content of the two documents, while similar in nature, was reorganized and renumbered for SLSOC so that it could be used as the basis for various panels and subpanels in an ALS Workshop.

PHASE 2 STUDY REPORT (Cont'd)

Historical data is the basis for the conclusion that incremental improvements of technology and methods cannot significantly improve LCC (by an order-of-magnitude) without major surgery. A system enabling the development of a radically simplified operational concept, reflected in SLSOC, was included so that proposed designs (and operations) could be compared to systems providing for simplicity -- rather than the current STS complexity.

The identified operational cost drivers from STS plus other historical data were used as background reference information in the development of each example concept designed to eliminate cost drivers. These example concepts, when integrated, would support an order-of-magnitude cost reduction in current (STS), exorbitant Life Cycle Costs (LCC). Individual operational requisites were developed for each element in the associated management systems, integration engineering, vehicle systems, and supporting facilities. These have associated rationale, sample concepts, identification of technology developments needed, and technology references to abstracts. The technology abstracts are provided in a separate volume, Vol. 5.

Technology changes almost daily, thus past trade studies may no longer be valid. In addition, old "trades" often used inaccurate estimates of "real" operational costs. Vehicle designs are compromises and have been performance oriented with operations methods/techniques based on those designs. It is the intent of our example concepts in the SLSOC to stimulate design teams to improve or replace conventional design approaches. Obviously, it is up to the responsible program design teams to provide design solutions to resolve operational cost drivers.

Volume 5 TECHNOLOGY REFERENCES

This document provides a repository for the Technology References for the SLSOC and the CIRCA 2000 System documents. The technology references, mostly from NASA RECON, are supplied to the reader to facilitate analysis on either the SLSOC or the CIRCA 2000 System documents. Some data references were also obtained via DIALOG. If more technical information is desired by an analyst, he must obtain the additional documentaiton thru his library or from some other appropriate source. The XTKB (EXpanded Technology Knowledge Base) provided a user-friendly tool for our analyses in identifying and obtaining the computerized database reference information contained in this document. Thousands of abstracts were screened to obtain the 300 plus citations pertinent to SLSOC in this Volume.

Volume 6 CIRCA 2000 SYSTEM OPERATIONAL REQUIREMENTS

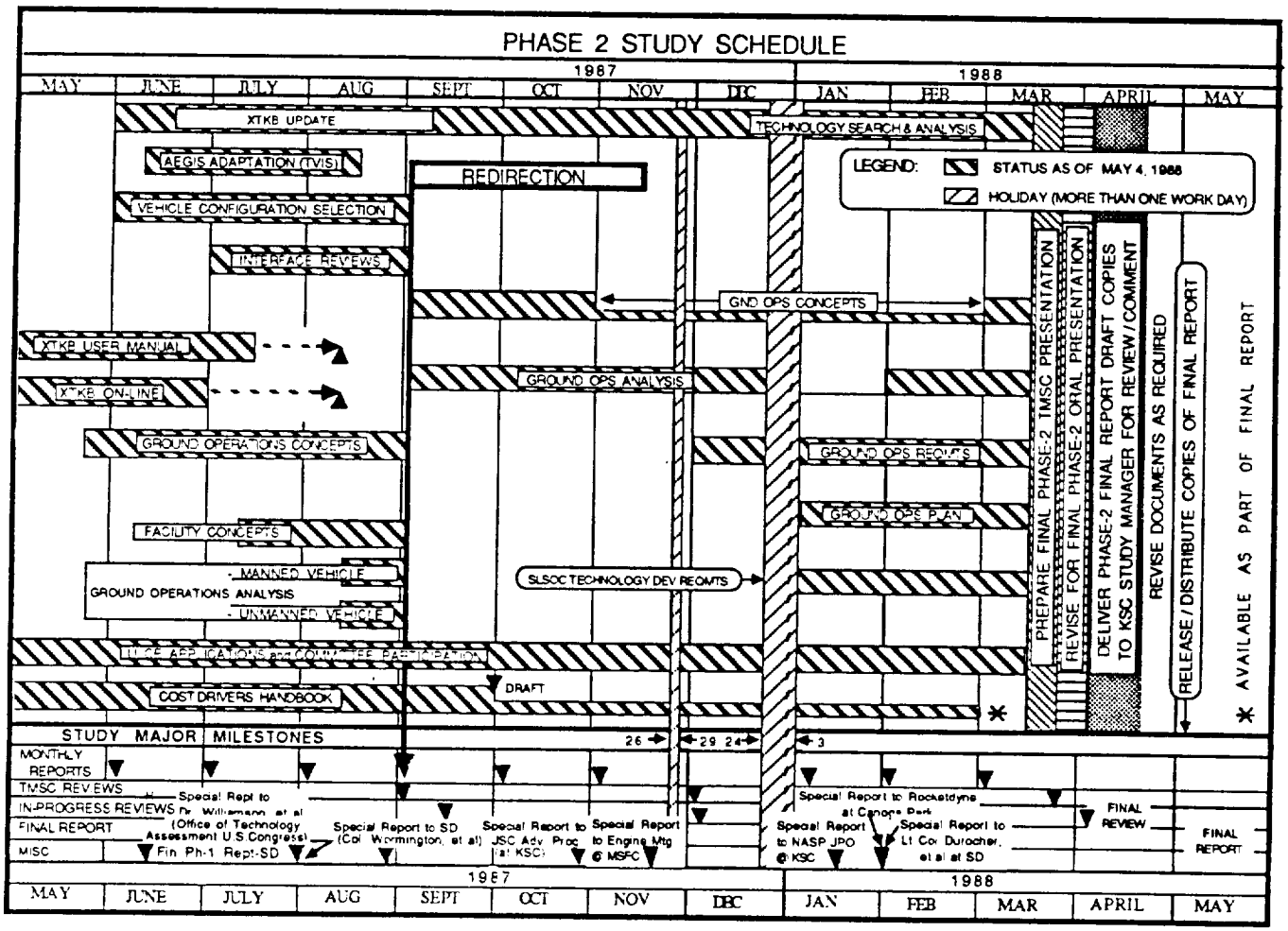
The Circa 2000 System Operations Requirements were developed using STS as a working data source. We identified generic operations cost drivers resulting from performance-oriented vehicle design compromises and the operations methods/techniques based on those designs. Those Cost Drivers include high-cost, hazardous, time & manpower-consuming problem areas involving vehicles, facilities, test & checkout, and management / system engineering. Operational requisites containing rationale, example concepts, identification of technology developments needed, and identification of technology references using available abstracts were developed for each Cost Driver identified. Elimination of cost drivers significantly reduces recurring costs for prelaunch processing and launch operations of space vehicles.

NOTE: Volumes 1,3,4 and 5 are being widely distributed. Volume 2 is a copy of presentation material already distributed and Volume 6 will be distributed only on request. Copies of the full 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.

PHASE 2 STUDY SCHEDULE

The Study Schedule, in **Figure 6,** shows the sequence of activities conducted during Phase 2.

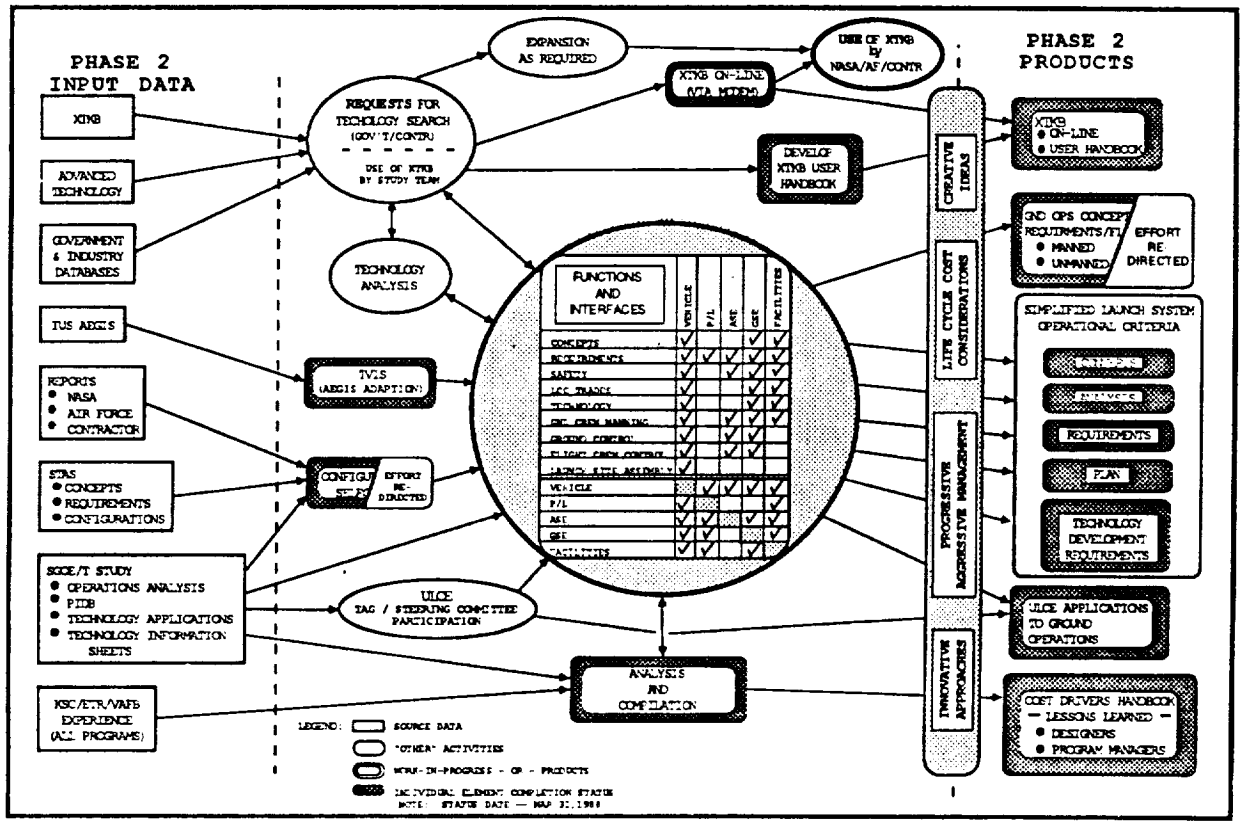
PHASE 2 STUDY SCHEDULE
Executive Summary
Figure 6



STUDY FLOW

The Study management approach to development of Phase 2 products is shown in Figure 7. A prime segment of Phase 2 efforts was based on the Phase 1 analysis of the STS/KSC ground operations. Tools were developed during Phase 1 to support Study analysis efforts.

SGOE/T STUDY, PHASE 2 FLOW
Executive Summary
Figure 7



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STUDY FLOW (Cont'd)

The assembly of tools for use by the various analysts shown in **Figure 8.** The study utilized several computerized databases for analysis support and portions of the study products produced.

OPERATIONS ANALYSIS FLOW
Executive Summary
Figure 8

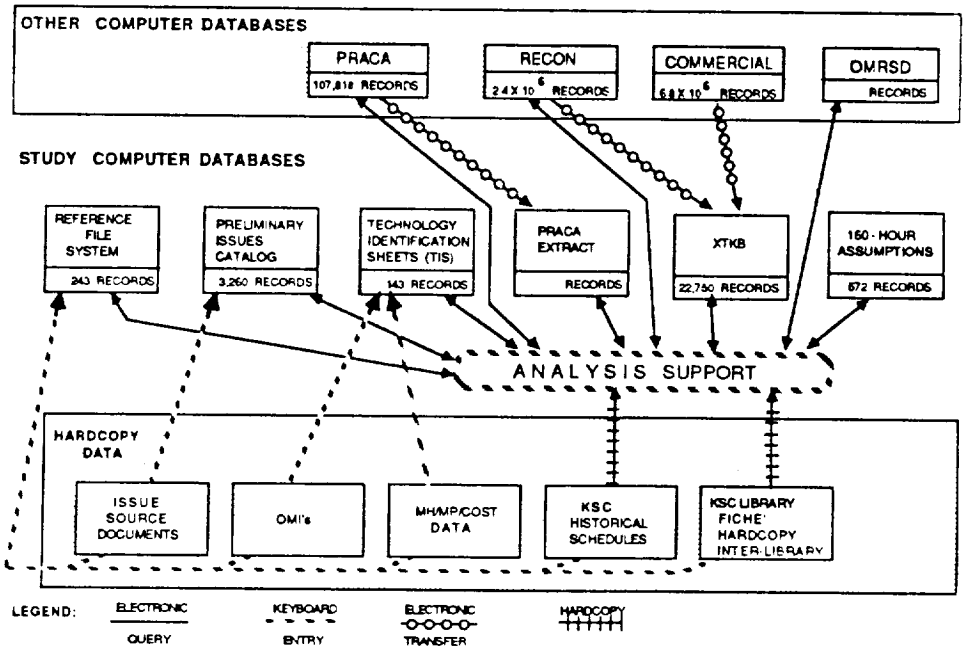
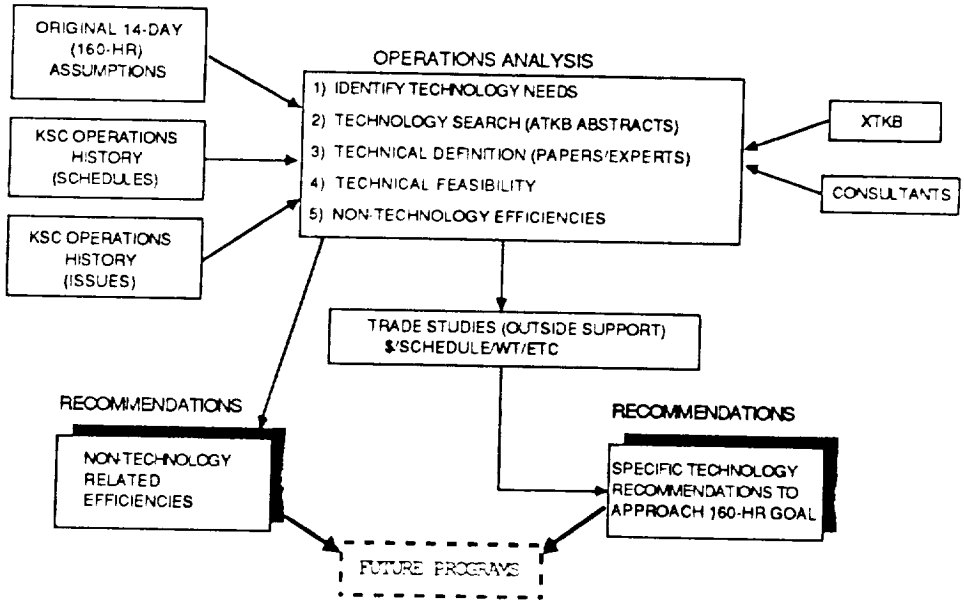


Figure 9 shows the identity and interaction of those databases used in development of the principal study products.

ANALYSIS SUPPORT
Executive Summary
Figure 9



TECHNOLOGY REQUIREMENTS SUMMARY

Development and application of numerous technologies (old and new) must be aggressively pursued to reduce ground operations life cycle costs. The following summarizes the related findings identified and addressed by this study.

Management and System Engineering

The technologies required in this area are available if their use is mandatated by upper management. There are several management methods available that will provide solutions for these problems. Many of the supporting technologies are established and readily available.

ENABLING METHODOLOGIES	STATUS
Design Build Teams	Commercially available
Deming-style Management	Commercially available
Risk Management	Commercially available

SOME RELATED SUPPORTING TECHNOLOGIES	
ULCE Sections	Some commercially available others in development
Computer Connectivity	Commercially available

Avionics and Software

The technologies required for solution of these problem areas are well established and are in current use by the majority of the airline and electronics manufacturers.

ENABLING TECHNOLOGIES	STATUS
Vehicle Health Monitoring System (VHMS) with BIT & BITE	Commercially available
Integrated Fault Tolerant Avionics Suite (IFTAS)	Proven, not commercially available
RF and Infrared Control	Commercially available
Distributed Architecture	Commercially available

Propulsion

The technology of rocket engines has been developing more complex combustion cycles, greater rotational speeds, higher pressures, higher temperatures and in general seem to be leading toward higher costs and even more difficult O&M. The technology to develop simpler and cheaper engines exists.

Propulsion (Cont'd)

ENABLING TECHNOLOGIES	STATUS
Soft start	Commercially available (RL-10)
Fully Throttleable	Commercially available (RL-10)
Elimination of High Maintenance Turbopumps	Proven, not commercially available
Multi-phase Engines	Beyond state-of-the-art

Facilities and Support Equipment

The quantity, complexity and operational manpower requirements for ground support facilities are driven entirely by basic vehicle configuration. The largest item not directly affected by vehicle configuration is the paperwork associated with ground operations. The technology associated with the reduction/elimination of paperwork is readily available.

ENABLING TECHNOLOGIES	STATUS
Computer Connectivity	Commercially available
Electronics Procedures	Commercially available
Text and Graphical Data Acquisition	State-of-the-art
Automated Requirements Verification	State-of-the-art

Power

The solutions are in work for improved on-board power sufficient to support all ground operations testing and flight operations. They are not yet available. To meet requirements for the next generation of vehicle will require accelerated development of high-capacity/high-density energy storage systems with emphasis on fuel cells and consideration of advanced batteries such as sodium/sulphur.

ENABLING TECHNOLOGIES	STATUS
Advanced Fuel Cells	In development but beyond current state-of-the-art
Sodium-sulphur Batteries	In development but beyond current state-of-the-art

Structures and Materials

The aerospace industry as a whole is rapidly developing the applications to solve many of the problems associated with structures and materials. Providing for improvements in the structural verification of recoverable vehicles, elimination of ordnance, and elimination of potential fuel/oxidizer leak paths are major areas of concern.

ENABLING TECHNOLOLGIES	STATUS
Strain and Corrosion Sensing Instruments	Commercially available
Laser Ignition Sources	Commercially available
Shape-Memory Alloys (Nitinol)	Commercially available
Leakproof Fittings (Nitinol Collars)	Commercially available
Independent Weapon Destruct	State-of-the-art

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. The same distribution listing system will be used for Phase 3 of the Study. See Figure 10 on the next page for the distribution listing at the end of Phase 2 of the Study.

SHUTTLE GROUND OPERATIONS EFFICIENCIES/TECHNOLOGIES STUDY
DISTRIBUTION LIST
Executive Summary, Figure 10

Aerospace Corp.		
P. Portanova		M5/558
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Boeing Aerospace Operations-Fla		
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K. K. Wagy		LSO-178
C. W. Floyd		LSO-178
G. Page		LSO-010
M. W. Edson		LSO-419
W. W. Brett		LSO-330
L. L. Yount		LSO-012
G. E. Artley		LSO-389
Martin Marietta		
Denver	J. Blackwell	G6802
	B. Zehnle	G6802
KSC	C. DiLoreto	MMC-30
	C. W. Case	MMC-G
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L. Moon		Conoga Park, CA
Teledyne Brown Engineering		
D. DeLong		Huntsville, AL
USBI Booster Production Company, Inc.		
H. P. Blanks		Huntsville, AL
J. H. Beardall		BPC-PI
Pratt & Whitney		
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P. Holloway	103A
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R. Schneider	B
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L. G. Meyer	CR
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SDIO-Washington, D. C.	
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Capt. G. S. Kirk	SS-LSO-AF
Fluor Daniel Co.	
G. Levin	Irvine, CA 4/11/88

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A/Scholz, A. L.; B/Hart, M. T.; C/Lowry, D. J.;
D/Byrd, R. J.

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16. Abstract

Phase 2 objectives to support the next generation of launch vehicles include: 1) identify significant operations cost drivers that affect efficiency of ground operations, 2) highlight new and developing technologies, and 3) conceptually apply identified technologies and cost drivers to ALS requirements; resulting in Simplified Launch System Operational Criteria (SLSOC).

Phase 2 applied SLSOC principals to a conceptual fully reusable vehicle (Circa 2000; C2K) developed from a moderately detailed comparison with STS/KSC. Areas of operations assessment included: 1) Management and System Engineering, 2) Test and Checkout, 3) Orbital Access Vehicle, and 4) Launcher/Pad.

Conclusions relative to C2K are: 1) for a reusable booster with orbiter, reduction in flight systems quantities and complexities (with attendant reduction in ground support operations, equipment and facilities) produces exponential LCC reductions, and 2) cargo cost of $600/lb to LEO (FY-85$) appear possible with a launch rate of 24/year. Cost is 11% of STS.

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