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DEVELOPMENT OF THE ENGINEERING DESIGN
INTEGRATION (EDIN) SYSTEM (A COMPUTER
AIDED DESIGN DEVELOPMENT EFFORT)
FINAL REPORT.

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Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Johnson Space Center
Houston, Texas 77058

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SYSTEM (A COMPUTER AIDED DESIGN DEVELOPMENT EFFORT)
FINAL REPORT

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C. R. Glatt and G. N. Hirsch - Sigma Corporation

SUMMARY

Sigma Corporation recently completed an one year contract with NASA/JSC to support the development of the EDIN (Engineering Design Integration) System and to provide manpower and resources to perform analysis, flow charting, coding, verification and documentation of the evolving system. The end product of the effort was a collection of hardware (GFE) and software, that enables the engineer to perform man-in-the-loop interactive evaluation of aerospace vehicle concepts. The study effort provided a set of upgraded engineering technology modules based on the earlier Level I EDIN System, and a set of requirements for NASA inhouse computer hardware to support the completion of the development of the EDIN capability at JSC. Study efforts were concentrated in the following areas:

1. Integration of new hardware with the Univac Exec 8 System.
2. Development of interactive software for the EDIN System.
3. Upgrading of the EDIN technology module (TM) library to an interactive status.
4. Verification of the soundness of the developing EDIN System.
5. Support of NASA in design analysis studies using the EDIN System.
6. Provide training and documentation in the use of the EDIN System.
7. Provide an implementation plan for the next phase of development and recommendations for meeting long range objectives.

All personnel assigned to the EDIN project maintained close liaison with NASA and other EDIN project personnel throughout the contract period. Nationally known experts in the field of computer aided design were consulted to assure a proper and successful EDIN development activity.

INTRODUCTION

A great deal of effort in the last several years has been expended in the pursuit of computer aided design capability. The extent has been to create a computational system that can be used effectively in the engineering design environment. These efforts have met varying degrees of success. References 1 through 12 describe a number of approaches to the problem. Most capabilities have been developed to support design synthesis for the study of vehicle concepts. They are usually implemented by one of two methods:

1. The vehicle under study is completely synthesized within a single computer program.
2. The vehicle under study is analyzed using separate technology modules which are linked by independent executive program control.

The use of the first method requires extensive computer programming and checkout before simulations can begin. The method is characterized by very large programs, limited applicability and complex data setup requirements. Programming bugs that appear after program checkout can cast doubt on simulation results. In addition, program modification required for design concept changes can cause delays in the engineering analysis process. In summary, the single program concept does not provide for a powerful computer aided design capability.

The use of the second method eliminates the need for large programming efforts allowing design simulations to begin almost immediately after a concept is formulated. Data setup is similar to the setup of the individual TM's. The executive program control concept effectively supports design simulations for conceptual studies involving a relatively small number of users. The concept does not provide the computer aided design environment necessary to support a large design staff nor does it permit sufficient user interaction with the analysis process.

Study efforts at JSC have resulted in the development of the EDIN (Engineering Design Integration) System. The system uses the independent TM concept of references 9 and 10. The Univac Exec 8 operating system provides the program linking capabilities and the file management software to drive the EDIN System. A data processor called DLG has been developed

for merging data base information with the normal input stream of the TM's and for storing technology data from the TM's in the data base. A geometry technology module, which also uses the EDIN data base concept, has been developed for the generation, maintenance and storage of geometry data. However, this function has been largely replaced by a series of geometry generation modules residing in the Univac and Adage computers. The stored geometry can be retrieved and used on either computer. Both two and three dimensional graphical analysis modules have been adapted for use in the EDIN System and a number of general and special purpose utilities have been developed to support design analysis. A summary of the EDIN software developed during the current contract period is shown in figure 1 and documented in references 13 through 33.

The EDIN System can be operated in a batch or demand mode. The system has interactive capability that can be employed for analysis and monitoring functions. A typical operating mode, illustrated in figure 2, is a combination of demand and batch modes of operation. The user of the system constructs an input stream from stored input data elements. The most current design information is obtained from the EDIN data base. A configuration analysis is performed using the GTM and auxiliary programs. The constructed input stream is submitted to the computer for execution and a graphical analysis follows. The user has the option of updating the data base and/or generating summary report information to support his analysis.

Objectives

The objectives of the study efforts were the continued development of the EDIN System, to provide Computer Aided Design (CAD) capability, which spans the engineering and management functions of the preliminary design process, and to provide the proper mix of computer software and hardware at Johnson Space Center (JSC) to significantly reduce the design time and improve the integrity of the design.

The hardware used to support the development of the EDIN System is illustrated in figure 3. The storage tube terminals, teletype compatible terminals and MOPS terminal shown on the left of the figure are currently used by the EDIN System. To support the JSC objectives for interactive CAD, the procurement (GFE) of a minicomputer based graphical display system (GDS) connected to the Univac host computer was required. The GDS minicomputer supports the geometry definition, input

AERODYNAMICS, STABILITY AND CONTROL

AIRFOIL: A Program for Generating Geometric and Aerodynamic Characteristics of Airfoil Sections.
DATCOM: Configuration Design Analysis Program (TRW).
DATCOM2: Configuration Design Analysis Program (MDAC).
HABACP: Hypersonic Arbitrary Body Aerodynamic Computer Program.

PROPULSION

CUSSER: Chrysler Upper Stage Sizing Program.
SIZER: Booster Rocket Sizing Program. .

MASS AND VOLUMETRIC PROPERTIES

ASPE: Weights Trend Analysis for Multiple Stage Vehicles.
CASPER: Reusable Booster/Orbiter Sizing.
CAWATA: Cost and Weight Analysis of Transport Aircraft.
ESPER: Weights Analysis for Shuttle Class Vehicle.
SSSP: Space Shuttle Synthesis Program.
VAMP: Volume, Area and Mass Properties using Harris Geometry.
WAATS: Weights Analysis for Advanced Transportation Systems.
TANK: A Program for Generating Fuel and Oxidizer Tank Design Characteristics such as Volume, Wall Thickness and Weight. Cornerpoint Geometry is Generated for Display Purposes.
SIZER: A Preliminary Booster Sizing Program Based upon Ideal Velocity and Mass Ratio Relationships. .
WAB: A Program that Computes Volume, Area and Mass Properties from any Combination of Gentry Geometry and Black Box Inputs.

FIGURE 1-A EDIN PROGRAM LIBRARY.
TECHNOLOGY MODULES.

PERFORMANCE

POST: Program for Rapid Earth-to-Space Trajectory Optimization.

ROBOT: Three-Degree-of-Freedom Launch Optimization Program.

VSAC: Vehicle Synthesis for High Speed Aircraft.

STRUCTURE

LOADS: Booster Loads Program.

APAS: Automated Procedure for Structural Sizing.

COSTS

DAPCA: Development and Production Cost of Aircraft.

PRICE: A Program for Improved Cost Estimation.

FIGURE 1-B EDIN PROGRAM LIBRARY.
TECHNOLOGY MODULES (Continued).

SPECIAL PURPOSE UTILITIES

- GTM: Geometry Technology Module for Generation, Manipulation and Display of Cornerpoint Geometry.
- PANEL: A Program for Generating Panelled Configuration Geometry.
- IMAGE: A Program for Displaying Three Dimensional Geometric Configuration on Tektronix, CALCOMP, SD4060, MOPS, etc. This Program Can Perform Rotations, Translations and Zooming.
- SFIT: A Surface Fitting Program which Generates Surfaces over Cross Sectional Definitions. The Surfaces Generated are Defined by Cornerpoint Geometry.
- GTM2: Collection of Component Geometry Generators.
- AIRCFT: Program to Generate Aircraft Type Configuration Geometry.
- AIRFOIL: A Program for Generating Geometric and Aerodynamic Characteristics of Airfoil Sections.

GENERAL PURPOSE UTILITIES

- PLOTTR: A General Purpose Plotter Program which Outputs to Tektronix, CALCOMP, SD4060, MOPS.
- AESOP: Automated Engineering and Scientific Optimization Program.
- DLG: Data Processor for Linking Independent Computer Programs and Providing Data Intercommunication.
- HDG: Heading Program.

FIGURE 1-C EDIN PROGRAM LIBRARY.
UTILITIES.

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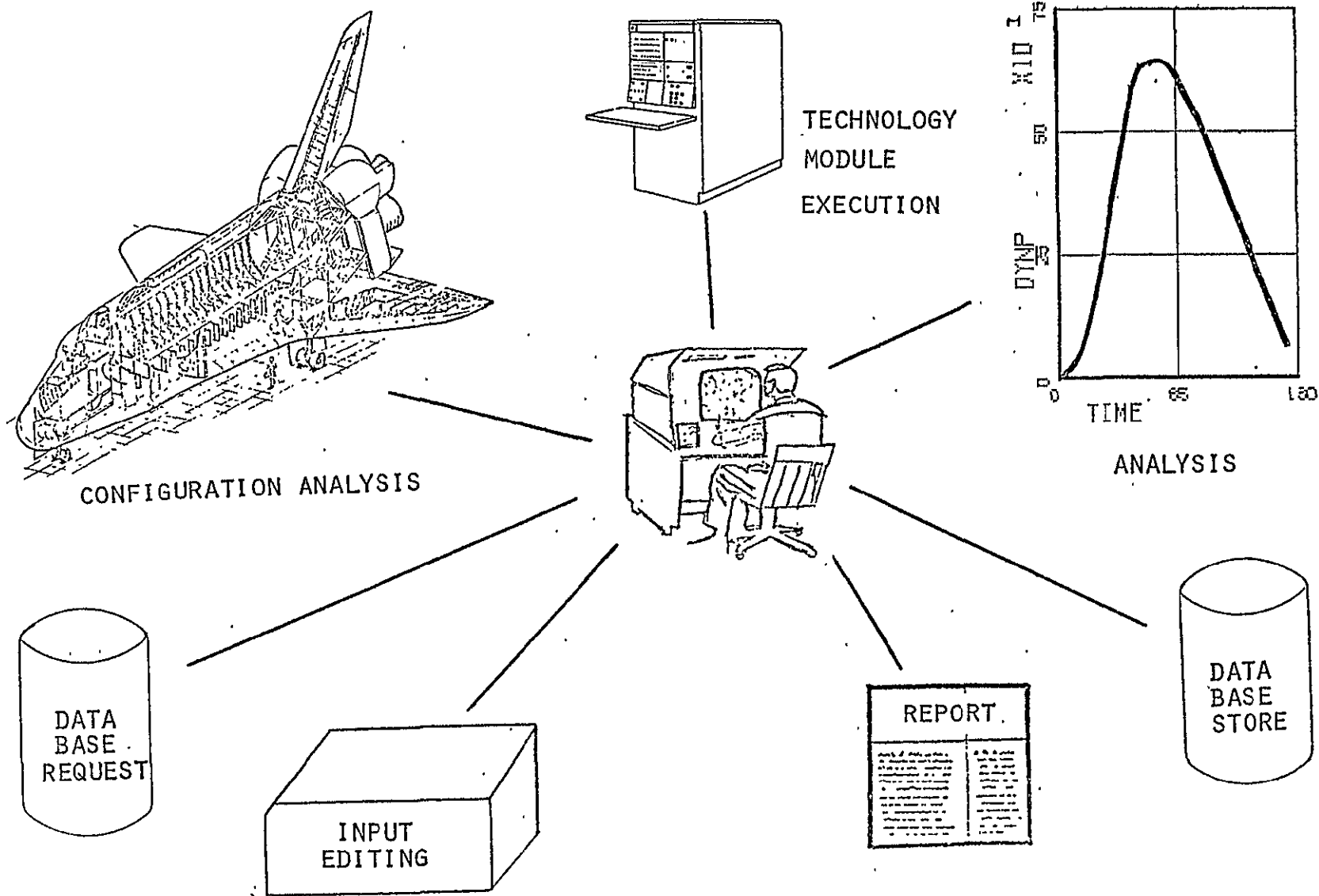


FIGURE 2

TYPICAL EDIN OPERATING MODE.

EDIN WORKROOM HARDWARE.

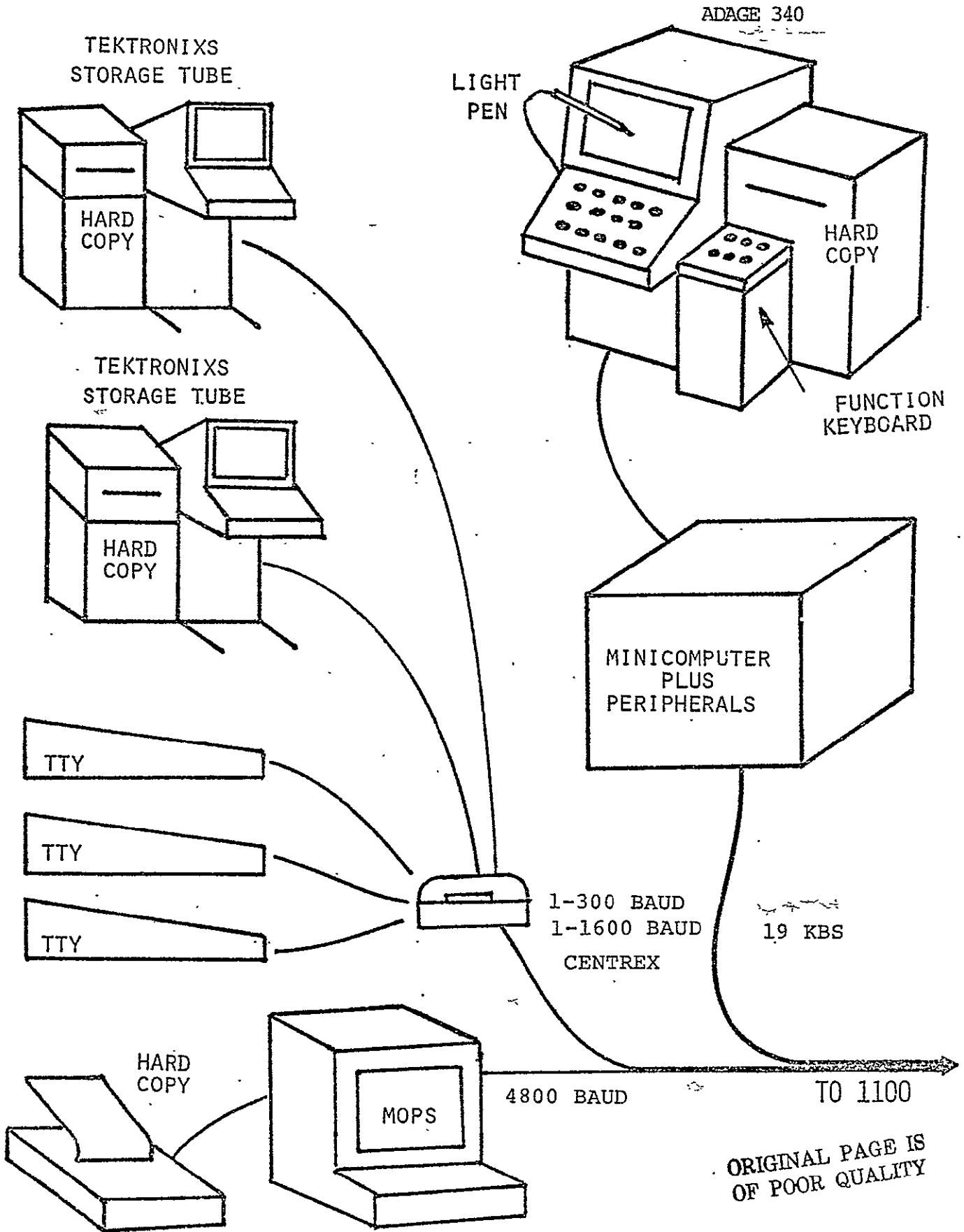


FIGURE 3 EDIN PERIPHERAL HARDWARE.

editing and engineering analysis functions and provides the interaction with the large scale TM's executing on the host computer.

Study Approach

User acceptance is a key element in the successful development of the EDIN System. Therefore, the study approach placed an equal weight on the application of the developing system and development of the system. The overall study approach is illustrated in figure 4. The NASA technical monitor would impose study requirements on the EDIN project. These requirements were used by the EDIN project to perform the required design analysis. The project members would define specific program development requirements using the technical proposal as a guideline. The defined requirements would then be used to launch a program development phase aimed at the modification or development of software that more adequately supports the original design analysis. Following the program development phase, the same or similar design analysis would be performed using the newly developed software. The sequence was repeated for each set of NASA directed study requirements.

The above study approach is considered to produce the best possible end product for the funds expended. This report presents the Sigma Corporation technical assessment of the study activities of Contract NAS9-14520.

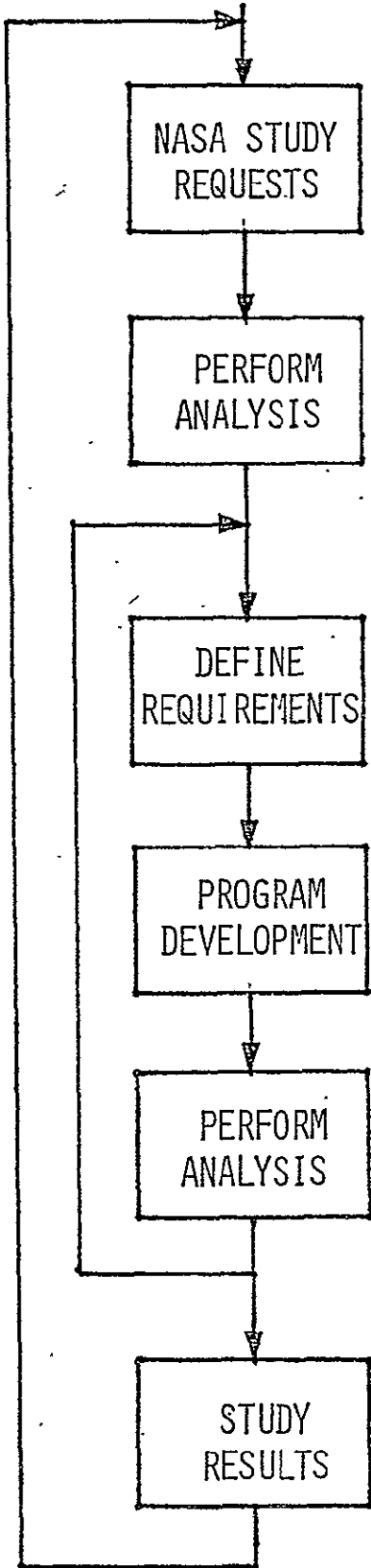
SCOPE

The program schedule in figure 5 was pursued in providing the necessary manpower and resources to perform analysis, flow charting, coding and checkout required to verify the soundness of the EDIN modifications and extensions.

General

Sigma Corporation supported the tasks illustrated in figure 5 with the necessary resources to design, modify and extend the existing EDIN System by supporting the contract monitor in the procurement of hardware and the acquisition, modification, design and development of the necessary software to provide an extended CAD system at Johnson Space Center.

In addition to the tasks outlined, Sigma Corporation participated in NASA chaired formal contract reviews at JSC. Sigma Corporation prepared and made available to the attendees all



NASA IMPOSES STUDY REQUIREMENTS ON EDIN SYSTEM.

EDIN PROJECT PERFORMS DESIGN ANALYSIS.

EDIN PROJECTS DEFINE PROGRAM DEVELOPMENT REQUIREMENTS.

PROGRAM DEVELOPMENT PHASE.

PERFORM ANALYSIS WITH NEWLY DEVELOPED SOFTWARE.

PUBLISH STUDY RESULTS.

FIGURE 4

STUDY APPROACH.

1976 MONTHS

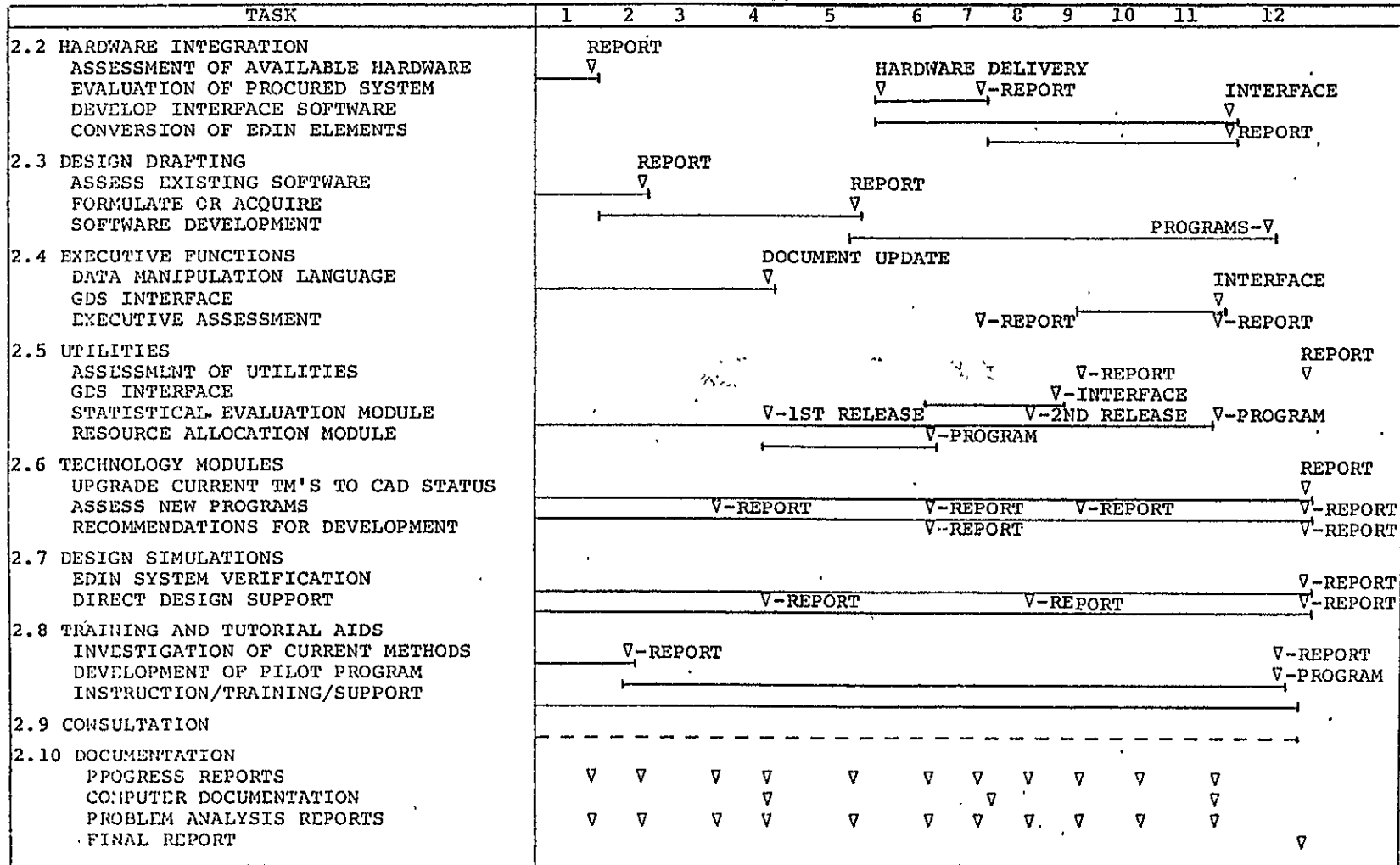


FIGURE 5 DEVELOPMENT OF THE ENGINEERING DESIGN INTEGRATION (EDIN) SYSTEM.

(A) PROGRAM SCHEDULE.

documentation necessary to accomplish the objectives of the reviews. Sigma Corporation also participated in other reviews and interface meetings with other contractors and NASA centers.

A summary outline of the work accomplished in each task is described in the following sections.

Hardware Integration

Sigma Corporation supported the integration of new or existing hardware by providing the following support:

1. Assess available CAD hardware to support the EDIN System.
2. Evaluate the display system and other elements of the hardware now being procured in support of the EDIN System.
3. Identify problem areas between the selected hardware and the Univac 1100 system and propose solutions.
4. Aid in the development of any required interface software.
5. Become familiar with programming languages and elements of the remote system.
6. Convert elements of the present EDIN System to the remote system.
7. Prepare and issue periodic reports on assessment of hardware and software associated with the system.

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Executive Function

Sigma Corporation enhanced the present EDIN executive by providing the following:

1. Provided a Fortran-like arithmetic expression capability in data replacement mode.
2. Expanded the editing and formatting capability such that one data base of one type may easily be re-formatted to another type for transmission to the remote system (Adage 340).
3. Continually assessed the EDIN executive made recommendations for modifications or additions.

Utilities

Sigma Corporation provided the following support for development of new or existing utility programs:

1. Assess general and special purpose utilities and made recommendations for extensions, modifications, or additions and issued periodic reports on utility assessment.
2. Provided engineering and programming to interface the existing special purpose utilities with the mini-computer graphical display system.
3. Studied the development of a special purpose utility for statistical evaluations.
4. Developed requirements document for Resource Allocation Module and information program utility for managerial maintenance of the EDIN System.

Technology Modules

Sigma Corporation provided the engineering and programming expertise to perform the following:

1. Upgrade all current EDIN programs to an interactive CAD status.
2. Assess, evaluate, acquired and developed new and existing technology modules and integrated them into the EDIN System.

3. Produced quarterly assessments of current EDIN TM's as well as external state-of-the-art developments. (Computerized reports were investigated for their potential use in the production of these assessments.)
4. Provided recommendations for future development or additions to the EDIN TM Library.

Design Simulation

Sigma Corporation provided design support in the evaluation of advanced vehicle concepts and carried these evaluations through sizing, conceptual design, cost and performance evaluations, mass properties and structural analysis. Simulations were established for either batch or demand mode. Results of these simulations were stored in the computer for recall and evaluation. Summary reports were computerized and made available upon demand from the user. Short term program extensions to accomplish these tasks were performed in coordination with the technical monitor.

Final reports on these studies were issued as they became available with all of them being completed at the end of the contract. Recommendations for future studies and techniques for incorporation to the EDIN System were made to the technical monitor.

Training and Tutorial Aids

Sigma Corporation provided the following for training on the use of the EDIN System:

1. Investigated state-of-the-art methods of computerized tutorial aids.
2. Developed a pilot program which provided the user of the EDIN System with sufficient instructions to setup and solve an engineering problem involving the use of the executive system, the utilities and one or more technology modules.
3. Provided training to NASA and contractor personnel in the use of the EDIN System.

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Consultation

During the course of the contracted effort, Sigma Corporation, with prior approval from the technical monitor and the contracting officer, requested the efforts and advice of known technical experts in the field of CAD.

Documentation

The following reports and documentation were provided as part of the study contract:

1. Monthly progress reports.
2. Computer program documentation on software development and major modification of existing software.
3. Engineering problem analysis reports on studies, assessments and requirements generated during the study.
4. Final report summarizing the results of the contract.

TECHNICAL DISCUSSION

A truly interactive design integration system involves an intricate relationship between the user of the system and the hardware/software system itself. The interactive system must provide a natural extension of the user's own capabilities. Therefore, any development activity related to interactive computer aided design must be highly user oriented and involvement of the user during this period is essential to the success of the system. A significant portion of the contracted effort was the application of the EDIN System to real engineering problems and the tutoring of potential users of the system. The objective was to establish a CAD capability at JSC which would merge the innovative talents of engineers and designers with the analytical potential of the developing EDIN System. The EDIN System allows the design to begin with the conceptual definition and rapidly proceed to the preliminary design stage. The system will allow the user to make concept perturbations, to interrupt and to interact with the analysis process at any point in the design simulation. In addition, individual analysis functions using the most current design information can be made available.

The success of a design project depends on a significant use of the geometry definition capability along with the enhancement of the existing input editing and analysis techniques,

data management functions and executive control functions. These expanded capabilities of the EDIN System utilize the new hardware and additional software discussed in the following sections.

Sigma Corporation supported JSC in the integration of the minicomputer based graphical display system (Adage 340) during the procurement process. The Adage 340 procurement represents a quantum jump in the basic hardware capabilities required for an interactive computer aided design system. Much of the graphics software capability formerly residing on the Univac 1100 has been transferred to the Adage 340. In addition, a geometry definition capability was developed which provides a cost effective tool that is attractive for the designer to use. The output of the geometry package is fully compatible with the existing geometric manipulation and storage technique. Executive functions which reside on the Univac 1100 have been evaluated to determine which functions should logically be transferred to the Adage. The executive functions were continually monitored throughout the contract and additions and modifications were provided as required. Interface requirements of the EDIN Technology Library were continually evaluated during the contract and utility programs were developed to meet the TM (Technology Module) interface requirements. Documentation of all new software and modifications thereof were provided.

General Requirements

The JSC requirement for a multiple station multiple user CAD system for use by a large design staff will be fulfilled over a number of years and will be based on the expansion and development of the current EDIN System concepts. General guidelines that were followed during the current study include:

1. Expand the EDIN System into a single station interactive CAD system.
2. Design the next phase of the CAD system.
3. Recommend long range hardware procurement and software development required to support the long range plan.

Sigma Corporation performed the necessary requirements documentation, analysis, flow charting, coding and program check-out to implement and verify the technical soundness and

integrity of the CAD developments. The corporation sought direct and indirect programming support from NASA for the above functions. The relationship between the contractor, NASA and the programming support staff is illustrated in figure 6. Category I support was sought directly through the NASA technical monitor. Category IV support was sought by the submission of software development requirements to the technical monitor.

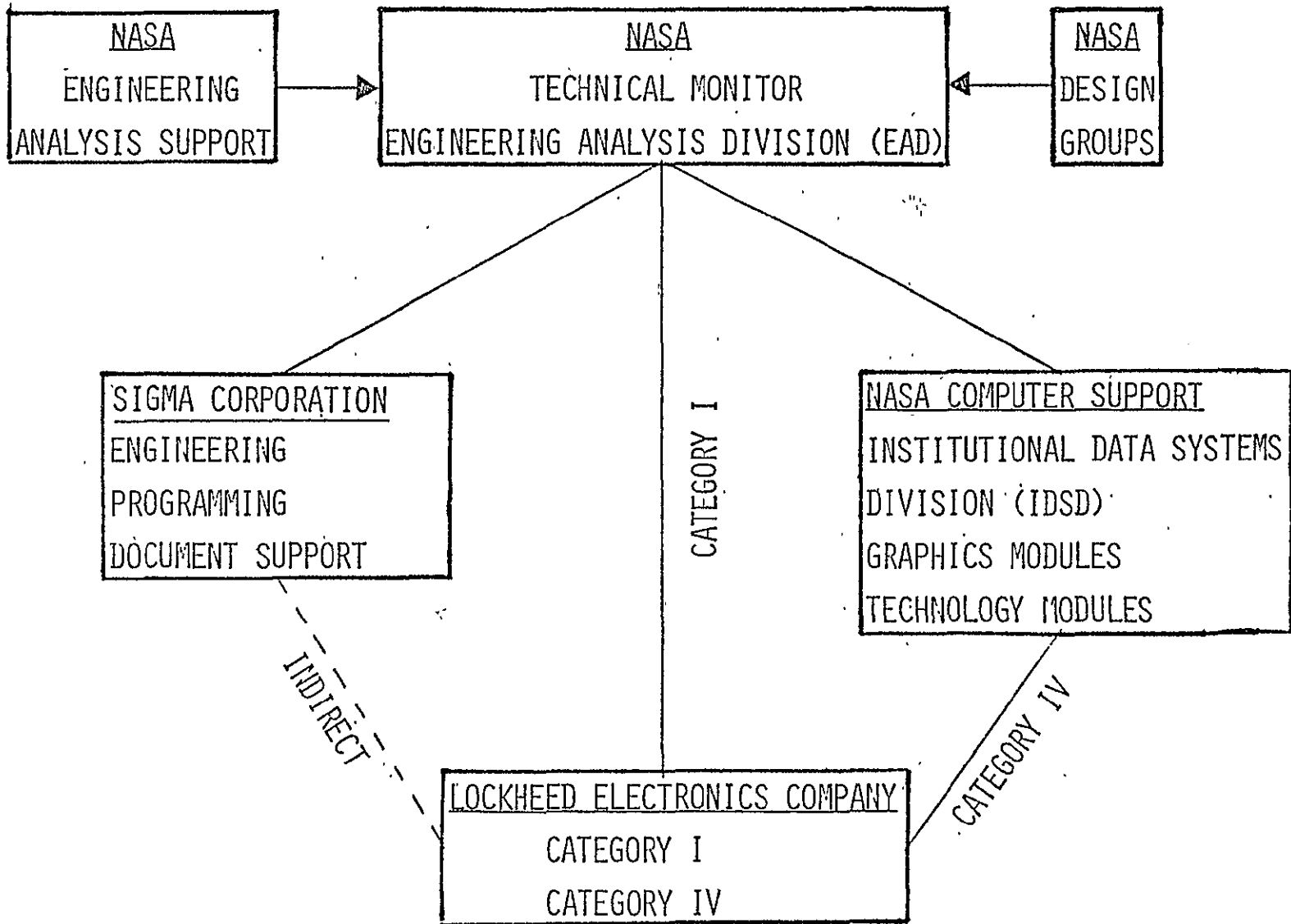
Hardware Integration

Sigma Corporation provided technical assessment of the ability of the GFE hardware to support the EDIN System at JSC. A continual assessment of the available CAD hardware was made and reported upon to the technical monitor. Specific tasks related to hardware procurement were the evaluation of the graphical display system (Adage 340) hardware, a definition of the necessary software, and the definition of interface requirements with the Univac operating system. Specific attention was given to the problems of data storage and the computational mix between the Adage 340 and the host computer. The study personnel became familiar with the programming languages of the remote Adage 340 and converted those elements of the EDIN System that could be handled by the Adage 340.

The Adage 340 consists of a minicomputer and an interactive graphics terminal along with some peripheral equipment such as disk, light pens, input tablets, etc. The Adage 340 is linked to a Univac 1100 computer via a high speed line as shown in figure 7. Technology modules and the EDIN data base reside on the Univac 1100. Graphical analysis programs reside on the Adage 340. The user interacts through the demand system on the 1100 and through the refresh terminal on the Adage 340. In the display mode, the available Adage 340 core is used largely for buffering display data. In a nondisplay mode, some technology modules may be executed.

For some classes of problems requiring the use of the Adage 340, data integrity between the minicomputer and the Univac 1100 must be maintained. Therefore, the transmission of data from the 1100 down to the Adage 340 requires special handling to provide the required data integrity. The file structure for the Adage 340 is compatible with the system data file and program file formats on the Univac Exec 8 system. A new Exec 8 utility was written to transmit data between the Univac and the Adage.

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FIGURE 6 NASA MANAGEMENT PLAN FOR THE EDIN SYSTEM DEVELOPMENT.

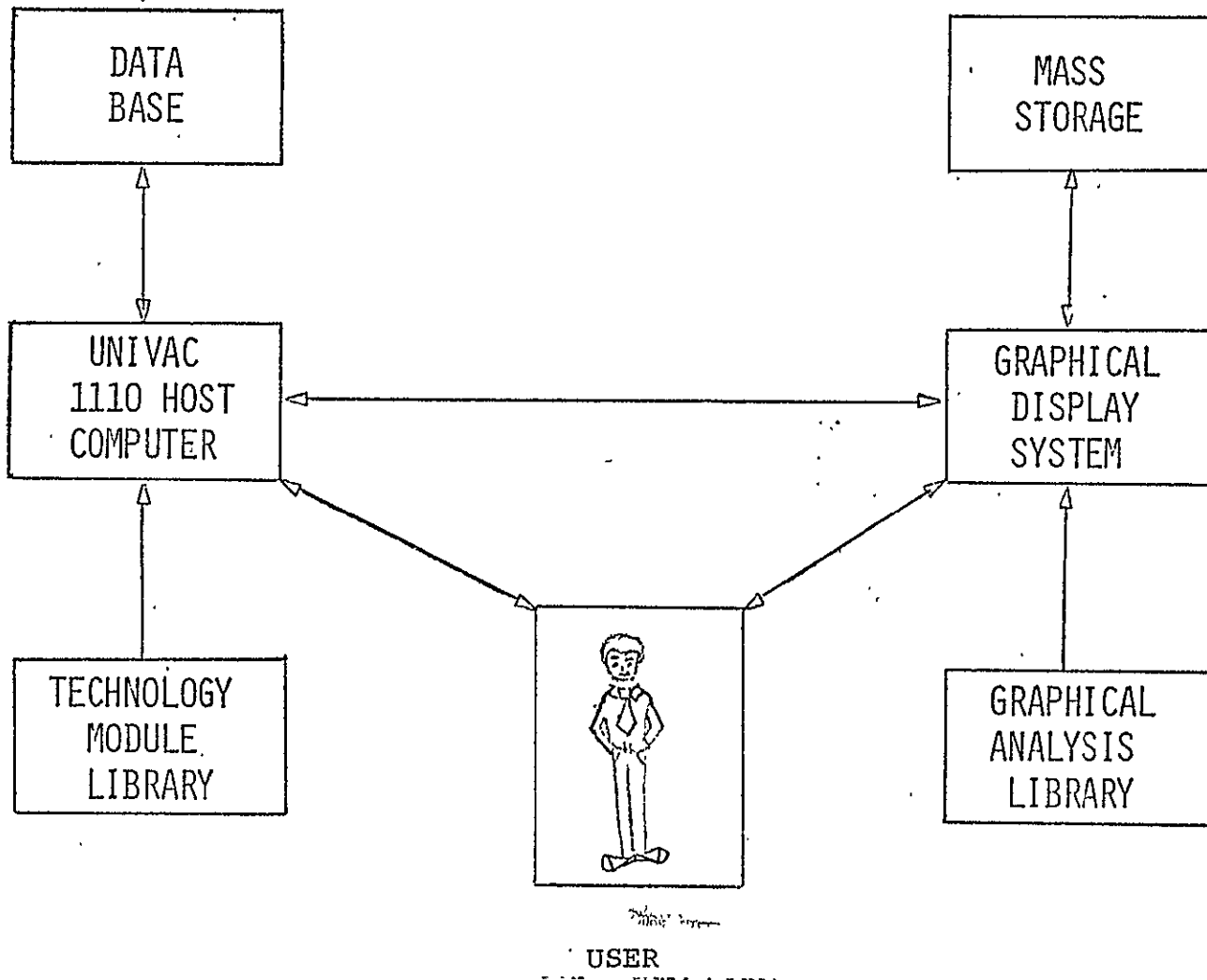


FIGURE 7 UNIVAC 1100/ADAGE 340 INTERFACE.

Two types of graphics display capabilities have been provided, static and dynamic. Many static graphic functions now available in the Univac system are also available on the Adage 340. In addition, new graphics functions have been developed to support graphical analysis programming for the Adage 340. The basic static graphic functions equivalent to the CALCOMP sub-routines PLOT, AXIS, LINE, GRID, SYMBOL, etc. have been provided for the Adage users. The development activities extended these basic graphic functions include a basic set of interactive graphic functions as well as most Adage 340 applications programs developed under that contract use this "second level" software.

Interaction with EDIN technology programs on the Univac is one goal in the development of CAD. Therefore, the user of the Adage 340 has been provided with demand access to the Univac 1100. Further, the access is achievable during execution of any Adage 340 program. The capability allows the user to effectively interact with executing programs on the Univac 1100 while performing Adage display and editing functions. A Fortran callable Exec 8 interrupt utility routine is used to handle program interrupts.

Graphical analysis programs which have applications to the EDIN remote Adage 340 are discussed below. Development of these programs were undertaken during the study.

Geometry Display. - Display of stored geometry data.

Input:	Standard cornerpoint geometry format (Gentry, Harris on GTM).
Function:	Collection of sections, components and clusters of components from display, translation, rotation and zoom.
Output:	Cornerpoint Geometry Displays.

Specialized Geometry Generation. - Creation of cornerpoint geometry for display or storage from specialized algorithms.

Input:	Basic geometry characteristics such as lengths, diameters, height, width, etc.
Function:	Generate panelled cornerpoint geometry.
Output:	Cornerpoint geometry in Gentry or other suitable format.

Geometry Manipulation. - Maintenance of geometry stored in the data base.

Input: Standardized geometry input.

Function: Tree structuring, stretching, shrinking, fitting, cutting of existing geometry.

Output: Modified geometry and displays.

Drafting. - Creation of geometric and other ordered sets of data.

Input: X-Y-Z data from keyboard, data tablet or disk input.

Function: Accept input in appropriate form and store data in the data base. Augment data with various mathematical functions; move or delete existing points, search for identified points, sections or components, display associated data sets, etc.

Output: Stored data sets and graphical displays.

IO Editor. - Interactive interface to technology programs.

Input: Input and output data associated with technology modules residing on the 1100.

Function: Provide graphical displays of results of TM analysis or input data (Exec 8 file elements).

Output: Input file for EDIN System or the TM's and displays of input and output data.

Generate Plotting. - Accept data in many formats and plot selected portions of the data.

Input: Plot data in array or observation format (BCD or binary) and plotting instructions.

Function: Scale and plot the data, generate titles, annotation, grids and textual information.

Output: Generated plots.

Report Writing. - Generate stylized reports for use by the various engineering disciplines.

- Input: Skeletonized reports which contain boilerplate information and data base requests for current design information. Also plot vector files from the other Adage programs.
- Function: Response to requests which include retrieval of design constraint definitions, geometry description, weights statements, performance plots, etc. Arrange textual and plot vector information in report format.
- Output: Reports which can be displayed or hard copied for dissemination to the design groups.

Executive Function

The DLG processor, whose functions are illustrated in figure 8, accepts data from other computer programs for storage into the data base and has the ability to merge data base information with input skeletons for use by other computer programs. This capability resides in the Univac 1100. DLG processing functions were assessed during the study to determine which functions should be performed on the Adage 340. The DLG executive system was interfaced with the Adage in such a manner as to provide data base editing, alteration of the program flow logic, or generation of reports. The capability for executing alternate simulation streams while in an interrupted state was investigated. Data base edit capability and formatting were expanded to include not only the EDIN data base but other data bases deemed essential to the support of the preliminary design activities at JSC. The executive functions were continually assessed and modifications were recommended.

Accounting Functions

Extensive logging and accounting capabilities are incorporated into the Univac executive system to collect information pertaining to each run and to perform certain general Exec 8 actions, such as I/O error logging. The information can be used for accounting and general postprocessing purposes. A summary accounting file containing information about each account is maintained and updated automatically by the stream

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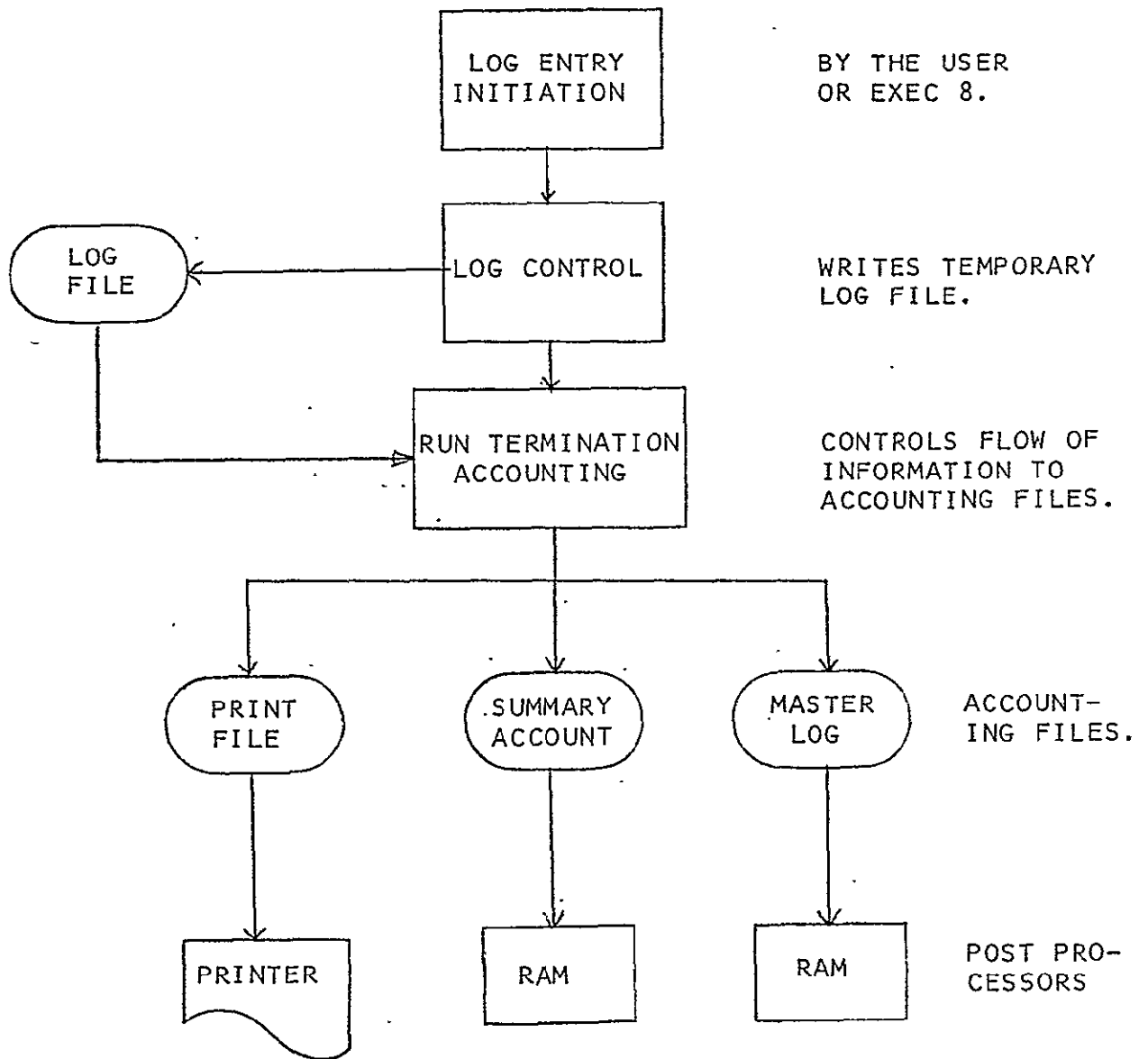


FIGURE 9 LOGGING AND ACCOUNTING PROCEDURES.

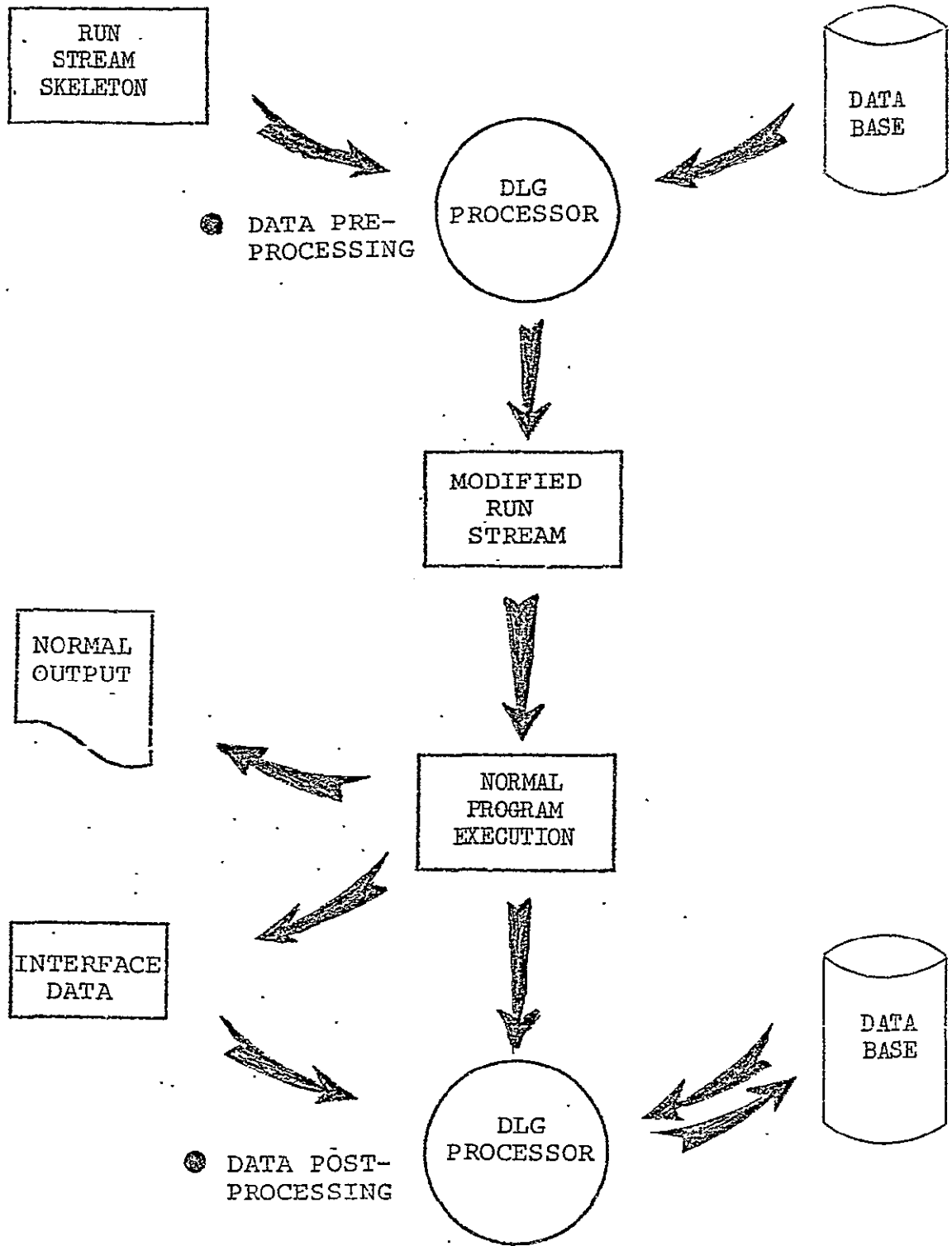


FIGURE 8 ALL UNIVAC DLG PROCESSOR FUNCTIONS.

at the termination of each run. In addition, a master log of all logging and accounting information is produced. It was proposed that the accounting files, which are written by the Exec 8 system, be used by the EDIN System to maintain a management overview of the computer resources allocated to specific design analysis functions. The information which is generated by the Exec 8 system is as follows:

- Run Initiation Time.
- User's Specified Log Control Statement.
- Program Initiation and Termination.
- I/O Errors.
- Console Activity.
- Read/Write/Punch Activity.
- Tape Labeling Information.
- Checkpoint/Restart Information.
- Facility Usage.
- Run Termination Time.
- Catalogued Mass Storage File Usage.

Figure 9 is an illustration of the logging and accounting process. The log control file controls the flow of all logging information that is generated. The information is placed on the temporary log file. As each logging request is made, the log control routine writes the new log entry information by run in the temporary log file. At the termination of the run, information which pertains to the run is placed at the end of the print file by the run termination accounting routine. The run termination accounting routine is also used to update the totals in the summary account file for a given account. This is done in the course of creating the master log file. It was proposed that the summary account file be used by the EDIN System for generating special accounting information of interest to the engineering design staff.

Sigma Corporation provided a specification for a Resource Allocation Module (RAM) that would process the information on the summary account file and provide a resource allocation report keyed on account number, file name or program name. The proposal was referred to the IDSD, the NASA division charged with the responsibility of machine accounting.

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Utilities

Sigma Corporation provided the engineering and programming expertise to interface the existing special purpose utilities which reside on the Univac Exec 8 system with the Adage 340 system. The Adage 340 utilities were continually assessed during the contract and recommendations were made for extensions and modifications. A utilities document was established and maintained during the contract period so that the capabilities developed for both the Univac 1100 and Adage 340 computers were available to potential users of the system.

These utilities were developed and documented as required to interface the EDIN technology modules and provide enhanced analysis capabilities.

Technology Modules

Sigma Corporation updated the EDIN programs as required to an interactive CAD status. Documentation was provided for all interfaces. Where required, new documentation was generated. New technology modules were acquired and integrated into the EDIN System as required to provide state-of-the-art analysis capability for aerospace vehicle design in EAD. Continual technology module reassessment took place throughout the contract. State-of-the-art assessments took place in conjunction with the NASA technical monitor and the author or supplier of each TM under evaluation. An assessment of the manpower and computer resources required to integrate new programs into the EDIN System was made for non-operational programs. As part of the state-of-the-art assessment, recommendations for the development of missing elements of the design analysis were made for each technology and estimates of the manpower and resources required to develop the capabilities were made.

Design Simulation

Sigma Corporation provided design support in the evaluation of advanced concepts and carried these evaluations through sizing, conceptual designs, cost and performance evaluations, mass properties and structural analysis. The analysis of the design concepts would begin with preliminary sizing and progress to detailed weight and balance estimates including some assessment of the internal arrangement of subsystems and airframe components. Aerodynamics was estimated in the subsonic and hypersonic range. Performance and flight dynamics evaluation included three (3) DOF liftoff to orbit

and reentry trajectory analysis, landing and cruise analysis, where applicable. Requirements imposed by mission and aerodynamics were fed back into the basic sizing programs for reassessment. Each simulation network was established in such a manner that any element or all elements could be executed from the demand or batch mode. Major analytical results were stored in the computer mass storage in a form which was recallable for ready evaluation. Stylized summary-type reports were made available from the computer upon demand for all design studies. The methods employed in the design studies utilized the latest computerized methods available in the JSC EDIN System. The computerized methods required short term program extensions to accomplish the design study objectives. Program extensions and recommendations were coordinated with the contract monitor.

 Salkeld Performance Evaluation

A performance evaluation of a modified shuttle single stage to orbit concept developed by Salkeld was performed. The vehicle characteristics and mission constraints are shown in the following summary. The evaluation of the concept was made using the mass properties published in the Salkeld report. Trajectory profiles are shown in figure 9. Vehicle performance is summarized as follows:

<u>ITEM</u>	<u>WEIGHT</u>	<u>WEIGHT</u>	<u>REMARKS</u>
PAYLOAD	-1562		
ORBITER WET WEIGHT	179369		
ORBITER AFTER ET SEPARATION		<u>177807.</u>	
ET INERT WEIGHT	140258		.9522 MASS FRACTION ESTIMATED
RP-1 ENGINES WEIGHT AT MECO	40000	<u>358065</u>	
ET PROP CONSUMED FROM RP-1 CUTOFF TO MECO	964464		
ET PROP CONSUMED FROM LIFTOFF TO RP-1 CUTOFF	1831471		
GLOW		<u>3154000</u>	

Based on preliminary tank weight and RP-1 engine weight estimates, the payload delivered is inadequate to perform the mission. In order to achieve the design payload of 65000 pounds, the tank mass fraction would have to be .9743.

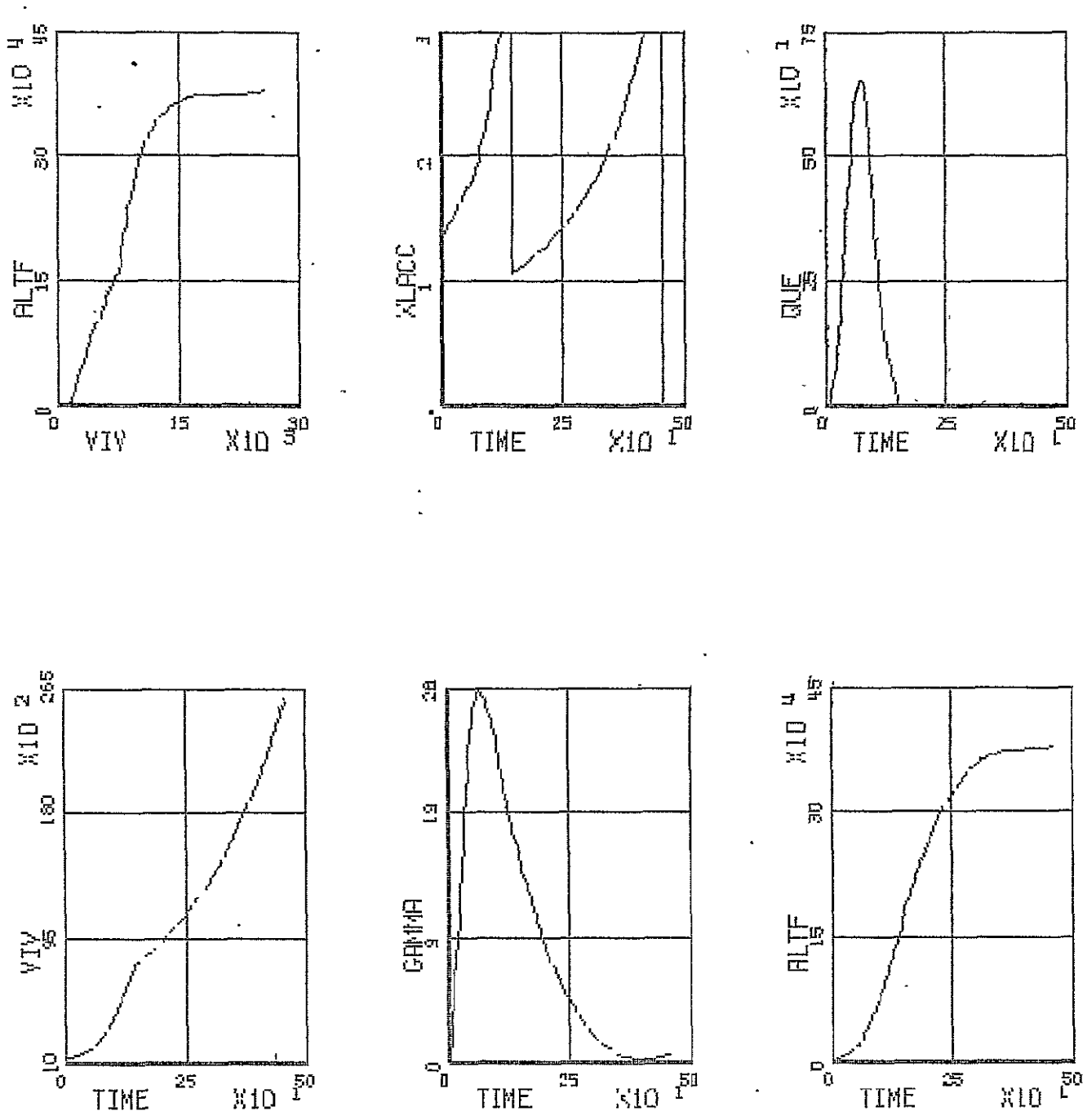


FIGURE 9 TRAJECTORY PROFILES

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Vehicle Characteristics

Propulsion

3 SSME's T(vac) = 470000 LB EACH
ISP(vac) = 455.3 SEC
AE = 41.88 SQ FT EACH

4 RP-1's T(sl) = 790000 LB EACH
ISP(sl) = 319.6 SEC
AE = 30.38 SQ FT EACH

Propellant Weights

RP-1 420000 LB
LH 197000 LB
LOX 2177000 LB
TOTAL 2794000 LB

Mission Constraints

GLOW = 3154000 LB
h = 380000 LB
 v_i = .5 DEG
 V_i = 25676 FT/SEC
qMAX = 650 PSF
ACCEL_{MAX} = 3 G

EDIN04

A simulation study, designated EDIN04, was performed using EDIN software and hardware. The information below is a summary for a preliminary assessment of a liquid rocket booster (LRB) replacement for the shuttle solid rocket booster. The concept uses the shuttle and the shuttle ET in essentially unmodified form. A RP-1 stage using three modified F-1 engines mounted behind the shuttle ET replaces the existing SRB's, figure 10. Some modification of the ET would be required to take thrust loads out at the back rather than along the side of the ET. No weight penalty for the ET redesign is assessed. The LRB stage is jettisoned at BECO and recovered for reuse. The LRB system is designed to fly to shuttle conditions and to meet mission 3A payload requirements with sufficient propellant to fly an AOA mission.

The NASA Engineering Analysis Division and Future Programs Division were involved in defining design requirements and constraints. Historical weight estimating relationships (WER) were developed using Saturn technology. The WER's should be considered preliminary until reviewed by the appropriate NASA design groups. Mission performance was computed using shuttle performance computation ground rules to allow the comparison of the EDIN04 design with the current shuttle system. February, 1975, mission data from Rockwell was used in the comparisons and the design studies.

The point mass trajectory analysis employed in the performance assessment dictated the use of a gravity turn during the LRB burn phase rather than the shuttle angle of attack profile. One F-1 engine was shut down 35 seconds after launch to limit the dynamic pressure to the shuttle orbiter limit of 650 psf.

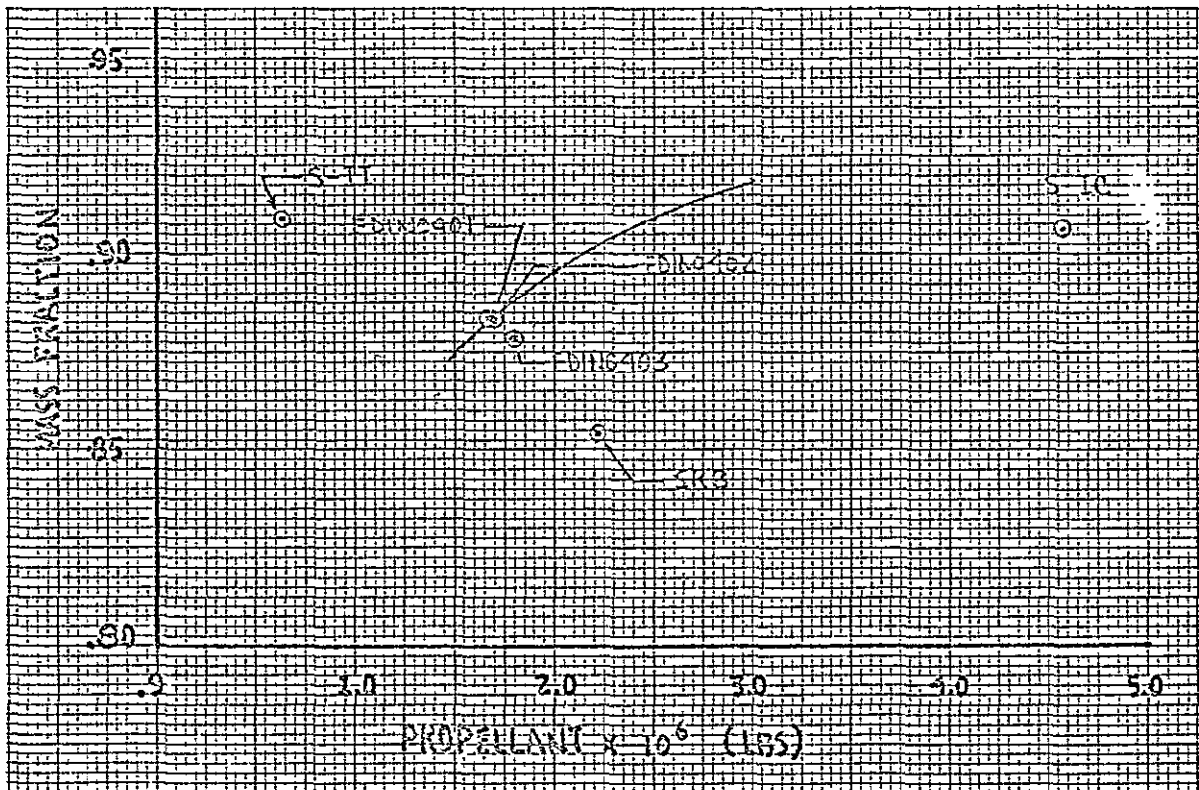
Three designs are included in the enclosed information, all of which utilize the SSME thrust profile. EDIN0401 is designed to meet the shuttle MECO conditions for mission 3A. EDIN0402 is designed to meet shuttle mission 3A RTLS/AOA flight conditions. The difference between EDIN0401 and EDIN0402, as indicated by the following table, is small.

	<u>SHUTTLE</u>	<u>EDIN0401</u>	<u>EDIN0402</u>	<u>EDIN0403</u>
GLOW	4.415M	3.758M	3.768M	3.876M
INJECTION WEIGHT	300729	300729	300729	300729
ET PROPELLANT	1.541M	1.541M	1.541M	1.541M
BOOSTER GLOW	2.573M	1.916M	1.926M	2.034M
BOOSTER PROPELLANT	2.211M	1.693M	1.701M	1.787M
BOOSTER INERT	361578	222502	224574	246976
BOOSTER MASS FRACTION	0.859	0.884	0.883	0.879

The EDIN0403 design is based on EDIN0402 ground rules with a 10% dry weight contingency added.

The studies have revealed that substantial reduction in GLOW is possible using a LOX/RP stage in place of the present SRB's. The saving is primarily due to a significant improvement in mass fraction using a liquid system.

The figure below illustrates the improvement in mass fraction. Shown for comparison are the Saturn S-IC and S-II stages which do not contain reentry and recovery systems. The mass fraction variation with propellant weight for EDIN0401 is also shown.



The EDIN0401 design used the mission 3A MECO conditions while EDIN0402 and EDIN0403 used RTLS/AOA as the terminal conditions. In all cases, the Mission 3A injected weight was used as a design constraint.

The propulsion data used in this study is shown below for the modified F-1 engines and the SSME engines:

<u>F-1 ENGINE</u>	THRUST (SL)	=	1606788.6	LBS
	THRUST (VAC)	=	1748060.	LBS
	ISP (SL)	=	266.01	SEC
	ISP (VAC)	=	289.40	SEC
	FLOWRATE	=	6040.2	LBS/SEC
	EXIT AREA	=	66.76	SQ FT
	MISTURE RATIO	=	2.27:1	

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<u>SSME ENGINE</u>	THRUST (SL) (100%)	= 375000 LBS
	THRUST (VAC) (100%)	= 470000 LBS
	ISP (SL)	= 363.2 SEC
	ISP (VAC)	= 455.2 SEC
	FLOWRATE (100%)	= 1032.5 LBS/SEC
	EXIT AREA	= 44
	ENGINE GIMBALLING CAPABILITY	= + 9.0 DEG
	ENGINE THROTTLING CAPABILITY	= 50% TO 109%
	MIXTURE RATIO	= 6:1

An aft shift of 374 inches in the center of gravity results from the use of the LRB as indicated by figure 12. The effect of the shift is to increase the null position of the SSME thereby reducing the performance during launch. This effect was not accounted for in the design simulations. Figure 12 provides a comparison of cg positions at launch and BECO for the current shuttle and EDIN0401.

The cg for the LRB alone was estimated on the basis of information available on the weights and geometry of the components. These data are available at JSC for inspection.

The EDIN04 concept consists of the shuttle orbiter, the shuttle ET and a new liquid rocket booster (LRB) to replace the SRB's. A two view of the concept is shown in figure 10. The assessment was performed assuming no change to the shuttle orbiter and no weight penalty for the structural modification to the ET. The LRB consists of a LOX/RP stage illustrated in figure 11. The tanks are nested to reduce the inter-tank length and insulation is provided. The inter-stage structure between the shuttle ET and the LRB contains the recovery equipment and the structure and controls for the aerodynamics, stabilization (reentry) system. Three modified F-1 engines are used with an expansion ratio of 10:1. The liquid oxygen is fed through the RP tank. A retro system is housed within the aft skirt to decelerate the reentered stage just prior to impact. An ablative heat shield is provided on the upper portion of the tank system for protection of the tank from SSME plume unpingement.

Mission Ground Rules

The shuttle mission 3A was used in the design studies. The launch was performed in four (4) phases.

- PHASE 1 Lift-Off to F-1 Engine Shutdown.
- PHASE 2 F-1 Engine Shut Down to BECO.

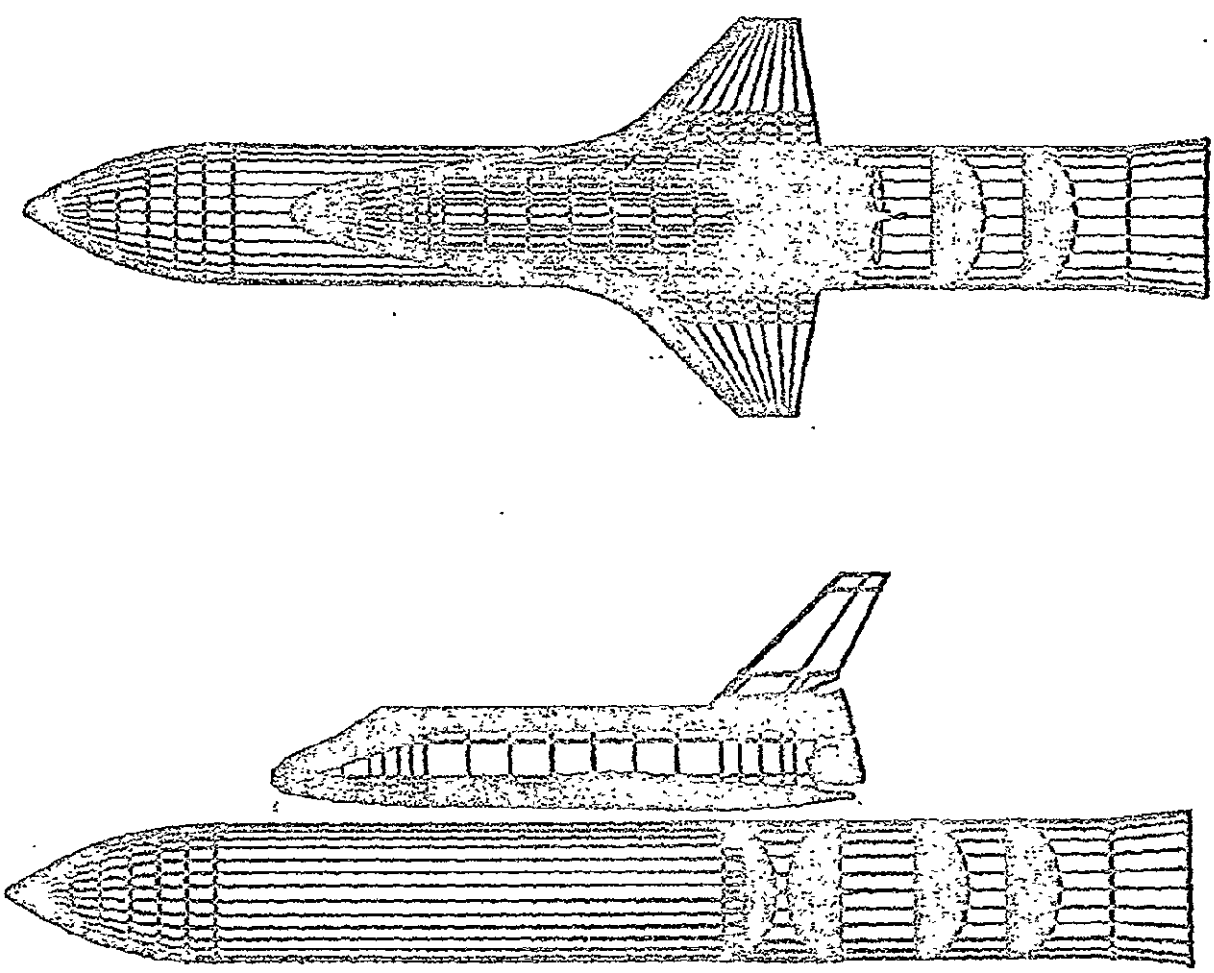
PHASE 3 BECO to RTLS/AOA Point (% 9000 fps).

PHASE 4 RTLS/AOA Point to MECO.

An initial pitch over was performed between 6 and 16 seconds followed by a gravity turn to BECO. Optimal guidance was employed from BECO and MECO. The SSME was operated at 109% of the rated power setting from liftoff to RTLS/AOA and 100% thereafter, except as required to limit the longitudinal acceleration to 3 g's. The F-1 engines were operated at 100% power at all times except that one F-1 was shut down at 35 seconds to limit the dynamic pressure to 650-psf.

The following conclusions were made as a result of this study:

1. Significant reductions in GLOW can be projected by the use of the LRB system as opposed to the SRB system.
2. A reduction in cost per flight would probably result from the use of the LRB concept but the additional cost of development would have to be factored against the cost savings. Cost savings were not assessed in the study.
3. Retrofitting or redesign of the ET is indicated by the change in the load carrying structure and the shift in center of gravity. Orbiter modifications may also be required because of the shift in cg.
4. Weakness in the prediction techniques for the re-entry and recovery system weights need to be investigated to add validation to the results of the study. Further the tank structure, aft skirt and holddown structure have not been adequately assessed. There is general doubt about the validity of the scaling laws at this time.



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FIGURE 10 EDINO4 CONCEPT
(A) TWO VIEW.

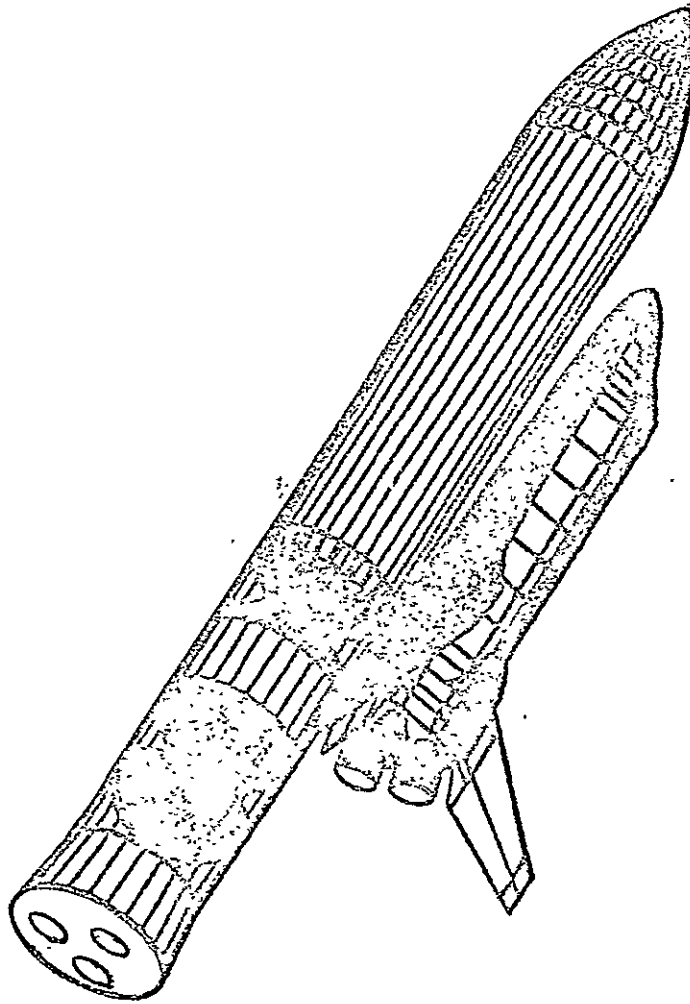


FIGURE 10 EDINO4 CONCEPT
(B) LAUNCH CONFIGURATION.

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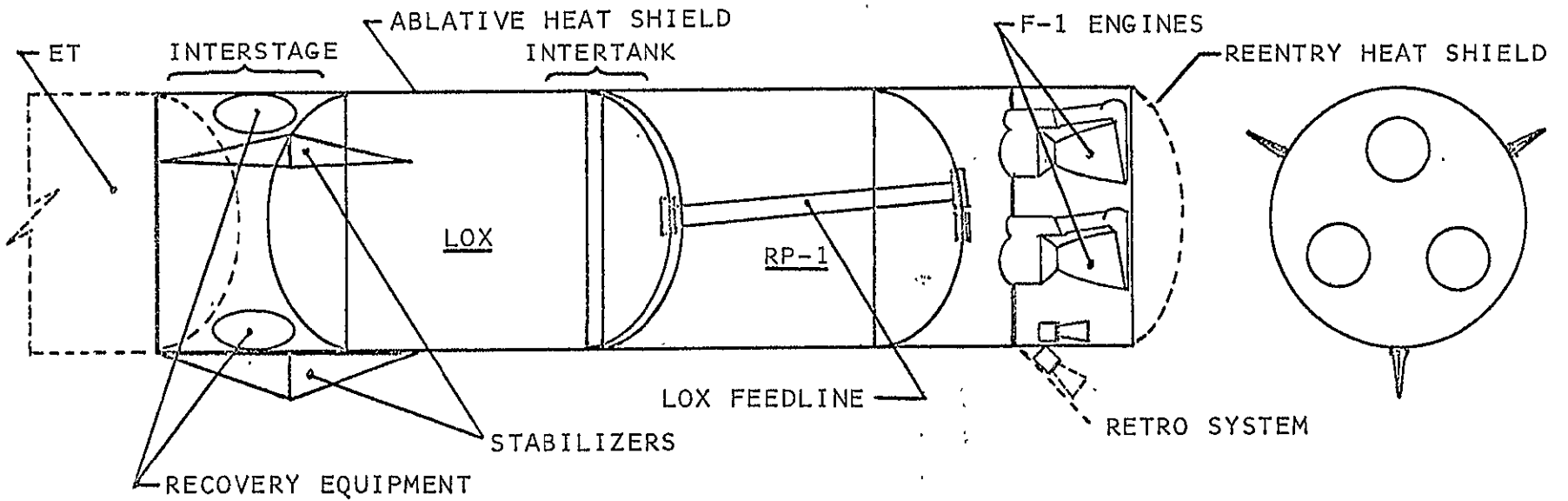
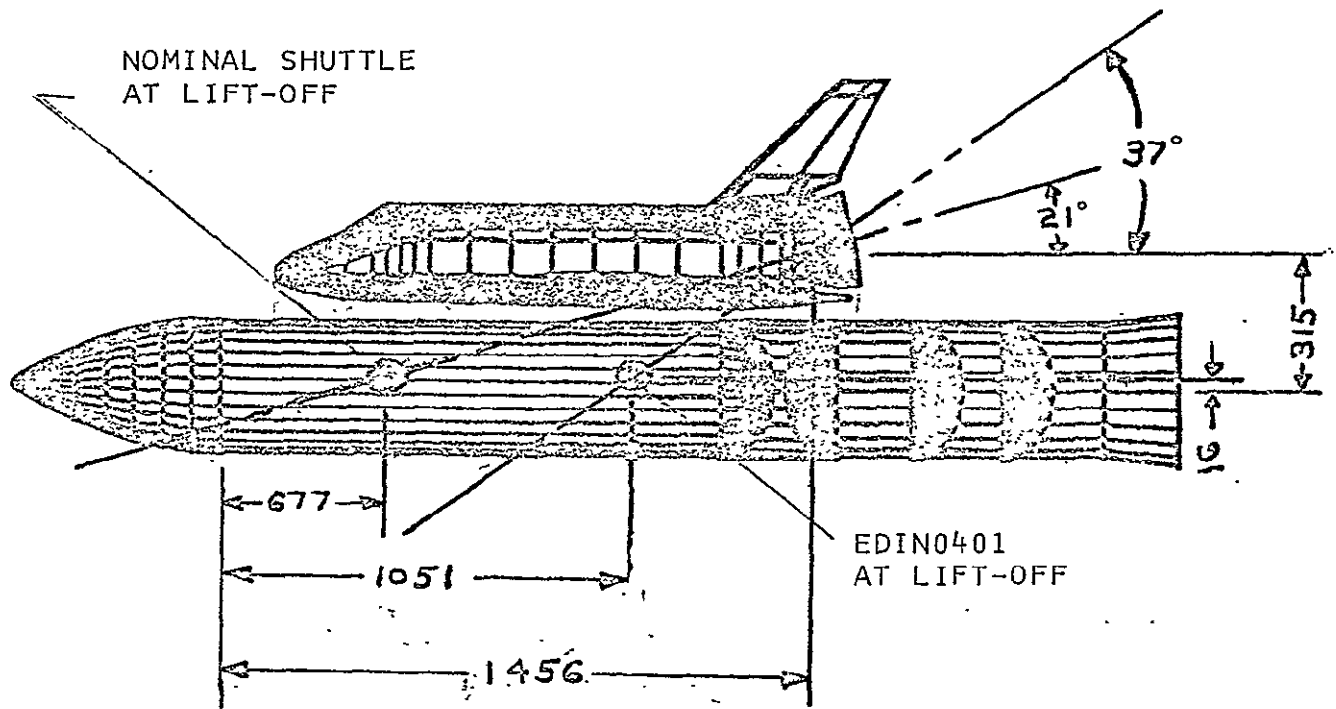


FIGURE 11 LIQUID ROCKET BOOSTER REPLACEMENT FOR SHUTTLE SRB.



LAUNCH SEQUENCE	SHUTTLE		EDIN 0401	
	WEIGHT	XCG	WEIGHT	XCG
LIFT-OFF	4415347.	677	3757835.	1051
BEFORE BOOSTER SEPARATION	1775725.	485	1650553.	583
AFTER BOOSTER SEPARATION	1424845.	354	1428051.	354

FIGURE 1:2 CENTER OF GRAVITY SHIFT.

EDIN05

The basic purpose of the EDIN05 study series was the conceptual design of several space shuttle configurations in which the solid rocket boosters (SRB's) were replaced by a recoverable liquid rocket booster (LRB) and the external tank (ET) were resized to satisfy performance requirements. The design point for the studies was the Shuttle Reference Mission 1, modified to achieve a greater payload. The launch trajectory was constrained to pass through both the RTLS/AOA and MECO points of the Shuttle Reference Mission 1. The initial tilt rate and exo-atmospheric pitch profile were optimized to obtain the trajectory for maximum payload or minimum gross liftoff weight (GLOW) in each study case. The trajectories employed a gravity turn from end of tilt to booster engine cutoff (BECO) and were constrained to prohibit dynamic pressure in excess of 650 psf and longitudinal acceleration in excess of 3.0 g by engine throttling and/or shutdown.

The LRB was sized according to weight estimating relationships (WER's) based on Saturn technology. ET sizing was accomplished by employing a fixed mass fraction to distribute ET component weights in accordance with the Shuttle ET weight statement. The orbiter corresponds to that of the February 1975 Shuttle, modified to include the additional structural weight necessary to accommodate the increased up payload.

The EDIN0501 design study employed three F-1 engines as the LRB propulsion system and sized both the LRB and the ET to minimize GLOW for a 100,000 pound payload.

The EDIN0502 design study produced two conceptual designs. In both designs, the three F-1 engines of EDIN0501 were replaced by seven of the 680,000 pound sea-level thrust high-pressure engines proposed by Beichel. The structure of the LRB was assumed to remain unchanged from that of EDIN0501, with the exception that the propulsion system weight was changed. In the EDIN0502A design study, the ET size was fixed at that of EDIN0501 and the obtainable payload determined. The EDIN0502B design study resized the ET to maximize payload.

The EDIN0503 design study replaced the three F-1 engines of EDIN0501 with six of the 800,000 pound sea-level thrust high-pressure engines proposed by Beichel. The structure of the LRB was assumed to remain unchanged from that of EDIN0501, with the exception that the propulsion system

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FIGURE 13 EDIN05 RESULTS SUMMARY

	SHUTTLE	EDIN050L	EDIN0502A	EDIN0502B	EDIN0503
GLOW	4.203M	4.853M	4.817M	4.928M	4.698M
ET LIFT-OFF	1.626M	1.805M	1.805M	1.911M	1.805M
ET INERT	86.3K	98.0K	98.0K	104.1K	98.0K
ET PROPELLANT	1,540M	1.707M	1.707M	1.807M	1.707M
BOOSTER LIFT-OFF	2,327M	2,760M	2.693M	2.693M	2,569M
BOOSTER INERT	309K	254K	189K	189K	190K
BOOSTER PROPELLANT	2.019M	2.506M	2.459M	2.459M	2,335M
PAYLOAD	65K	100K	132K	137K	136K

weight was changed. As in EDIN0502A, the ET size was fixed at that of EDIN0501 and the obtainable payload determined. Figure 13 summarizes the results of the EDIN05 simulation.

EDIN06 HHLV Simulation Study

The purpose of this study was to define a heavy lift launch vehicle for the solar power satellite system. Each solar power satellite has been estimated to weigh nearly 91,000 metric tons (200,000,000 pounds) in geosynchronous earth orbit, and would thus require the launch vehicle fleet to deliver close to 227,000 metric tons (500,000,000 pounds) to a low earth assembly orbit for each power satellite.

The mission profile used in sizing the launch vehicles was an unmanned launch from the Kennedy Space Center to an elliptical earth orbit. The launch vehicle injected the payload into a 92.5 X 500 kilometer (50 X 270 nautical mile) orbit; the orbit injection point was near the 92.6 kilometer (50 nautical mile) perigee. After injection, the payload was separated from the launch vehicle's second stage. The payload was then placed into a circular orbit at the 500 kilometer (270 nautical mile) apogee by a propulsive system in the payload. Payload at 500 kilometer (270 nautical mile) circular was 453.59 metric tons (1,000,000 pounds). The second stage of the launch vehicle would reenter the earth's atmosphere at an altitude of 121,920 meters (400,000 feet after one orbit). The mission profile required each spent stage of the launch vehicle to be returned to the launch site for reuse.

Candidate concepts for the launch vehicle were sized based on a predicted technology level expected in 1995. In addition, 20 percent of the vehicle's booster stage dry weight was established for growth allowance. The configurations investigated were two stage launch vehicles; the propulsion sequence was a series burn. Recovery systems were defined and sized for each stage. The systems studied were: (1) winged, powered flyback and (2) winged, nonpowered glide-back systems.

A 3 degree-of-freedom launch trajectory program was used to simulate vehicle flight for each of the configurations studied. The analysis program optimized the launch vehicle tilt profile and exo-atmospheric portion of the flight. A parametric study was made of stage mass fractions, wing configuration and booster fuel. The launch vehicles considered were sized for payloads of 453.59 metric tons (1,000,000 pounds).

The launch vehicle defined in this study was a two stage, series burn, winged vehicle with a payload capability to the target orbit of 453.59 metric tons (1,000,000 pounds). Vehicle gross lift off weight was 13,738 metric tons (30,286,651 pounds) and the thrust to weight ratio at lift off was 1.3. The booster stage was a heat sink powered flyback stage that required 20 LOX/C₃H₈ high chamber pressure engines for boost and airbreathing engines for flyback to the launch site. Landing speed for both the booster and the upper stage was 92.6 meters per second (180 knots). The second stage of the baseline vehicle was powered by seven Space Shuttle main engines and its wings were sized to permit unpowered atmospheric glide back to the launch site after one orbit. Main propulsion systems for both stages were uprated in performance characteristics to that considered feasible in the 1995 time frame.

From an assumed launch site at a latitude of 7 degrees the payload capability of the vehicle was determined; a simulated due east launch was flown to the target orbit. The payload was 466.75 metric tons (1,029,006 pounds).

For the initial investigation, six candidate vehicles were sized for a range of stage mass fractions typical of winged launch vehicles. The payload for these vehicles was chosen as 226.795 metric tons (500,000 pounds) and the payload was delivered to a 92.6 X 500 kilometer (50 X 270 nautical mile) elliptical orbit.

Two booster engines were used in this study:

1. High chamber pressure, staged combustion cycle engines using LOX/RP-1 propellant.
2. High chamber pressure, staged combustion cycle engines using LOX/LH₂ propellant.

Performance characteristics of these booster stage engines, provided by the Power and Propulsion Division, are given in figure 14. The data represent the performance characteristics expected achievable for these engine types by 1995. The mass fractions used in this preliminary sizing are given in figure 15 which shows a matrix of the six vehicles initially investigated. The upper stages of all the vehicles used uprated Space Shuttle Main Engines (SSME's). The performance characteristics of these engines were also estimated for the 1995 time period and their specifications are included in figure 14.

Three degree-of-freedom trajectory computer programs were used to simulate launch vehicle flight and performance. The trajectories were optimized for initial tilt rate and exo-atmospheric pitch profile. Weight estimating routines (WER's) were used to determine subsystem weights and resulting stage mass fractions. The WER's were developed and equation coefficients chosen to provide system weights expected to be achieved in the target 1995 time frame. Subsequent to the initial sizing of the 226.795 metric tons (500,000 pounds) payload class vehicles, ground rules were established which pointed the study toward developing launch vehicles capable of injecting greater payloads into the required orbit. Consequently, the candidate vehicles were sized for payloads of 453.59 metric tons (1,000,000 pounds). The ground rules for this study are given in figure 16.

A propulsion system was sized to circularize the payload at 500 kilometers (270 nautical miles). A vacuum specific impulse of 2942 newtons - second per kilogram (300 seconds) and a mass fraction of 0.8 was assumed for this system. The velocity change required at apogee for this maneuver was 117.35 meters per second (385 feet per second). The shroud for the payload was considered to be included in the 453.59 metric tons (1,000,000 pounds) of the payload.

The initial concept for the winged vehicle consisted of a heat sink straight wing booster and a delta winged second stage. The booster would be flown back to the launch site; air breathing engines (ABE's) of 222,411 newtons (50,000 pounds) thrust were used in the flyback simulation. The upper stage did not use ABE's but was designed to reenter the earth's sensible atmosphere after one orbit and glide back to the launch site. This first sizing effort resulted in a launch vehicle using LOX/RP-1 booster engines and weighed over 32 million pounds at lift off. Mr. W. Taub of the Spacecraft Design Division provided layout support for the transportation system sizing effort, and several of his drawings of this initial vehicle are included. Figure shows views of the booster stage and incorporates some unique concepts. The ABE's are shown stored in the nose cone of the booster stage, deployable for powered flyback. Landing gear stowage areas are given and an engine packaging scheme is shown. Figure 17 gives similar views of the delta winged upper stage. The stages are shown in a stacked launch configuration in figure 19. A conceptual "piggy-back" launch configuration is provided in figure and figure 20 shows a launch arrangement for a parallel

PROPELLANT (OX/FUEL)	BOOSTER STAGE		UPPER STAGE
	LOX/LH ₂	LOX/RP*1	LOX/LH ₂
CHAMBER PRESSURE, $\frac{N.}{M^2} \times 10^6$ (PSIA)	27.579 (4000)	27.579 (4000)	27.579 (4000)
SEA LEVEL SPECIFIC IMPULSE, $\frac{N.-SEC.}{KG.}$ (SEC.)	3994.2 (407.3)	3037.9 (309.8)	—
VACUUM SPECIFIC IMPULSE, $\frac{N.-SEC.}{KG.}$ (SEC.)	4334.5 (442)	3373.5 (344)	4569.9 (466)
OX/F RATIO	6:1	2.6 : 1	6 : 1
EXPANSION RATIO	40 : 1	50 : 1	200 : 1
VACUUM THRUST, NEWTONS (POUNDS)	8,596,384 (1,932,544)	8,496,500 (1,910,089)	4,230,000 (950,000)

FIGURE 14 ENGINE PERFORMANCE CHARACTERISTICS.

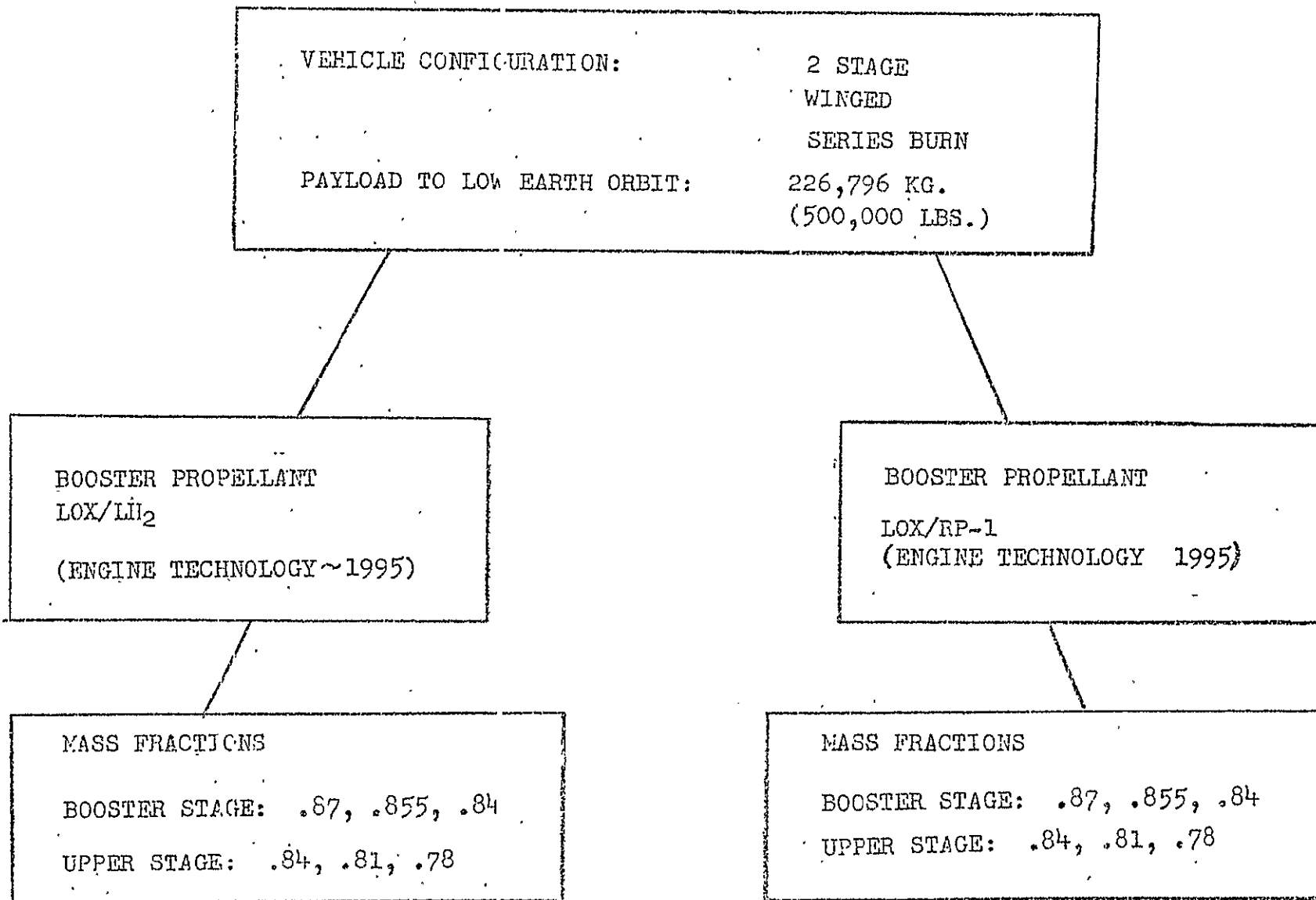


FIGURE 15 MASS FRACTIONS.

- PAYLOAD SHROUD DIAMETER . . . 12-34 METERS (40-100 FT.)
- PAYLOAD DENSITY 56-80 KG./M³ (3.5-5 LBS./FT.³)
- PAYLOAD 453-907 M.TONS (1.2 X 10⁶LBS.)
- NO PAYLOAD RETURN
- MAXIMUM ACCELERATION 4 G's
- MAXIMUM PAYLOAD BAY TEMPERATURE 93°C. (200° F.)
- UNMANNED LAUNCH
- RANGE SAFETY IS THE ONLY ABORT CONSIDERATION
- REQUIRED LAUNCH RELIABILITY = 0.97
- LAUNCH SITE RECOVERY OF SPENT STAGES
- PAYLOAD ORBIT : 500 KM. (270 N.M.)
- ORBIT INCLINATION EQUAL TO LAUNCH SITE LATITUDE
- RENDEZVOUS, DOCKING DELTA V IS IN THE PAYLOAD
- FO PAYLOAD \Rightarrow LAUNCH VEHICLE SERVICES REQUIRED
- LAUNCH RATE CAPABILITY WILL BE 50% GREATER THAN THE
AVERAGE OF THE ANNUAL LAUNCH RATE

FIGURE 16 HHLV GROUND RULES.

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burn liftoff. No trajectories were flown for the parallel burn operations mode, but the illustration shows the height of the liftoff configuration could be considerably reduced. A further reduction in launch configuration height is shown in figure 19 which shows the payload in two modules; one mounted on each wing of the upper stage. Such diverse conceptual designs as these by Mr. Taub are an integral part of the definition of a viable launch vehicle. Figure 20 using the parallel burn launch configuration, provides an illustration of the HHLV winged launch vehicle mission profile.

After several simulations certain parameters were selected and held constant in order to equitably evaluate both the LOX/RP-1 and the LOX/LH2 flying booster concepts. The booster wing loading was established at 5267 newtons per square meter (110 pounds per square foot) of wing area, the leading edge sweep was selected as 10 degrees, and a landing speed of 92.6 meters per second (180 knots) was chosen. The thrust to weight ratio at liftoff was 1.3 for all cases; the initial thrust to weight ratio of the upper stage was 0.97. Subsequent iterations also led to the selection of a straight wing for the upper stage with the same loading; its leading edge sweep was also 10 degrees. Trajectory constraints for all simulations were (1) 4 g maximum acceleration during ascent and (2) maximum dynamic pressure of 31.122 newtons per square meter (650 pounds per square foot).

The LOX/RP-1 vehicle was sized to a gross liftoff weight (GLOW) of 13,359 metric tons (29,451,478 pounds). This weight includes an allowance for growth in the booster stage, which was fixed at twenty percent of the booster dry weight.

The GLOW of the LOX/LH2 vehicle was 11,054 metric tons (24,370,200 pounds). Since the performance characteristics of the booster engines were closer to those of the upper stage than were the LOX/RP-1 booster engines, the ideal velocity for the stages was about equal. The LOX/LH2 booster staging point was about 12,000 meters (41,000 feet) higher and the velocity about 230 meters per second (750 feet per second) greater than that of the LOX/RP-1 booster.

After these vehicles had been sized, a LOX/C3H8 (propane) engine was proposed for the boost stage of an HLLV. Sizing studies and trajectory analysis defined the propane

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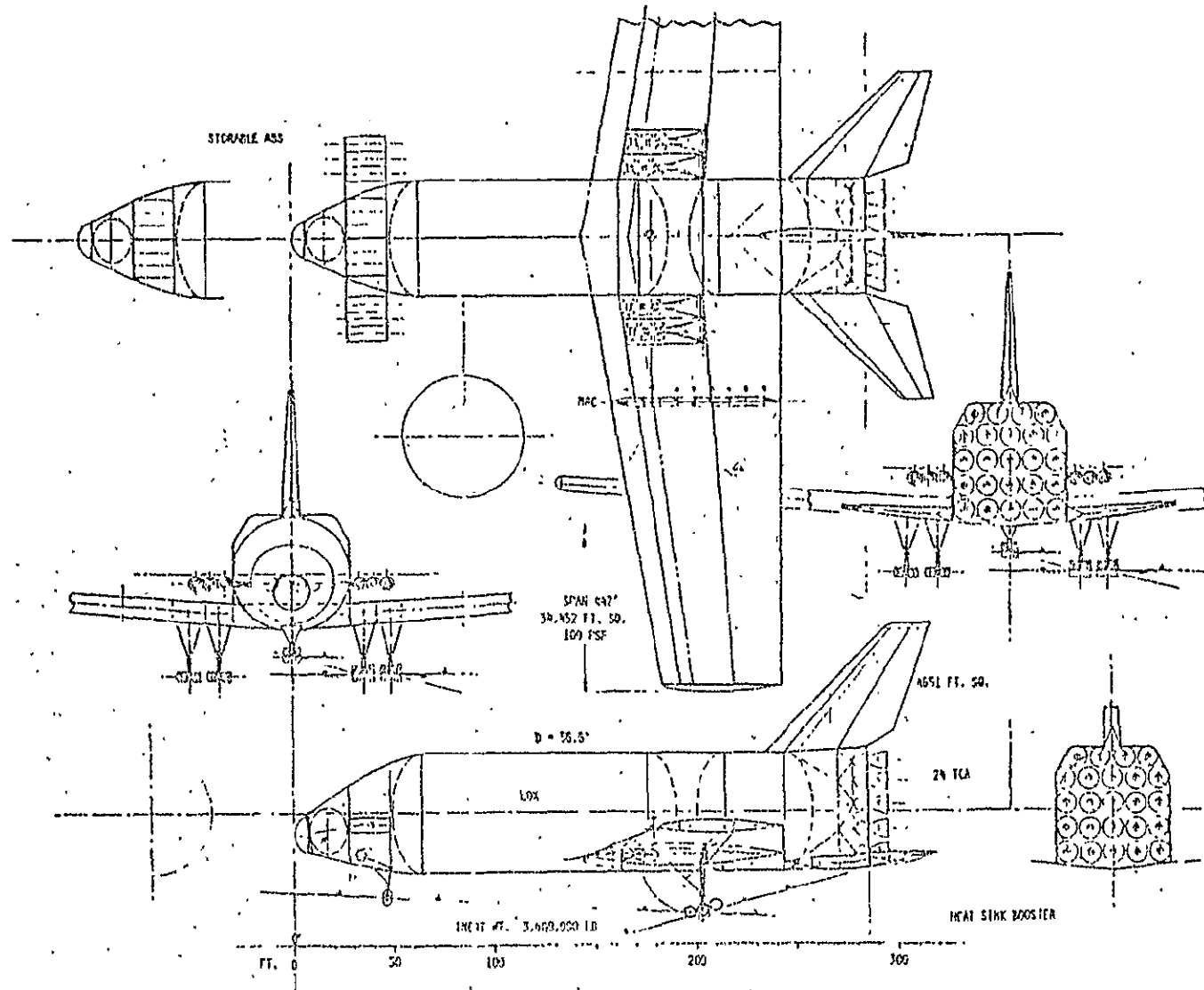


FIGURE 17

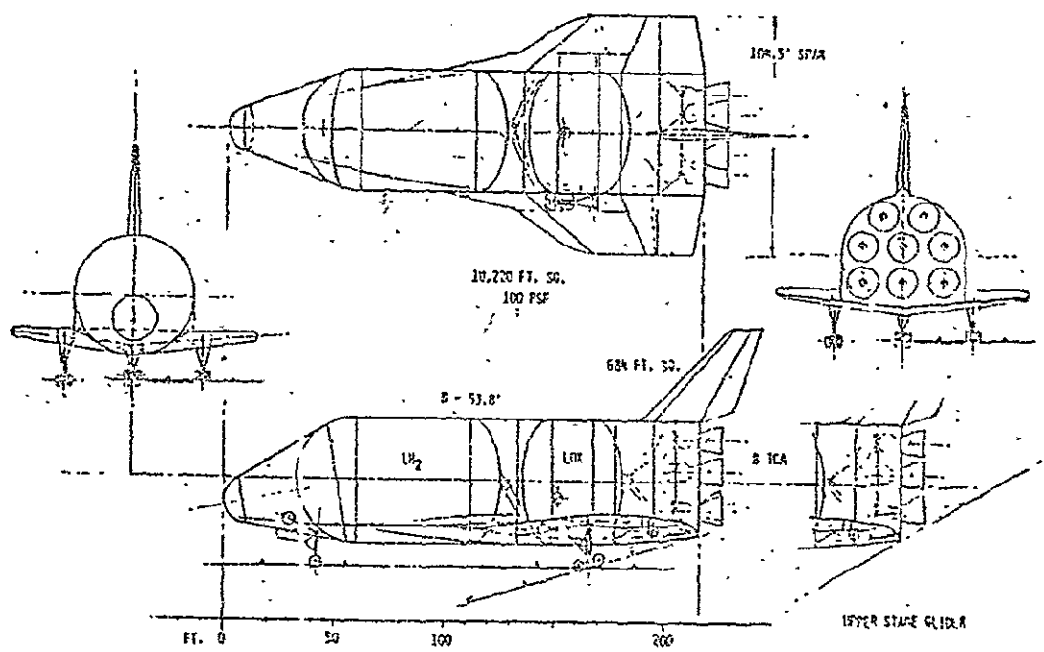
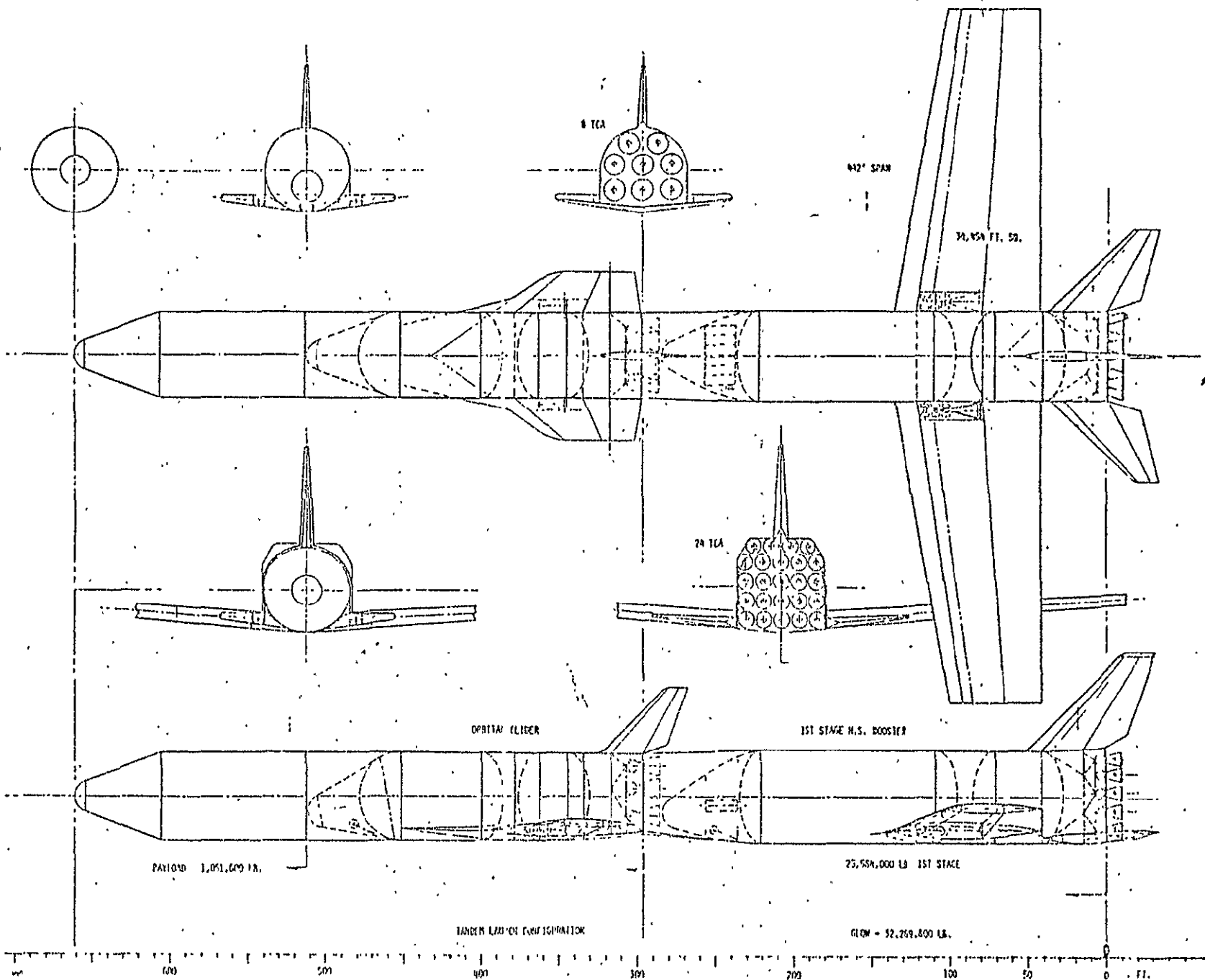


FIGURE 18

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FIGURE 19



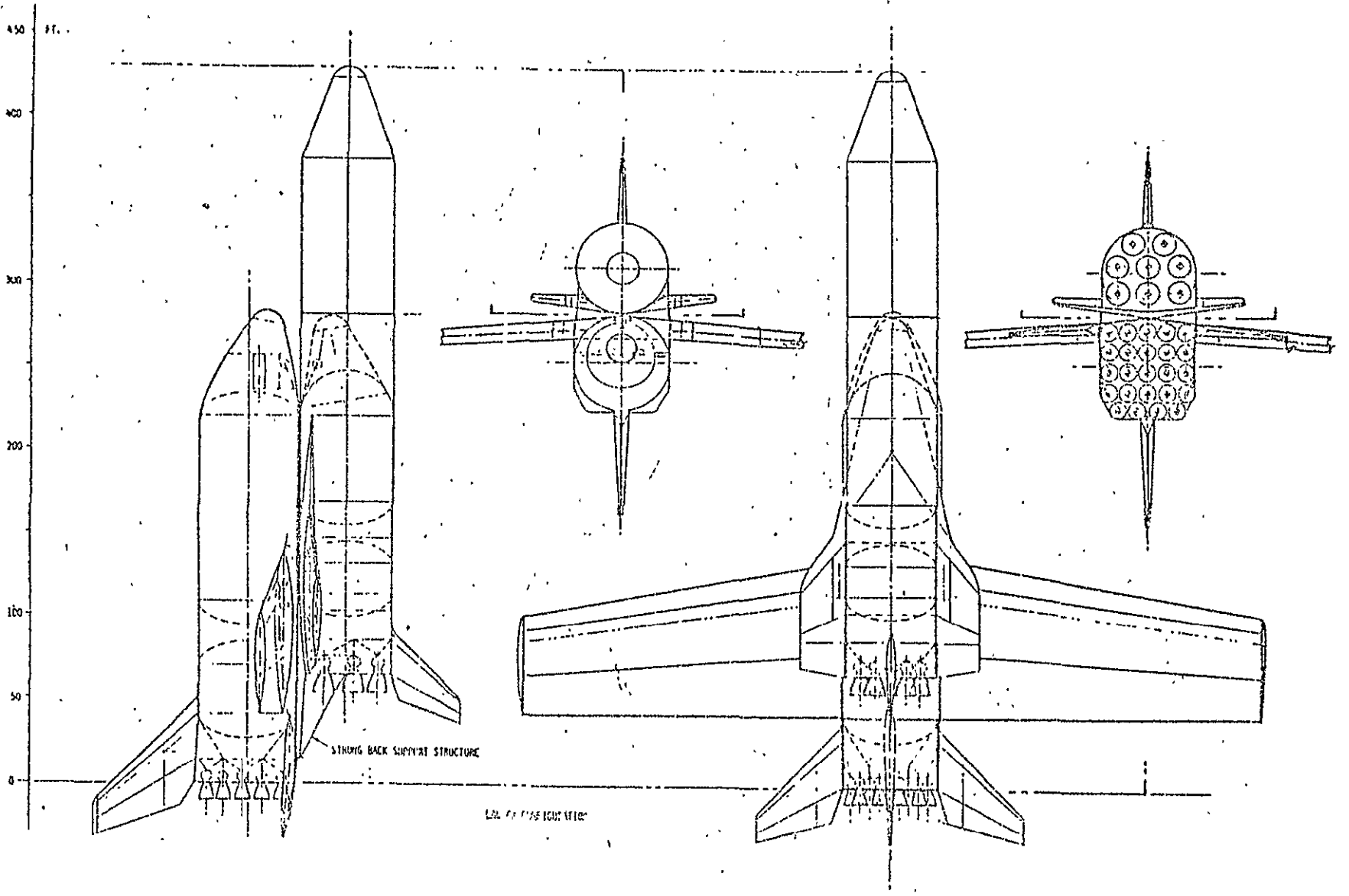


FIGURE 20

vehicle; its GLOW was 13,737.8 metric tons (30,286,651 pounds). As with the other vehicles, a growth allowance of twenty percent dry weight was maintained.

Preliminary Design Analysis of a Space Power Satellite
Heavy Lift Launch System (EDIN EX-358-76)

The purpose of this study was to determine the preliminary requirements for a tandem-staged, reusable straight-winged launch vehicle to deliver the solar power satellite (SPS) into a 270 nautical mile parking orbit via a 50 X 270 nautical mile insertion orbit. The vehicle was sized to deliver an one million pound payload to the parking orbit when launch due east from a 5.5 degree latitude. The payload was placed into circular orbit at the 270 nautical mile apogee using a 51,390 pound propulsion system.

A 50 foot diameter was assumed for both stages. The vehicle stages were sized using a set of weight and geometry estimating relationships (WAGERS). The coefficients for these WAGERS were derived from Space Shuttle Phase B System Studies. The booster was assumed to be an aluminum heat sink entry vehicle with titanium alloy covering areas with excessive heating. The second stage used a hardened compacted fiber thermal protection system (TPS). A 10% dry weight contingency was added to each stage to allow for weight growth. The booster stage rocket engine propulsion system weight scaling and performance characteristics reflects a 1995 technology level. The second stage used uprated existing space shuttle main engines (SSME's). A 30 pound per cubic foot payload density was used for this configuration. Also, an expendable interstage was assumed. The vehicle was sized using a 1.3 liftoff thrust to weight ratio (T/W) and a 1.1 second stage T/W. Finally, the configuration used LOX/C₃H₈ for the booster propellant and moderate chamber pressure ($P_c=3000$ PSIA) gas generator cycle engines. These engines were limited to a maximum vacuum thrust of 2 million pounds. The second stage used LOX/LH₂ propellant with high chamber pressure ($P_c=4000$ PSIA) staged combustion cycle engines. These engines were uprated to a maximum vacuum thrust level of 580 thousand pounds.

Both vehicle stages were designed to be aerodynamically trimmed hypersonically at an angle-of-attack of 60 degrees to minimize aerodynamic heating during entry. This was

accomplished by proper selection of aerodynamic surface areas and deflections. However, it was determined that a 75,000 pound ballast had to be added in the booster nose to locate the entry center of gravity (c.g.) properly to prevent the aerodynamic surfaces from becoming excessively large.

The gross liftoff weight of the vehicle was 21,095,563 pounds. The booster stage weighed 14,094,797 pounds while the second stage weighed 5,867,823 pounds. The booster required 16 LOX/PROPANE engines; the second stage required 14 LOX/LH₂ engines. The configuration was summarized in detail in the plots and tables presented in this analysis. The configuration is designated as EDIN EX-338-76.

EDIN EX-345-76

The purpose of this study was to determine the preliminary requirements for a tandem-staged, reusable straight-winged launch vehicle to deliver the solar power satellite (SPS) into a 270 nautical mile parking orbit via a 50 X 270 nautical mile insertion orbit. The vehicle was sized to deliver an one million pound payload to the parking orbit when launch due east from a 5.5 degree latitude. The payload was placed into circular orbit at the 270 nautical mile apogee using a 51,390 pound propulsion system.

A 50 foot diameter was assumed for both stages. The vehicle stages were sized using a set of weight and geometry estimating relationships (WAGERS). The coefficients for these WAGERS were derived from Space Shuttle Phase B System Studies. The booster was assumed to be an aluminum heat sink entry vehicle with titanium alloy covering areas with excessive heating. The second stage used a hardened compacted fiber thermal protection system (TPS). A 10% dry weight contingency was added to each stage to allow for weight growth. The booster stage rocket engine propulsion system weight scaling and performance characteristics reflects a 1995 technology level. The second stage used uprated existing space shuttle main engines (SSME's). A 10 pound per cubic foot payload density was used for this configuration. Also, an expendable interstage was assumed. The vehicle was sized using a 1.3 liftoff thrust to weight ratio (T/W) and a 1.1 second stage T/W. Finally, the configuration used LOX/C₃H₈ for the booster propellant and moderate chamber pressure ($P_c = 3000$ PSIA) gas generator cycle engines. These engines were limited to a maximum vacuum thrust of 2 million pounds. The second stage used LOX/LH₂ propellant with high chamber

pressure ($P_c=4000$ PSIA) staged combustion cycle engines.

These engines were uprated to a maximum vacuum thrust level of 580 thousand pounds.

Both vehicle stages were designed to be aerodynamically trimmed hypersonically at an angle-of-attack of 60 degrees to minimize aerodynamic heating during entry. This was accomplished by proper selection of aerodynamic surface areas and deflections. However, it was determined that a 75,000 pound ballast had to be added in the booster nose to locate the entry center of gravity (c.g.) properly to prevent the aerodynamic surfaces from becoming excessively large.

The gross liftoff weight of the vehicle was 22,693,496 pounds. The booster stage weighed 15,251,504 pounds while the second stage weighed 6,307,590 pounds. The booster required 17 LOX/PROPANE engines; the second stage required 14 LOX/LH₂ engines. The configuration was summarized in detail in the plots and tables presented in this analysis. The configuration is designated as EDIN EX-345-76.

EDIN EX-344-76

The purpose of this study was to determine the preliminary requirements for a tandem-staged, reusable straight-winged launch vehicle to deliver the solar power satellite (SPS) into a 270 nautical mile parking orbit via a 50 X 270 nautical mile insertion orbit. The vehicle was sized to deliver an one million pound payload to the parking orbit when launch due east from a 5.5 degree latitude. The payload was placed into circular orbit at the 270 nautical mile apogee using a 51,390 pound propulsion system.

A 50 foot diameter was assumed for both stages. The vehicle stages were sized using a set of weight and geometry estimating relationships (WAGERS). The coefficients for these WAGERS were derived from Space Shuttle Phase B System Studies. The booster was assumed to be an aluminum heat sink entry vehicle with titanium alloy covering areas with excessive heating. The second stage used a hardened compacted fiber thermal protection system (TPS). A 10% dry weight contingency was added to each stage to allow for weight growth. The booster stage rocket engine propulsion system weight scaling and performance characteristics reflects a 1995 technology level. The second stage used uprated existing space shuttle main engines (SSME's). A 20 pound per cubic foot payload density was used for this configuration. Also, an

expendable interstage was assumed. The vehicle was sized using a 1.3 liftoff thrust to weight ratio (T/W) and a 1.1 second stage T/W. Finally, the configuration used LOX/C₃H₈ for the booster propellant and moderate chamber pressure (P_c=3000 PSIA) gas generator cycle engines. These engines were limited to a maximum vacuum thrust of 2 million pounds. The second stage used LOX/LH₂ propellant with high chamber pressure (P_c=4000 PSIA) staged combustion cycle engines. These engines were uprated to a maximum vacuum thrust level of 580 thousand pounds.

Both vehicle stages were designed to be aerodynamically trimmed hypersonically at an angle-of-attack of 60 degrees to minimize aerodynamic heating during entry. This was accomplished by proper selection of aerodynamic surface areas and deflections. However, it was determined that a 75,000 pound ballast had to be added in the booster nose to locate the entry center of gravity (c.g.) properly to prevent the aerodynamic surfaces from becoming excessively large.

The gross liftoff weight of the vehicle was 21,427,939 pounds. The booster stage weighed 14,323,098 pounds while the second stage weighed 5,971,559 pounds. The booster required 16 LOX/PROPANE engines; the second stage required 14 LOX/LH₂ engines. The configuration was summarized in detail in the plots and tables presented in this analysis. The configuration is designated as EDIN EX-344-76.

EDIN EX-349-76

The purpose of this study was to determine the preliminary requirements for a tandem-staged, reusable straight-winged launch vehicle to deliver the solar power satellite (SPS) into a 270 nautical mile parking orbit via a 50 X 270 nautical mile insertion orbit. The vehicle was sized to deliver an one million pound payload to the parking orbit when launch due east from a 5.5 degree latitude. The payload was placed into circular orbit at the 270 nautical mile apogee using a 51,390 pound propulsion system.

A 50 foot diameter was assumed for both stages. The vehicle stages were sized using a set of weight and geometry estimating relationships (WAGERS). The coefficients for these WAGERS were derived from Space Shuttle Phase B System Studies. The booster was assumed to be an aluminum heat sink entry vehicle with titanium alloy covering areas with excessive

heating. The second stage used a hardened compacted fiber thermal protection system (TPS). A 10% dry weight contingency was added to each stage to allow for weight growth. The booster stage rocket engine propulsion system weight scaling and performance characteristics reflects a 1995 technology level. The second stage used updated existing space shuttle main engines (SSME's). A 30 pound per cubic foot payload density was used for this configuration. Also, an expendable interstage was assumed. The vehicle was sized using a 1.3 liftoff thrust to weight ratio (T/W) and a 1.1 second stage T/W. Finally, the configuration used LOX/C₃H₈ for the booster propellant and moderate chamber pressure ($P_c=3000$ PSIA) gas generator cycle engines. These engines were limited to a maximum vacuum thrust of 2 million pounds. The second stage used LOX/LH₂ propellant with high chamber pressure ($P_c=4000$ PSIA) staged combustion cycle engines. These engines were updated to a maximum vacuum thrust level of one million pounds.--

Both vehicle stages were designed to be aerodynamically trimmed hypersonically at an angle-of-attack of 60 degrees to minimize aerodynamic heating during entry. This was accomplished by proper selection of aerodynamic surface areas and deflections. However, it was determined that a 75,000 pound ballast had to be added in the booster nose to locate the entry center of gravity (c.g.) properly to prevent the aerodynamic surfaces from becoming excessively large.

The gross liftoff weight of the vehicle was 21,031,159 pounds. The booster stage weighed 13,896,739 pounds while the second stage weighed 6,001,005 pounds. The booster required 16 LOX/PROPANE engines; the second stage required 8 LOX/LH₂ engines. The configuration was summarized in detail in the plots and tables presented in this analysis. The configuration is designated as EDIN EX-349-76.

The purpose of this study was to determine the preliminary requirements for a tandem-staged, reusable straight-winged launch vehicle to deliver the solar power satellite (SPS) into a 270 nautical mile parking orbit via a 50 X 270 nautical mile insertion orbit. The vehicle was sized to deliver a 500 thousand pound payload to the parking orbit when launched due east from a 5.5 degree latitude. The payload was placed into circular orbit at the 270 nautical mile apogee using a 25,695 pound propulsion system.

A 40 foot diameter was assumed for both stages. The vehicle stages were sized using a set of weight and geometry estimating relationships (WAGERS). The coefficients for these WAGERS were derived from Space Shuttle Phase B System Studies. The booster was assumed to be an aluminum heat sink entry vehicle with titanium alloy covering areas with excessive heating. The second stage used a hardened compacted fiber thermal protection system (TPS). A 10% dry weight contingency was added to each stage to allow for weight growth. The booster stage rocket engine propulsion system weight scaling and performance characteristics reflects a 1995 technology level. The second stage used updated existing space shuttle main engines (SSME's). A 30 pound per cubic foot payload density was used for this configuration. Also, an expendable interstage was assumed. The vehicle was sized using a 1.3 liftoff thrust to weight ratio (T/W) and a 1.1 second stage T/W. Finally, the configuration used LOX/C₃H₈ for the booster propellant and moderate chamber pressure ($P_c=3000$ PSIA) gas generator cycle engines. These engines were limited to a maximum vacuum thrust of 2 million pounds. The second stage used LOX/LH₂ propellant with high chamber pressure ($P_c=4000$ PSIA) staged combustion cycle engines. These engines were updated to a maximum vacuum thrust level of 580 thousand pounds.

Both vehicle stages were designed to be aerodynamically trimmed hypersonically at an angle-of-attack of 60 degrees to minimize aerodynamic heating during entry. This was accomplished by proper selection of aerodynamic surface areas and deflections. However, it was determined that a 50,000 pound ballast had to be added in the booster nose to locate the entry center of gravity (c.g.) properly to prevent the aerodynamic surfaces from becoming excessively large.

The gross liftoff weight of the vehicle was 11,584,050 pounds. The booster stage weighed 7,815,211 pounds while the second stage weighed 3,192,359 pounds. The booster required 9 LOX/PROPANE engines; the second stage required 8 LOX/LH₂ engines. The configuration was summarized in detail in the plots and tables presented in this analysis. The configuration is designated as EDIN EX-350-76.

EDIN EX-356-76

The purpose of this study was to determine the preliminary requirements for a tandem-staged, reusable straight-winged launch vehicle to deliver the solar power satellite (SPS) into a 270 nautical mile parking orbit via a 50 X 270 nautical mile insertion orbit. The vehicle was sized to deliver a 500 thousand pound payload to the parking orbit when launched due east from a 5.5 degree latitude. The payload was placed into circular orbit at the 270 nautical mile apogee using a 25,695 pound propulsion system.

The diameters for the booster and second stages were 50 and 40 feet, respectively. The vehicle stages were sized using a set of weight and geometry estimating relationships (WAGERS). The coefficients for these WAGERS were derived from Space Shuttle Phase B System Studies. The booster was assumed to be an aluminum heat sink entry vehicle with titanium alloy covering areas with excessive heating. The second stage used a hardened compacted fiber thermal protection system (TPS). A 10% dry weight contingency was added to each stage to allow for weight growth. The booster stage rocket engine propulsion system weight scaling and performance characteristics reflect a 1995 technology level. The second stage used up-rated existing space shuttle main engines (SSME's). A 30 pound per cubic foot payload density was used for this configuration. Also, an expendable interstage was assumed. The vehicle was sized using a 1.3 lift off thrust to weight ratio (T/W) and a 1.1 second stage T/W. Finally, the configuration used LOX/LH₂ for the booster propellant and high chamber pressure ($P_c=4000$ PSIA) staged combustion cycle engines. The mixture ratio used for the booster engines was 7.0:1 and the nozzle expansion ratio was 40:1. These engines were limited to a maximum vacuum thrust of 2 million pounds. The second stage used LOX/LH₂ propellant with high chamber pressure ($P_c=4000$ PSIA) staged combustion cycle engines. These engines were up-rated to a maximum vacuum thrust level of 580 thousand pounds.

Both vehicle stages were designed to be aerodynamically trimmed hypersonically at an angle-of-attack of 60 degrees to minimize aerodynamic heating during entry. This was accomplished by proper selection of aerodynamic surface areas and deflections. However, it was determined that a 25,000 pound ballast had to be added in the booster nose to locate the entry center of gravity (c.g.) properly to prevent the aerodynamic surfaces from becoming excessively large.

The gross liftoff weight of the vehicle was 9,626,156 pounds. The booster stage weighed 6,208,146 pounds while the second stage weighed 2,827,656 pounds. The booster required 7 LOX/LH₂ engines; the second stage required 7 LOX/LH₂ engines. The configuration was summarized in detail in the plots and tables presented in this analysis. The configuration is designated as EDIN EX-356-76.

EDIN EX-358-76

The purpose of this study was to determine the preliminary requirements for a tandem-staged, reusable straight-winged launch vehicle to deliver the solar power satellite (SPS) into a 270 nautical mile parking orbit via a 50 X 270 nautical mile insertion orbit. The vehicle was sized to deliver an one million pound payload to the parking orbit when launch due east from a 5.5 degree latitude. The payload was placed into circular orbit at the 270 nautical mile apogee using a 51,390 pound propulsion system.

The diameters for the booster and second stages were 60 and 50 feet, respectively. The vehicle stages were sized using a set of weight and geometry estimating relationships (WAGERS). The coefficients for these WAGERS were derived from Space Shuttle Phase B System Studies. The booster was assumed to be an aluminum heat sink entry vehicle with titanium alloy covering areas with excessive heating. The second stage used a hardened compacted fiber thermal protection system (TPS). A 10% dry weight contingency was added to each stage to allow for weight growth. The booster stage rocket engine propulsion system weight scaling and performance characteristics reflects a 1995 technology level. The second stage used uprated existing space shuttle main engines (SSME's). A 30 pound per cubic foot payload density was used for this configuration. Also, an expendable interstage was assumed. The vehicle was sized using a 1.3 liftoff thrust to weight ratio (T/W) and a 1.1 second stage T/W. Finally, the

configuration used LOX/LH₂ for the booster propellant and high chamber pressure ($P_c=4000$ PSIA) staged combustion cycle engines. The mixture ratio used for the booster engines was 7.0:1 and the nozzle expansion ratio was 40:1. These engines were limited to a maximum vacuum thrust of 2 million pounds. The second stage used LOX/LH₂ propellant with high chamber pressure ($P_c=4000$ PSIA) staged combustion cycle engines. These engines were uprated to a maximum vacuum thrust level of 580 thousand pounds.

Both vehicle stages were designed to be aerodynamically trimmed hypersonically at an angle-of-attack of 60 degrees to minimize aerodynamic heating during entry. This was accomplished by proper selection of aerodynamic surface areas and deflections. However, it was determined that a 75,000 pound ballast had to be added in the booster nose to locate the entry center of gravity (c.g.) properly to prevent the aerodynamic surfaces from becoming excessively large.

The gross liftoff weight of the vehicle was 17,558,479 pounds. The booster stage weighed 11,241,835 pounds while the second stage weighed 5,167,590 pounds. The booster required 13 LOX/LH₂ engines; the second stage required 12 LOX/LH₂ engines. The configuration was summarized in detail in the plots and tables presented in this analysis. The configuration is designated as EDIN EX-358-76.

A final report was submitted at the end of each study phase. Recommendations for design study scenario changes, new or modified hardware and software development efforts were made. The reports contained analysis techniques recommended for future studies.

Training and Tutorial Aids

The success of the EDIN computer aided design system depends to a large degree of the acceptance of the system by the ultimate users. Therefore, Sigma Corporation provided documentation and training on the use of the EDIN System. A program development activity was initiated for the implementation of computerized tutorial aids. The end product of this development effort was to be a pilot program which provides the user of the EDIN System with sufficient instructions to setup and solve an engineering problem involving the use of the executive system, the general purpose and special purpose utilities and one or more technology programs. A pilot program was written for the executive system. An evaluation revealed that with a rapidly changing system, training could best be provided by working directly with NASA end users.

Consultation

There has been a virtual explosion in the availability of interactive graphics hardware in the past few years. Software development which utilizes the latest hardware innovations are not far behind. It is recognized that computer aided design is an expanding field and developing expertise is evolving from many sources. Sigma Corporation acquired consulting services of experts throughout the contract period for the enhancement of the development activities at JSC. The primary objectives in seeking outside consulting were:

1. To maintain a close look at the state-of-the-art development in CAD.
2. To assure that the methods selected for implementation by JSC are the best possible choice.
3. To provide exposure of JSC to other CAD applications and design problems with CAD.
4. To recommend additions or changes to the EDIN System.

Many university and institutional applications of CAD have elements which could be of some benefit to JSC. The aerospace industry as a whole, has been applying CAD techniques for years and many are offering expertise in the field. Finally, computer manufacturers and software houses have contributed significantly to the developing CAD field. Sigma Corporation maintained visibility of external CAD activities during the contract period and recommended consultation, acquisitions and development activities to the NASA technical monitor.

CONCLUSIONS AND RECOMMENDATIONS

The EDIN System, as installed on the Univac 1110 computer at JSC, is operated remotely from teletype, storage tube and interactive (Adage 340) terminals. The total system has a three-level release schedule. Level I is the basic EDIN System consisting of a library of independent computer programs and an executive data management program for inter-program communication. The Level I system was released in 1975. Interactive man-in-the-loop capability was planned for Level II and III. Level II is a single-station, single-user system which is now in the development phase. Level III will be a multiple-station, multiple-user system that will support many projects. Sigma Corporation recommends that the Level II system be completed by the end of CY-1977. The tasks required to complete the Level II system are as follows:

1. Develop a data base management system which spans the needs of a multidisciplinary design environment.
2. Develop interactive computer programs for analyzing weight and cost estimating relationships.
3. Provide Adage computer interactive interfaces to selected EDIN programs operating on the Univac 1110 computer.
4. Develop an interactive plot analysis program for manipulating retrieval, wind tunnel and flight test data.
5. Develop an interactive geometry definition module to support preliminary design activities at the Johnson Space Center (JSC).

6. Provide consultation, training and simulation effort in the use of the EDIN System.

The end-product of the effort should be a Level II single-station interactive system for performing man-in-the-loop interactive design studies for other JSC programs. This Level II EDIN System should include the following computer programs:

1. Univac 1110 Data Base Management System.
2. Adage GS 340 Data Base Management System.
3. Interactive Weight and Cost Analysis Model Program.
4. ROBOT Trajectory Optimization Interface Program.
5. Interactive Plot Analysis Program.
6. Interactive Geometry Definition Program.

Once the Level II System is near an operational state, detailed specifications for a Level III System that provides multiple station interactive capability of using the EDIN System.

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