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SPACE TUG AVIONICS DEFINITION STUDY

FINAL REPORT

VOLUME V ✦ COST & PROGRAMMATICS

GENERAL DYNAMICS
Convair Division

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FOREWORD

This final report on the Space Tug Avionics Definition Study was prepared by General Dynamics, Convair Division for the National Aeronautics and Space Administration's George C. Marshall Space Flight Center in accordance with Contract NAS8-31010. The study was conducted under the direction of NASA Contracting Officer Representative, Mr. James I. Newcomb, and deputy COR, Mr. Maurice Singley.

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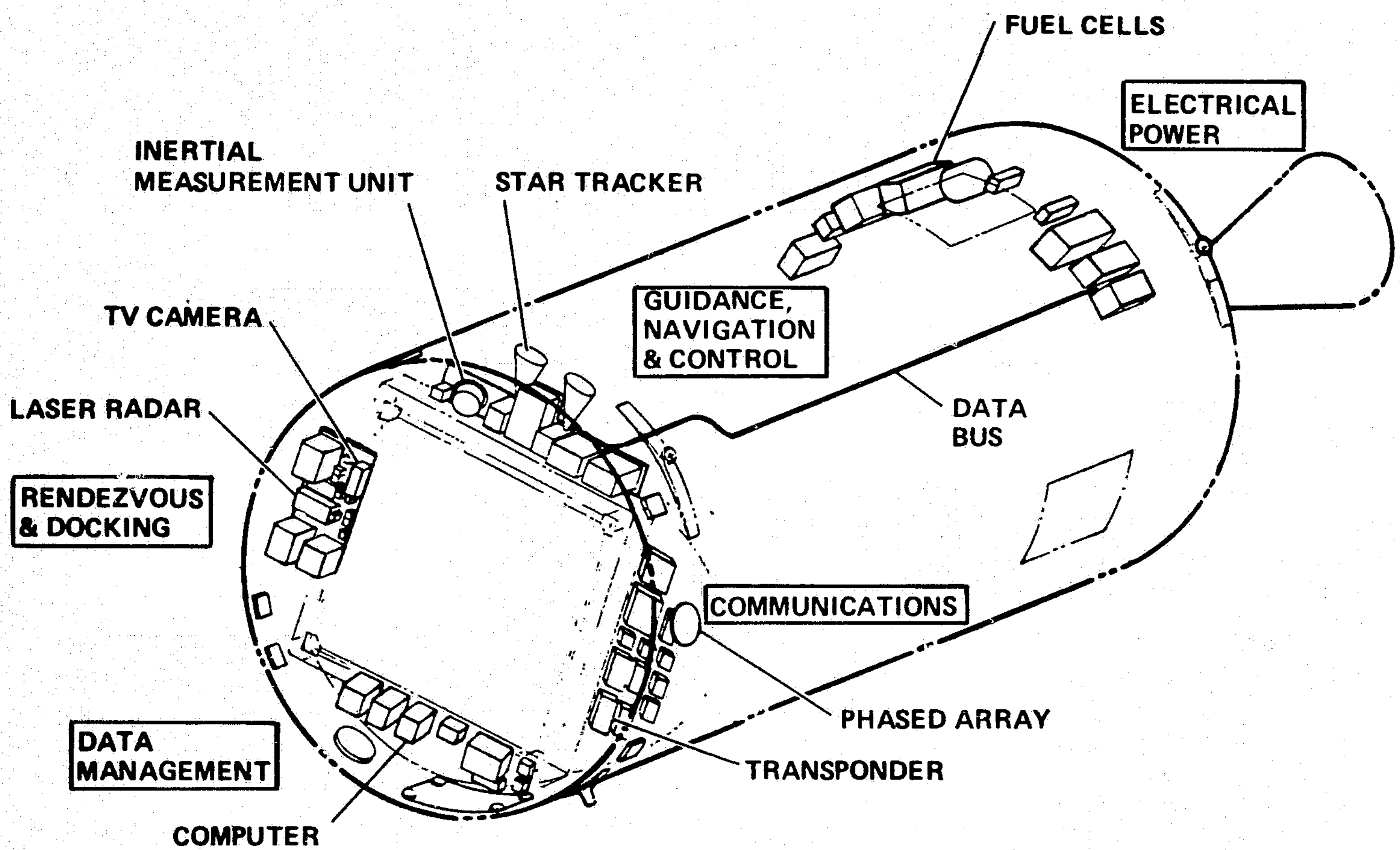

FUEL CELLS
ELECTRICAL POWER
INERTIAL MEASUREMENT UNIT
STAR TRACKER
TV CAMERA
GUIDANCE, NAVIGATION & CONTROL
LASER RADAR
DATA BUS
RENDEZVOUS & DOCKING
COMMUNICATIONS
PHASED ARRAY
DATA MANAGEMENT
TRANSPONDER
COMPUTER

SUMMARY

The Space Tug Avionics Definition Study was performed by General Dynamics Convair Division under Contract NAS8-31010 to the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Alabama. The objectives of this eight month study were to:

Define a baseline avionics system to meet Tug requirements using (circa) 1978 technology.

Define critical subsystems, functions and interfaces.

Identify areas requiring significant hardware technology advances.

The preferred baseline avionics system features a central digital computer that integrates the functions of all of the Tug's subsystems by means of a redundant digital data bus. The major subsystems of the avioncs system are:

Data Management Subsystem – The central computer consists of dual central processor units, dual input/output processors, and a fault tolerant memory utilizing internal redundancy and error checking. Control of the data bus is through a computer interface unit, which directs the bus traffic to and from the digital interface units that provide the interfaces to the various subsystems.

Communications Subsystem – Three electronically steerable phased arrays provide downlink transmission from any Tug attitude directly to ground or via TDRS.

Guidance, Navigation and Control Subsystem – Six laser gyros and six accelerometers in a dodecahedron configuration make up the Inertial Measurement Unit. Interferometric landmark tracking of ground based radars provides autonomous updates of position and velocity. Startrackers and sun sensors are onboard for attitude update.

Rendezvous and Docking – Both a scanning laser radar (LADAR) and a TV system employing strobe lamps are required as acquisition and docking sensors.

Electrical Power – Primary DC power at a nominal 28 volts is supplied from dual lightweight, thermally integrated fuel cells which operate from propellant grade reactants out of the main tanks.

Instrumentation – Provides conditioning and multiplexing of data from all Tug systems.

This volume of the final report documents the cost estimates developed during the study, identifies the present status of those technologies that were the basis for component selection, and defines the recommended technology progress needed to establish confidence in component development and in the total Tug program development at the beginning of Phase C/D.

Significant conclusions and recommendations discussed in the following sections include:

Total DDT&E cost estimates for the Avionics System of $94 million.

Early year funding (1975-78) reduces component development risk by the start of Phase C/D and reduces the total DDT&E for avionics to $75 million.

Technology progress is critical to the Tug program in the areas of SUMC computer, software, lightweight technology fuel cell, and the laser radar.

Subsystem/system technology efforts associated with redundancy management, software interfaces and optimum sensor mixes need to be pursued.

$6 million early year funding (1976-1978) recommended for supporting research and technology efforts in Tug-related component and subsystem technologies.

SECTION 1

INTRODUCTION

The Avionics System for the full-capability Space Tug to be developed by NASA for initial operations in late 1983 will be driven by requirements of 1) performance to deliver 8000 pounds of payload into geosynchronous orbit and retrieve 3500 pounds, 2) mission duration up to 185 hours, 3) payload retrieval with potential for on-orbit servicing in the future, 4) autonomous flight operations, 5) Shuttle crew safety and mission success reliability (0.97 for all missions), and 6) 1983 IOC date for first operational flight. The 1978 Phase C/D timing will allow the Tug program to take maximum advantage of technology advances in the avionics implementation of these requirements to attain low system weight, power system capacity, sensors and software for rendezvous and docking, navigation update, checkout, redundancy and its management.

The major output of this study was the definition of the baseline avionics system for the Space Tug. That definition consists of system requirements, configuration descriptions, interfaces, cost estimates and technology support requirements. This volume is concerned with the latter two elements of that baseline definition.

The advanced technology nature of this avionics system has a significant influence on the system's total development cost. The advanced components selected for the baseline system definition were projections from research/technologies presently being pursued. From the current status of these technologies, the further technology development effort was defined that would be required before component design and development could be started or procurement specifications prepared. This is an essential first step in the whole process of getting an advanced hardware system designed, built, tested, qualified, and flown. There are two approaches for the accomplishment of these needed additional technology activities:

a. Perform these activities after Phase C/D starts. The overall Tug development schedule calls for Phase C/D to start in late 1978, culminating with first operational flight in December 1983. The total DDT&E cost of avionics development for this approach was estimated to be $92.8 million.

b. Perform these activities during the three-year period prior to the start of Phase C/D. The confidence gained by the early solution to problems and the proofing of techniques will reduce the risk during the actual component development phase and will reduce the total DDT&E cost of avionics development to $74.1 million.

This volume contains an assessment of the applicable technologies – their present status and the additional technology advancement needed. Planning of this additional effort is included as it applies to each avionics subsystem. The influence of the two approaches toward accomplishing these technology tasks will be seen in the detailed cost estimates and methodology.

SECTION 2

TECHNOLOGY ASSESSMENT

The total development cost of an avionics system represents all of the expected expenditures at the completion of the development program: the engineering design, development, and testing as well as the potential changes and uncertainties (which depend on the quality of the schedule estimates, funding constraints, requirements, etc.). These latter factors are risks in development and are accounted for in the cost estimates through the use of multiplying factors, called uncertainty or growth factors.

The key to the magnitude of an uncertainty factor is the status of the state of the art associated with component hardware selected for use in the avionics system. Based on data developed in previous contracts (Reference 1), these factors range from 10% for development programs using off-the-shelf equipment to 90% for programs using advanced state-of-the-art hardware plus high concurrency development of subsystems.

Since many of the components are based on advanced state-of-the-art techniques presently being pursued through supporting research and technology efforts, the potential status of these on-going technologies in late 1978 when Phase C/D begins was assessed to determine the appropriate uncertainty value to be used in the cost estimates.

It is this technology assessment that is addressed in this section.

2.1 APPROACH

The rationale used to establish the 1978 technology base is illustrated in Figure 2-1. The two primary inputs to the technology assessment are 1) the component/subsystems selections as defined in Volume III, and 2) the on-going technology programs being pursued in government laboratories or in industry. These on-going technology programs included those specifically aimed toward the Tug program as well as those directed toward other aerospace programs but which have applicability to Tug avionics. These on-going programs were then projected as to their status in 1978 based on current project planning and funding.

In addition, the technologies needed specifically to support Tug avionics were assessed to evaluate the potential risk that the projected 1978 status presented to the avionics development program. The differences between them is the additional technology effort needed as a minimum in support of Tug avionics and the period planned for their accomplishment influences the uncertainty factors. As illustrated in Figure 2-1 these additional technologies can be accomplished prior to Phase C/D (1975-78) or they can be accomplished during Phase C/D (after 1978). If the required technology funding is made available during 1975-78 as illustrated by the shaded area of the annual funding curve then the risk to the Tug avionics development program will be greatly reduced

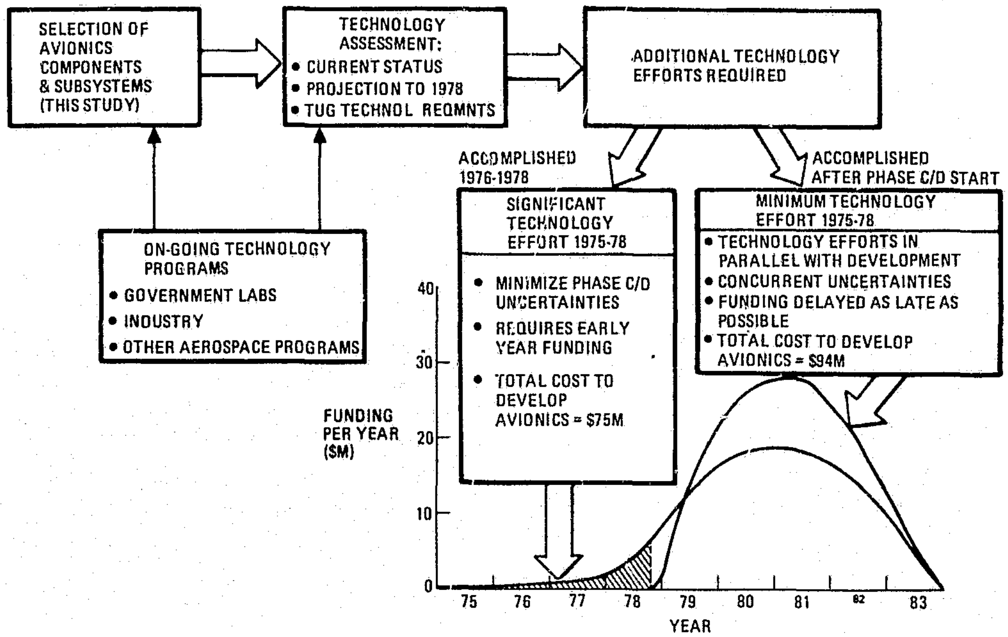


Figure 2-1. Approach to Establishing 1978 Technology Base

and the system can be developed for less total dollars ($74.1 million). This is because the 1975-78 technology funds are used to minimize the technical uncertainties and this in turn minimizes the interdependency between subsystem and components during Phase C/D. The 1975-78 technology program includes activities at the component level, subsystem level, and system level as well as demonstration of the compatibility of interfaces — both internal and external to the avionics system.

If technology funding is not available during 1975-78, then these technology efforts will have to be done during the early part of Phase C/D. These technologies would then be accomplished in parallel with development. Since most activities are either on or close to the critical path, problems in any one component have schedule and cost impacts on the total development program. Because of these strong interactions between subsystems and components, more uncertainty exists, and the total cost to develop Tug avionics will be approximately 25% higher ($92.8 million). Cost details are shown in Section 4.

2.2 REQUIREMENTS FOR TECHNOLOGY ACTIVITIES

Figure 2-2 illustrates the five phases through which any technology program must go to establish a high confidence that the hardware or component application from the technology can be readily designed, developed, manufactured, tested, and qualified in a low risk/low cost DDT&E program. The major milestones of the Tug program are shown at the top of the figure. The preliminary design review (PDR) is indicated as being the dividing line between technology and development. The schedule relationship of the five phases is not significant except that the technology tasks progress from top to bottom and left to right.

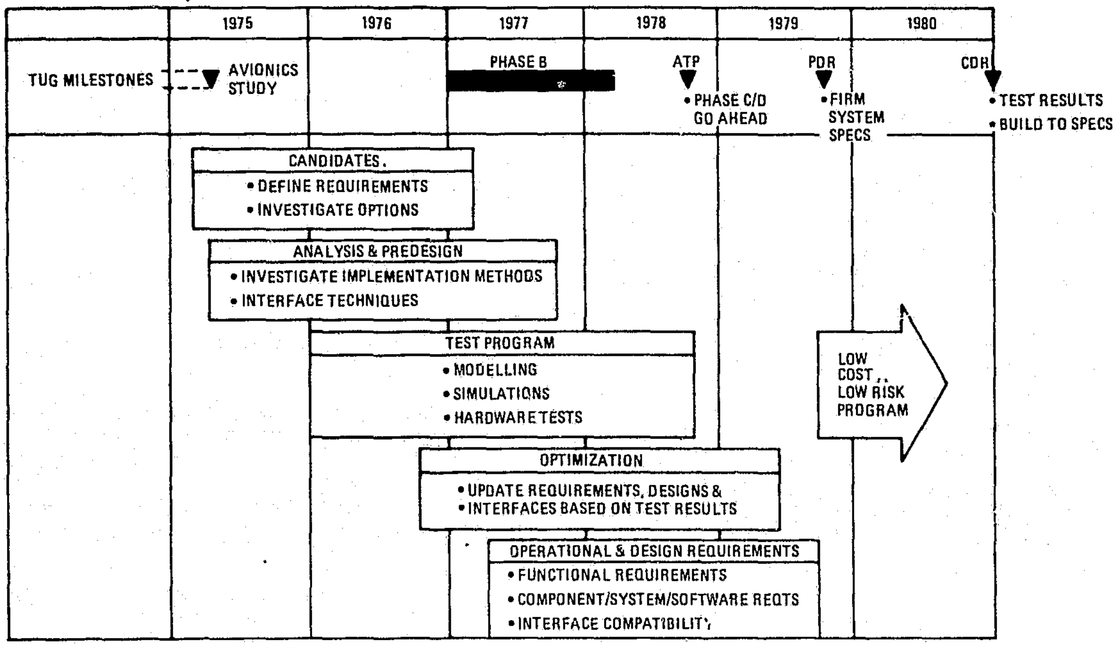


Figure 2-2. Technology Program Phases

The PDR is conducted prior to commencing the detailed design process to assure that the approach is feasible and sound from a design, development, test, and activation viewpoint and that the performance/design requirements in the Part I Design Specification can be effectively met. Data to be produced at the PDR includes:

a. Preliminary interface control documents.

b. Design analyses.

c. Layout, general arrangement, and envelope drawings.

d. Schematics and block diagrams.

e. System sizing and trade study results.

f. Material and process specification listings.

g. Applicable procurement specifications.

h. Test requirements.

i. Design support test results.

j. Mockups and models.

k. Updated plans, procedures and schedules.

l. Commonality candidates and rationale.

m. Part I of the End Item specification.

PDR's are usually performed incrementally – subsystem by subsystem.

The significance of Figure 2-2 is that it provides a framework for 1) judging the effectiveness of on-going technology programs, 2) recommending additional technology programs, and 3) planning an integrated technology program. This will ensure that the technology progresses year-by-year until the desired features are obtained at the required date. In addition, the framework provides a means of measuring the relative progress of each technology element and then allocating funds on a priority basis.

2.3 CURRENT TECHNOLOGY STATUS

Table 2-1 summarizes the assessment of the current status of the technology of each major component in the avionics system. The left-hand column lists the major components within the avionics subsystems. The center column describes their current status, and indicates on-going efforts that are contributing to the advancement of those programs with respect to what is needed for Tug. The right-hand column shows the technology drivers that are crucial to Tug avionics development.

Table 2-1. Current Status Assessment of On-going Technologies

SUBSYS/COMPONENTS	TECHNICAL STATUS	PROGRAM DRIVERS
DATA MGT SYSTEMS		
DIGITAL COMPUTER	SIMPLEX TESTING 1976/77, PROTOTYPE UNITS, SPACELAB APPLICATIONS	REDUNDANT HARDWARE CONFIGURATION, REDUNDANCY MGT, INTEGRATION WITH OTHER SUBSYS, SOFTWARE
DATA BUS	CURRENT TECHNOLOGY, SIMPLEX TESTING	REDUNDANCY MGT, ERROR CONTROL, TRAFFIC CONTROL, INTEGRATION, SOFTWARE
TAPE RECORDER	NASA STANDARD	NONE
GUID, NAV & CONTROL		
LASER GYRO IMU	EXPERIMENTAL HARDWARE/SIMPLEX CONFIG BEING TESTED, DODECAHEDRON IN DESIGN	DODECAHEDRON CONFIG, FAILURE DETECTION/ RECONFIGURATION, INTEGRATION WITH DMS, SOFTWARE
LASER RATE GYROS	EXPERIMENTAL HARDWARE BEING TESTED	NEED FOR RATE GYROS, REDUNDANCY MGT
STAR TRACKER/ SUN SENSOR	UNITS DEVELOPED	ADAPTION TO TUG, SOFTWARE
INTERFEROMETRIC LANDMARK TRACKER (ILT)	TECHNIQUES UNDERSTOOD, COMPONENTS AVAILABLE	CONCEPT NOT VERIFIED (NEEDS SYSTEM INTEGRATION), NEED FOR ILT DEPENDS ON AUTONOMY LEVEL
CONTROL ELECTRONICS	HARDWARE DEVELOPED, PROBLEMS UNDERSTOOD	REDUNDANCY MANAGEMENT
RENDEZVOUS & DOCKING		
SCANNING LASER RADAR	LAB UNITS EXIST	PERFORMANCE, FUNCTIONAL & PHYSICAL PACKAGING
TV CAMERA & ELECTRONICS	MODIFIED APOLLO BLACK & WHITE	MAN-IN-LOOP NEEDS FEASIBILITY DEMO
LED RANGING SYSTEM	CURRENT STATE OF ART	SYSTEM DEVELOPMENT/INTEGRATION
COMMUNICATIONS		
ELECT. STEERED PHASED ARRAY	EXPERIMENTAL HARDWARE AVAILABLE	TESTS TO PROVE FEASIBILITY TO TUG MISSION, PHYSICAL INTEGRATION INTO TUG, REDUNDANCY
COMMAND DECODER & DISTRIBUTION	ESSENTIALLY EXISTING FLIGHT HARDWARE	INTEGRATION INTO DMS
SGLS ENCODER/DECODER	1978 USAF DESIGN	NONE (GFE)
NETWORK COMPATIBILITY	BEING DEVELOPED FOR ORBITER	ADAPTABILITY OF SHUTTLE COMPONENTS TO TUG, SYS INTEGRATION INTO DMS
AUTONOMY LEVEL	LEVEL II PROBLEMS ARE UNDERSTOOD	SYSTEM INTEGRATION IMPACTS IF AUTONOMY LEVEL IS CHANGED
ELECTRICAL POWER		
FUEL CELL	LIGHTWEIGHT DEVELOPMENT CELL BUILT & INITIAL TESTING	UNIT CONFIG, RELIAB/LIFE, INTEGRATION, POWER LEVEL (DMS, PL, SLR, HEATERS), REDUNDANCY MGT, PERFORMANCE ENVELOPE
THERMAL CONTROL SYS	ORBITER SYS BUILT & TESTED	SYSTEM INTEGRATION, REDUNDANCY MGMT
PRODUCT WATER SYS	HARDWARE IS STATE OF ART	
PURGE, VENT & SAFING SYSTEM	HARDWARE IS STATE OF ART	
REACTANT SUPPLY SYSTEM	TESTED HARDWARE EXISTS	IMPACT OF HELIUM IN FUEL CELL REACTANTS
POWER PROCESSING & CONTROL	USE 1978 STATE OF ART	SYSTEM INTEGRATION & PERFORMANCE
BATTERY	OFF THE SHELF	NONE

Specifics of the on-going technology programs are:

Data Management System — Modules of the SUMC digital computer are being developed in an on-going program that includes configuration verification testing – scheduled at MSFC in 1976-77. This testing is for a simplex configuration and is for application of the SUMC to the Spacelab program. Redundant hardware investigations are lacking if this program is to support the Tug program. Fault tolerant memories are in the breadboard development phase. This is a critical technology for Tug. Spare memory planes as well as spare memory modules are superior to providing complete redundant memories. The data bus uses current technology in development for the Shuttle, B-1, and other programs. DIU's and the CIU utilizing LSI technology and power reducing techniques need early concept work.

Guidance, Navigation, and Control System — Experimental hardware of the laser gyro IMU in a simplex configuration is currently being tested in an on-going program at MSFC. A dodecahedron configuration is being designed. Star tracker/sun sensors are essentially off-the-shelf units but will need adaptability and software for the Tug missions. For the interferometric land mark tracker – the techniques are understood and hardware components are in design; however, adaptability to the Tug needs to be demonstrated.

Rendezvous and Docking System – Scanning laser (LADAR) laboratory units have been developed. Operational problems involving field of view and spurious responses limit close in docking capability. The TV camera is off-the-shelf hardware. This study has demonstrated the feasibility of manned remote rendezvous and docking. Stereo TV-type displays have future applicability to this function. Work is going on now at MSFC on stereo display techniques.

Communications System — Phased array hardware is being developed. The "transmit only" requirement (newly defined by this study) should be factored into that program. Techniques for optimum signal processing to obtain network compatibility are being pursued in the industry.

Electrical Power System – The power plant element of the Shuttle's electrical power system is an on-going program as well as the adaptation of that high pressure supercritical storage fuel cell to the Tug. The 1976-78 technology fuel cell, called the lightweight fuel cell, has also been in development, and cells have been through preliminary testing. This latter technology has been selected as the baseline configuration for Tug. Support of its development is crucial. Parallel work should continue using the Shuttle-type power plant to investigate low pressure operation, helium contamination solutions, redundancy implementations, etc., as a low risk backup to the lightweight technology.

Instrumentation System – Maintenance support is a driver of special instrumentation requirements particularly oriented toward mechanical systems where rotating equipment is involved. Sensor technologies associated with acoustical emission are being studied and developed. Potential for passive detector development is seen for chemical, temperature, and vibration sensitive paints, strips or fusing compounds used in limit detecting, and bi-state and nonreverting applications with no electrical interface. Magnetic accumulator plugs in lubricant reservoirs detect wear. Since reusability is needed by the Tug, post-mission assessment of component condition is an important function.

2.4 ADDITIONAL TECHNOLOGY EFFORTS

Table 2-2 shows the additional technology effort that is needed at the component level and at the subsystem/system level. These data were obtained by evaluating the status of the on-going technology programs and determining the modifications to the on-going programs and the recommended subsystem/system technologies that are needed to be pursued.

Data Management – The investigation of redundancy management techniques both internal to a modular computer and external out to the LRU's is key to the development of the data management process. Spare memory planes as well as spare memory modules are superior to providing complete redundant memories. DIU's and the CIU utilizing LSI technology and power reducing techniques need early concept work. Integration of redundant memories, CPU's, IOP's and data bus components is required — investigating such techniques as fault and error detection, handling software traffic, and switchover approaches involving automatic cross-strapping.

Table 2-2. Additional Technology Efforts Needed

	COMPONENT	SUBSYSTEM/SYSTEM
DATA MANAGEMENT	• FAULT-TOLERANT MEMORY TECHNIQUES & TESTING • REDUNDANT RECONFIGURATION TECHNIQUES • DIUs & CIUS USING LSI/POWER REDUCING TECHNIQUES	• REDUNDANCY MANAGEMENT TECHNIQUES: FAULT DETECTION & ERROR CORRECTION APPROACHES SOFTWARE TRAFFIC MODELING AUTOMATIC CROSS-STRAPPING TECHNIQUES
GUIDANCE NAV & CONTROL	• DODECAHEDRON LASER GYRO IMU TESTING • ADAPTATION OF UPDATE SENSORS TO TUG REQUIREMENTS	• MULTISENSOR FAULT DETECTION/RECONFIGURATION TECHNIQUES • UPDATE SENSOR COMBINATIONS MODELING • MULTISENSOR INPUT FILTER MODELS
COMMUNICATION	• OPTIMIZE SIGNAL PROCESSING & MODULATION TECHNIQUES • ADAPT PHASED ARRAYS TO "TRANSMIT ONLY" REQUIREMENT	• REDUNDANCY MANAGEMENT TECHNIQUES FOR AUTOMATIC RECONFIGURATION • ADAPT SHUTTLE CROSS-STRAPPING TECHNIQUES TO TUG REQUIREMENTS
ELECTRICAL POWER	• ESTABLISH LIGHTWEIGHT FUEL CELL TECHNOLOGY: DESIGN & BUILD UNIT CONFIGURATION PERFORMANCE TESTING USING MAIN PROPELLANTS • MODIFY SHUTTLE FUEL CELL (BACKUP) LOW-PRESSURE TESTING He CONTAMINATION TESTING	• THERMAL INTEGRATION TECHNIQUES • REDUNDANCY MANAGEMENT/AUTOMATIC RECONFIGURATION TECHNIQUES TO ACHIEVE A FAIL-OPERATIONAL CONFIGURATION
RENDEZVOUS & DOCKING	• HIGHER POWER LASERS • CLOSE-IN SENSOR FOR DOCKING • SOLID-STATE IMAGE CAMERAS • RELIABILITY IMPROVEMENTS	• STUDY/MATH MODELING/SIMULATIONS FOR: • IMPACT OF SERVICING FUNCTION ON RENDEZVOUS & DOCKING • AUTONOMOUS CONTROL ALGORITHM SIMULATIONS FOR DOCKING • OPTIMUM COMBINATION OF SENSORS • LOS TECHNIQUES FOR IMPROVING POSITION ACCURACY (INTERACTION WITH GN&C SYSTEM)
INSTRUMENTATION	• TRANSDUCER DEVELOPMENT • PASSIVE DETECTORS	• REDUNDANCY VERIFICATION TECHNIQUES • APPLICATION OF MICROPROCESSOR TECHNIQUES

Guidance, Navigation, and Control — Laser gyro IMU in a simplex configuration has been tested. Star tracker/sun sensor are essentially off-the-shelf units. For the Interferometric Landmark Tracker — the techniques are understood and hardware components are in design. Several technologies need investigation, such as recursive filtering for ILT; star tracker/sun sensor information as it applies to navigation update capability; fault detection, isolation and reconfiguration of dodecahedron sensors; and unique methods of combining sensor inputs for optimum accuracy capability.

Communications – Phased array hardware is being developed. Techniques for optimum signal processing to obtain network compatibility need to continue in the industry. Dual redundancy requires redundancy management techniques to handle automatic reconfiguration.

Electric Power — The lightweight fuel cell program needs to be supported. Unit configurations need to be built and tested using low-pressure, helium-diluted propellants. Parallel work should adapt the Shuttle-type power plant to Tug requirements. Thermodynamic technologies are key to the efficient use of waste heat and thermal integration techniques need to be investigated. Redundancy management techniques are needed.

Rendezvous and Docking — Scanning laser (LADAR) laboratory units have been developed. Higher power units are desirable. TV camera is off-the-shelf hardware but could benefit from advanced technologies. Recursive filtering will play a major role in the accuracy and adequacy of the sensor or combination of sensors employed. Control algorithm investigations for the docking phases is a driving technology. Techniques for improving position uncertainty need investigation and simulation.

Instrumentation – Technologies include the investigation of techniques for the verification of redundant paths and the assessment of mechanical system readiness. Unique applications of microprocessors and variable (programmable) gain amplifier are required.

These subsystem technologies have applicability to spacecraft and other upper stage programs as well as the specific benefits to the Tug program as outlined. Pursuit of component technology alone does not guarantee a compatible subsystem development. Without timely pursuit of subsystem technologies, the integration of the component technologies becomes a Phase C/D development task with attendant increases in risk and uncertainty in accomplishing the development task within the estimated cost.

Based on this assessment, Figure 2-3 shows the major technology issues of the baseline avionics system by subsystem and what subsystems are impacted by each issue. The check marks provide an initial indication of the degree of impact. Redundancy management, interface, and integration techniques have significant impact on all subsystems. The three right-hand columns show the potential impact that each of the major technology issues could have on the Phase C/D program.

SYSTEM	ISSUE	SUBSYSTEMS AFFECTED							POTENTIAL ADVERSE IMPACT ON TUG PROGRAM		
		DMS	GNC	EPS	R&D	COMM	INST	S/W	MISSION CAPABILITY	COST	SCHED
DMS, ALL	SUBSYS INTERFACES/ SYS INTEGRATION	HIGH	MEDIUM	MEDIUM	MEDIUM	MEDIUM	LOW	HIGH		HIGH	HIGH
SUMC COMPUTER	TECHNOLOGY, AVAILABILITY OF REDUNDANT CONFIG	HIGH						HIGH	MEDIUM	HIGH	HIGH
DODEC LASER GYRO	REDUNDANCY MGT, INTEGRATION WITH SUM C	MEDIUM	HIGH					HIGH	MEDIUM	MEDIUM	MEDIUM
INTERF LAND TRACK	SYS PERFORMANCE ADAPTATION TO TUG	LOW	MEDIUM					LOW		MEDIUM	
LWT FUEL CELL	PERFORMANCE/ AVAILABILITY			HIGH					HIGH	LOW	LOW
ELECTRICAL PWR	INTEGRATION	MEDIUM		MEDIUM				MEDIUM		MEDIUM	MEDIUM
ELECT. ST ARRAY	SYSTEM PERFORMANCE ADAPTION TO TUG	LOW				MEDIUM		LOW	MEDIUM	LOW	
RENDEZVOUS & DOCKING	PERF., MAN IN LOOP?, SYSTEM INTEG	LOW			HIGH			LOW	HIGH	HIGH	HIGH

DEGREE OF IMPACT: √ HIGH √ MEDIUM ● LOW

Figure 2-3. Major Technology Issues

The conclusion of this assessment is that significant technology work still remains to be accomplished before major avionics development can start.

2.5 RECOMMENDED APPROACH TO ACCOMPLISHMENT OF ADDITIONAL TECHNOLOGY EFFORTS

The previous section has shown the additional technologies that have to be completed sometime; when these technologies are done has a big impact on schedule/risk/cost of Tug avionics. If the technologies are completed early in the program, all high risk areas will have been subjected to study, simulation, modelling, or hardware testing prior to issuance of end item specifications. This will provide a high confidence in the procurement specifications for flight hardware/software and therefore lower risk and lower cost during the Phase C/D program.

On the other hand, if these technologies are accomplished during the Phase C/D program, they are all being performed in parallel, most of them will be on a critical schedule path, and they will interact strongly with each other. Problems in any one subsystem will impact the cost and schedule of all of the other subsystems. Section 4 shows that these two approaches will result in a total development cost of $74.172 million and $92.856 million respectively.

Because of the 25% cost advantage plus minimum schedule impact, the recommended approach is to perform the technology activities early in the program. As discussed previously in Section 2.2, these technology activities should be completed by the preliminary design review of the Tug Phase C/D program – scheduled in August 1979.

2.6 OVERALL TECHNOLOGY PLAN

The data management system interfaces with all of the other avionics subsystems and with many of the mechanical/fluid subsystems. Because of this, integration of the DMS with other subsystems and the verification of interface and software concepts is considered to be a key accomplishment of the Tug avionics technology program during 1975-79. A major milestone of the technology program is therefore to demonstrate feasibility of Tug avionics system concepts in a Tug Avionics Integration Laboratory (TAIL), and to accomplish this by the preliminary design review – August 1979. If these types of activities are accomplished, then Part I of the end item specifications can be more definitive, and Phase C/D will progress with higher confidence.

As shown in Figure 2-4, the Tug Avionics Integration Laboratory should be operational by late 1979. Backing up from this date would require approximately 1-1/2 years of integrating the data management system with the other subsystems, validating the hardware/software interfaces, and demonstrating that the proposed redundancy management

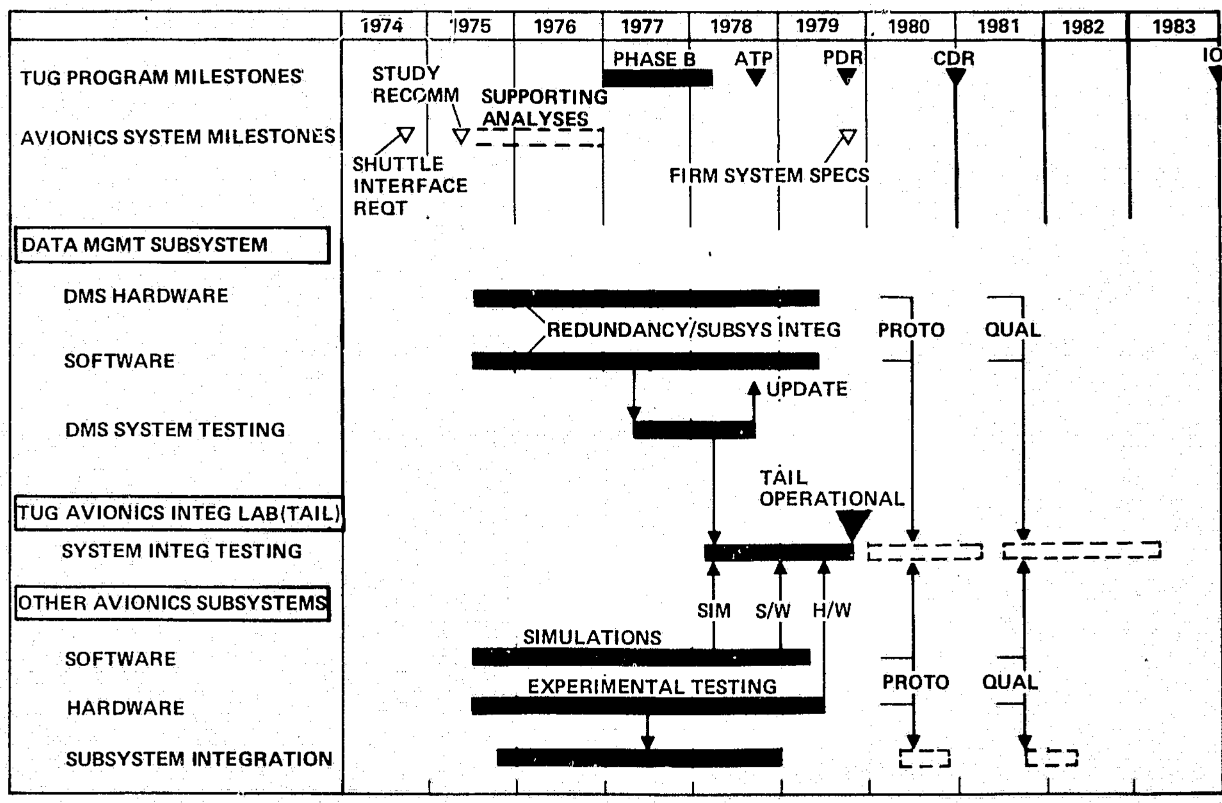


Figure 2-4. Avionics System Technology Plan

schemes are reasonable. Hardware for the data management system and software must be developed in a timely way to support the integration activity and this is shown starting in 1975. The on-going simplex SUMC computer program needs to be extended to the redundancy configuration needs of the Tug program and subsystem testing completed by early 1978. The data management system can then be extended into integration activities during 1978-79.

To support these data management integration activities, the interfaces of the other avionics subsystems are needed. These interfaces can be simulated during the early phases of the integration activities. These simulations can then be followed by software/hardware substitution as it becomes available from these parallel activities. For each of the avionics subsystems, integration at the subsystem level will be developing during 1976-78 and an integration laboratory will be available for each major subsystem of electrical power, guidance/navigation, rendezvous/docking, communications, and data management. These subsystem integration laboratories and the avionics integration laboratory can all be used during the Phase C/D program to verify prototype and flight hardware.

2.6.1 TECHNOLOGY SUBPLANS. Supporting plans are shown for each of the major subsystems and for software.

Data Management System Technology Plan is shown in Figure 2-5. On-going technology (broken lines) is aimed at configuration verification testing of SUMC modules - 1977.

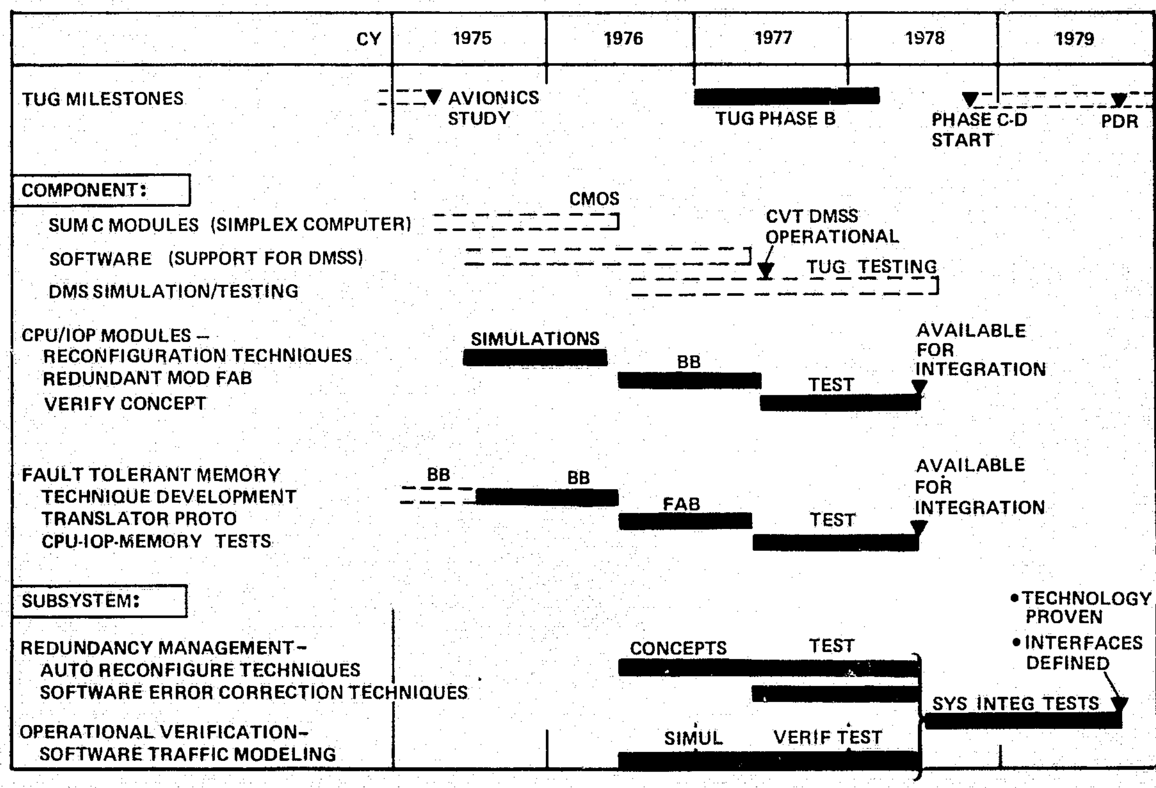


Figure 2-5. Data Management System Technology Plan

This will be for Spacelab application and in simplex mode. The objective of the DMS technology plan is to demonstrate redundancy concepts and define interfaces by 1979. The solid bars indicate the additional, Tug-peculiar activities that must be pursued for the on-going technology programs to evolve into the system integration/demonstration testing during 1979. As discussed in Section 2, these additional activities are mainly for the redundant modules and redundancy management techniques required for Tug.

Communication System Technology Plan is shown in Figure 2-6. On-going component technology programs using hardware modules and computer simulations will demonstrate the adequacy of component level technology by late 1976. System level technologies need to be initiated as shown. Cross-strapping techniques will use Shuttle-developed hardware and techniques. The TAIL will be used to verify the adaptability of these concepts to Tug mission requirements.

Guidance, Navigation and Control Technology Plan is shown in Figure 2-7. On-going technology programs (broken line) on the dodecahedron IMU components will establish concept feasibility by mid-1977. ILT component testing of breadboard units is needed. System level testing needs to be initiated in three areas: ILT modelling, simulations and integration with the data bus, IMU redundancy management including integration with the data bus, and flight control system testing to establish the need for rate gyros. If these activities are completed by mid-1978, the results can be interfaced with the data management system and integration testing performed in the TAIL in 1979.

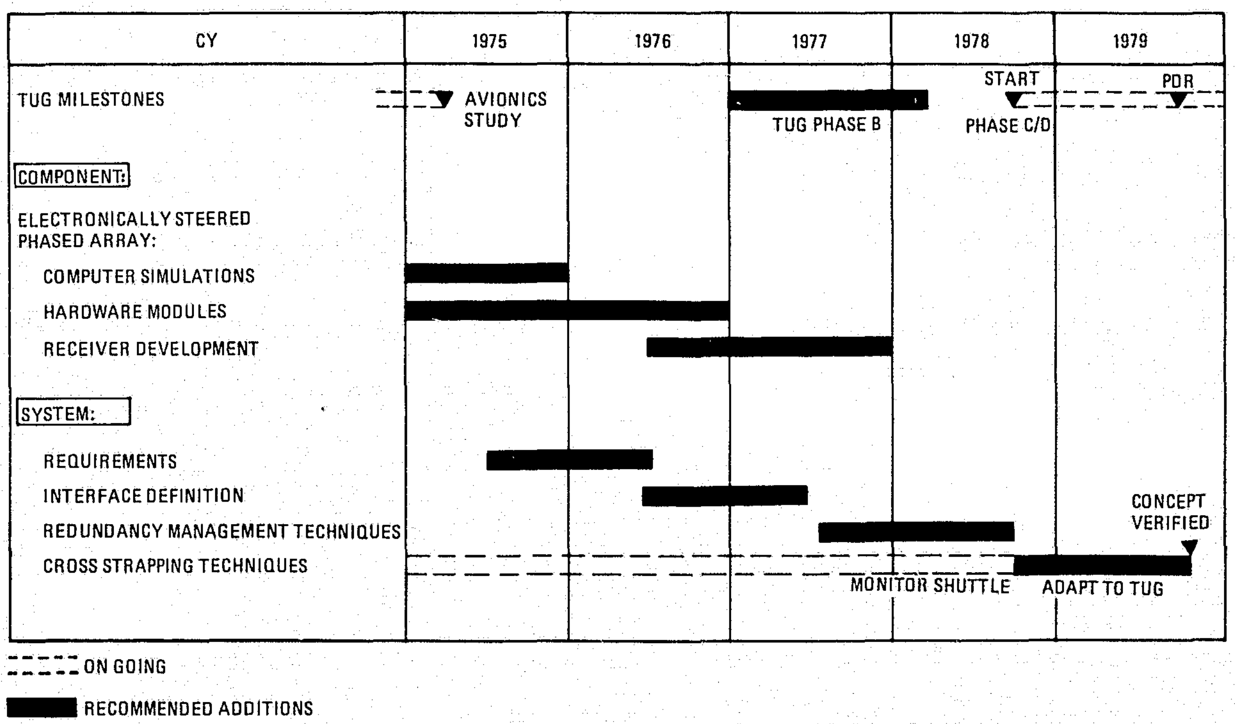


Figure 2-6. Communication System Technology Plan

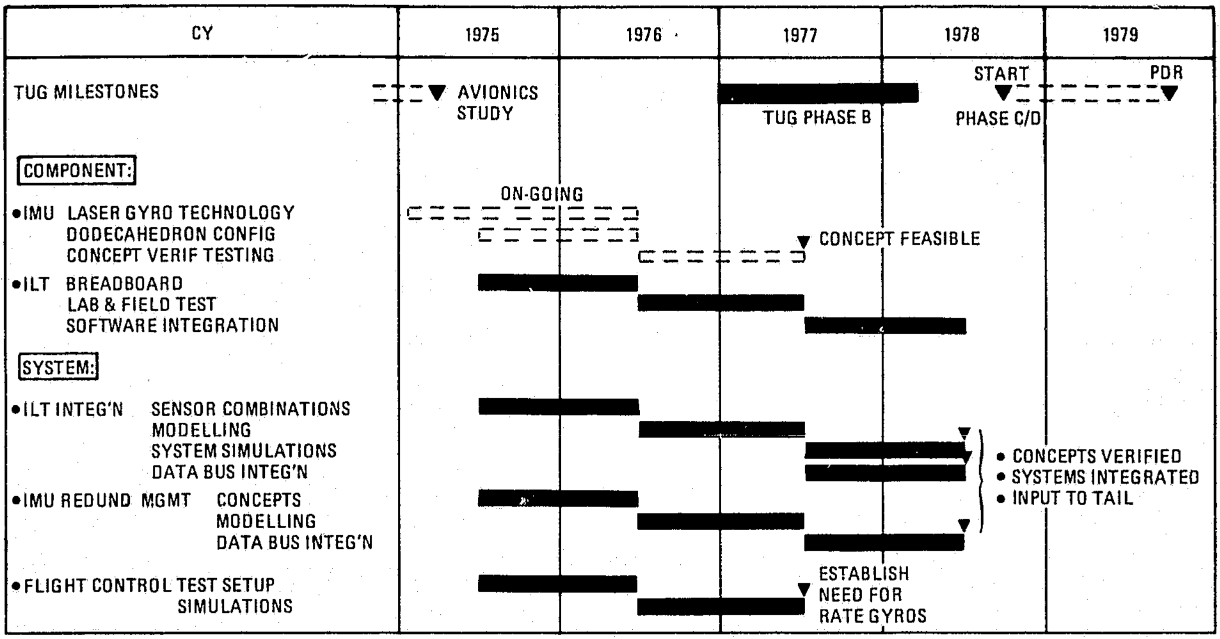


Figure 2-7. Guidance, Navigation, and Control System Technology Plan

Electrical Power System Technology Plan is shown in Figure 2-8. At the component level the main activity is to design, build, and test experimental units of the lightweight fuel cell stack. In addition a back-up program is recommended on the modified Orbiter fuel cell to establish its suitability to Tug mission requirements. System level technologies are needed for the two critical areas of thermal system integration and redundancy management. The results of these system activities will provide the electrical power system interfaces for TAIL testing during 1979.

Rendezvous and Docking Technology Plan is shown in Figure 2-9. On-going and scheduled activities are shown by the broken lines. Component technology activities in laser tech-technology, beam steerer, scanning laser radar, and docking mechanism are needed. Generally, these are extensions to on-going technology programs in the S&E laboratories at MSFC. System level type activities need to be initiated for each of the major elements of the system, i.e., rendezvous, docking, and servicing and teleoperator simulation, should be performed. These system level activities culminate in support of TAIL activities in 1979. The support will be in the form of interface definition and system software.

Software Technology Plan is shown in Figure 2-10. These activities are needed to support the component and system level technology activities shown in the previous six figures. The TAIL integration activities during 1979 are the main drivers for the software activities shown.

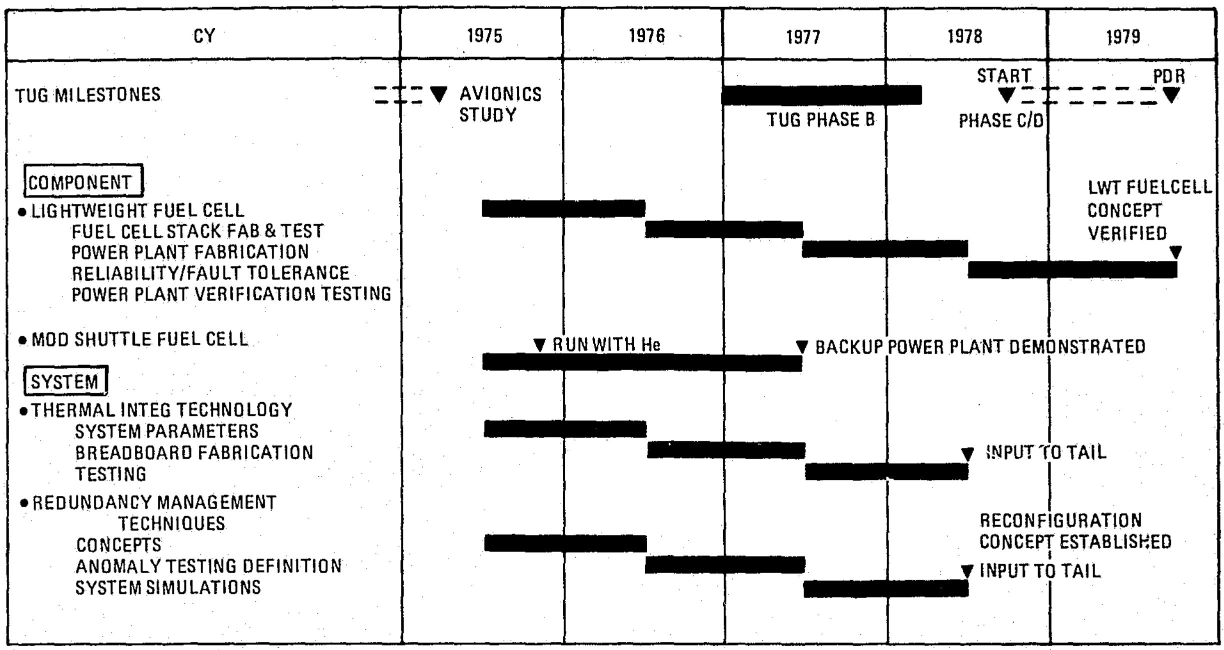


Figure 2-8. Electrical Power System Technology Plan

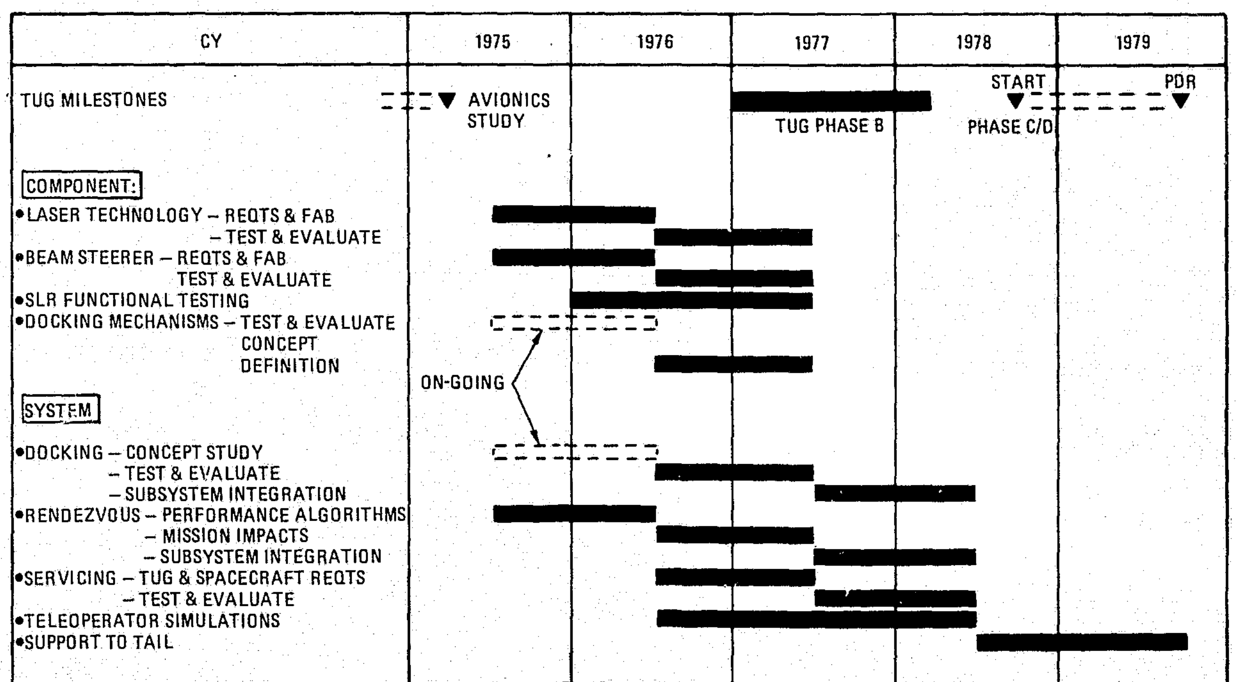


Figure 2-9. Rendezvous and Docking System Technology Plan

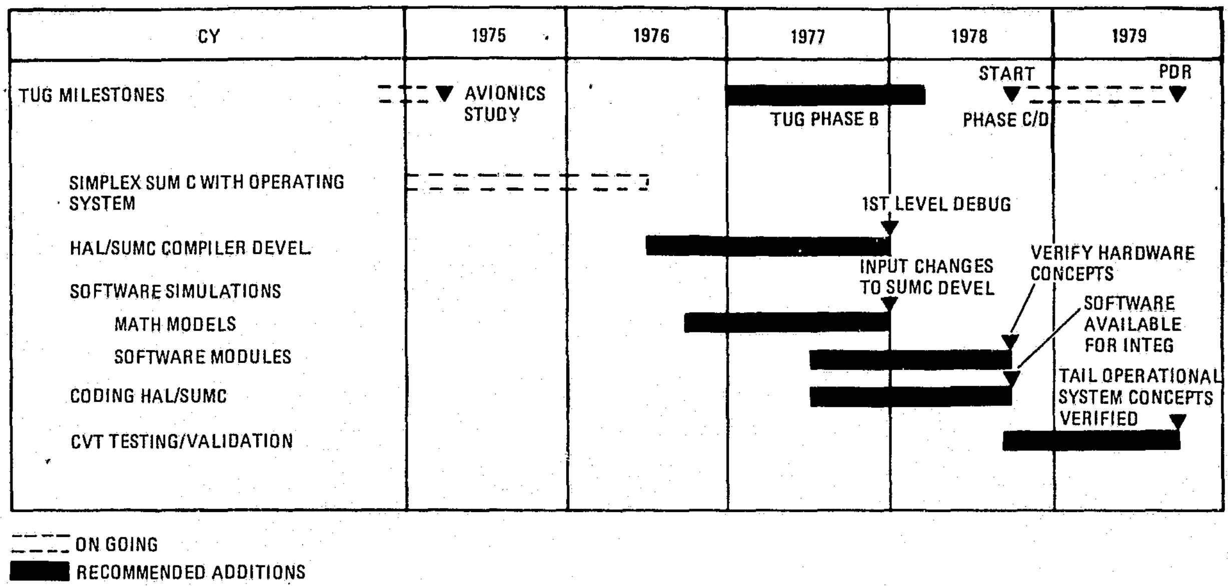


Figure 2-10. Software Technology Plan

2.6.2 RECOMMENDED PRIORITY FOR TECHNOLOGY EFFORTS. Development costs of Tug avionics depends on the scope of supporting research and technology (SRT) activities that are applied to proofing concepts and techniques during 1975-78. This study has shown the cost advantages of pursuing technology activities in all subsystems. Moreover these activities have been structured into an overall plan that will incrementally build the necessary technology base by 1978. Without timely pursuit of these technologies, the integration of the component technologies becomes a Phase C/D development task with attendant increases in risk and uncertainty in accomplishing the development task within the estimated cost.

Table 2-3 suggests a priority rating for the activities to be accomplished in the technology plan. The rating of a particular technology area is based on the technology assessment plus an estimate of the criticality of the technology and its potential for adverse impacts on the Tug program.

As shown in Table 2-3, the activities are in two categories: component and system/subsystem. Most of the component level activities are on-going and most of the system level activities are new. A major recommendation of this study is that system level SRT type activities are needed in addition to the on-going, component level SRT type activities. Pursuit of component technologies does not ensure development of a compatible subsystem and both levels of activities should be pursued in parallel.

Also of importance is the ranking (in descending order) of the subsystems as to the risk that a component in that subsystem places on the whole Tug development program should an unforeseen event cause it to become the critical pacing item. The SUMC computer, the flight software and the fuel cell are such critical components and become the recommended programs for early year funding.

Table 2-3. Recommended Priority for Technology Efforts – 1975-1978

SUBSYSTEMS	COMPONENT LEVEL SRT	SUBSYSTEM LEVEL SRT
DATA MANAGEMENT	COMPUTER MODULES FAB (0) FAULT TOLERANT MEMORY (0) REDUNDANT CONFIGURATIONS (N)	REDUNDANCY MANAGEMENT TECHNIQUES (N) SOFTWARE INTERFACE APPROACHES MODULE & WORKLOAD MODELING
ELECTRICAL POWER	LWT FUEL CELL TECHNOLOGY (N)	SYSTEM DESIGN/THERMAL INTEGRATION (N) REDUNDANCY MANAGEMENT TECHNIQUES (N)
RENDEZVOUS & DOCKING	SENSOR CAPABILITY (0)	MAN-IN-LOOP SIMULATIONS (0) OPTIMUM SENSOR COMBINATIONS (N)
GUIDANCE, NAV & CONTROL	DODECAHEDRON LASER GYRO (0)	REDUNDANCY MANAGEMENT (N) OPTIMUM SENSOR COMBINATIONS (N)
COMMUNICATION	PHASED ARRAY (M)	REDUNDANCY MANAGEMENT TECHNIQUES (N)

(N) = NEW (M) = MODIFIED (0) = ON GOING
SUBSYSTEMS IN DESCENDING ORDER OF IMPACT ON TOTAL PROGRAM DEVELOPMENT RISK

SECTION 3

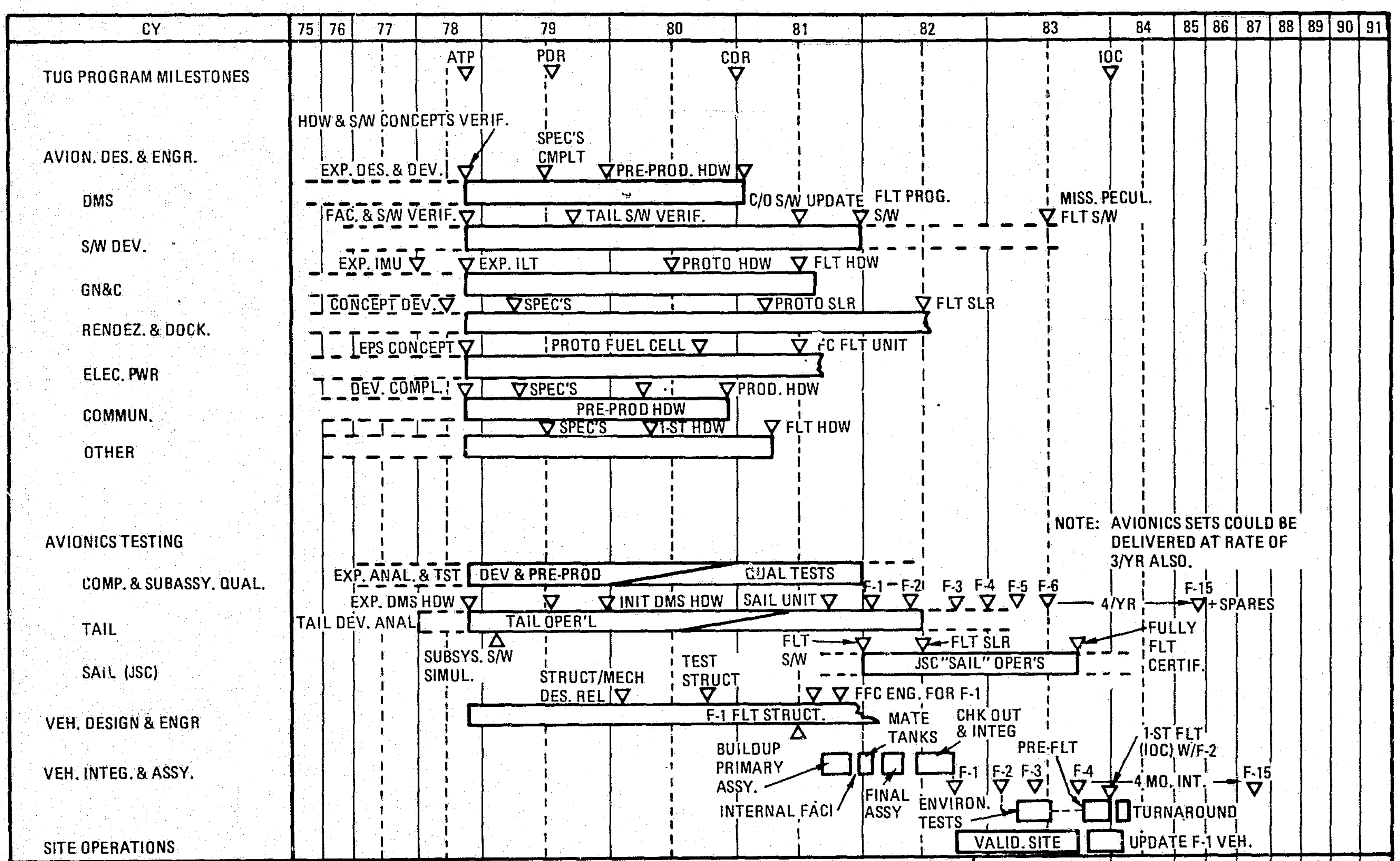
TUG AVIONICS PHASE C/D PROGRAM PLAN

The lower cost approach Tug avionics Phase C/D program plan and schedule is shown in Figure 3-1. Major milestones are Authority to Proceed (ATP) in September 1978, PDR in August 1979, CDR in December 1980, and Tug IOC in December 1983. An important concept in the Tug development plan is the use of both a Tug Avionics Integration Laboratory (TAIL) and the Shuttle Avionics Integration Laboratory (SAIL). Tug avionics subsystems and the associated software will be integrated in the TAIL. In 1982 there is a transition to integration of Tug avionics and Tug/Shuttle Interface with Shuttle, using the SAIL.

The schedule in Figure 3-1 reflects final development of the Tug-Avionics Subsystems as defined during the study. It includes the timely integration of avionics subsystems with a full-capability Tug development program, such as developed under Program 2 of the "Space Tug System Study," Contract NAS8-29676. The avionic subsystems development activities and spans as derived and shown in this schedule are based on certain key advanced development work being accomplished prior to the proposed Tug development go-ahead in fourth quarter, 1978.

The Tug program milestones are shown across the top of the schedule and are significant to the specific timing of avionics development, and in turn are affected by availability of critical avionic subsystem data. The major subsystems are designated under the avionics Design and Engineering heading in the left margin, each with a separate bar schedule and denoting both design and hardware availability milestones which reflect an important time interface with the on-going development activities of the basic Tug vehicle.

Advanced technology programs listed in Table 2-2 will reduce the time-critical hardware developments to be performed during the Tug development phase, (such as was identified under Tug Program 2 Contract NAS8-29676), i.e., scanning laser radar (SLR) for rendezvous and docking, lightweight fuel cell in the power system, redundancy management of specific avionic hardware and operations. Developmental testing of some hardware is reduced due to analyses and testing performed during 1975-78. Early simulations and/or demonstrations of proposed avionic concepts and hardware expedite the development of the proposed Tug-avionics integration laboratory (TAIL) and, consequently, reduce the time necessary to validate this TAIL for Tug-avionics integration after Tug program go-ahead. The entire integrated avionic system will be developed in the TAIL with initial computer hardware and subsystem simulations, and eventually progress through total system verification with one equivalent set of pre-production hardware. This initial set of avionics will be delivered to the Shuttle Avionics Integration Laboratory (SAIL) at JSC for pre-launch orbiter integration and checkout.



FLIGHTS @ ETR	15	21	22	17	18	16	27	22
FLIGHTS @ WTR	1	2	1	1	1	2	1	1
EXPENDED TUGS	2	4	2	2	0	0	1	1

Figure 3-1. Tug Avionics System Development Plan

Subsequent integrated avionic system sets will be verified as a total system in TAIL prior to being installed on the flight vehicle during the latter's final assembly operation. Fifteen flight sets will be required, in addition to spares requirements, and produced at initial rate of four-month intervals increasing to three-month intervals as indicated in the schedule. These deliveries are scheduled to support the final assembly operations for each of the 15 flight vehicles.

The basic Tug vehicle development schedule is summarized at the bottom third of the schedule; it reflects the basic design and engineering, vehicle integration and assembly, and flight site operations. IOC is coincident with the first flight, some 63 months after Tug development go-ahead (ATP). This is essentially the same time span as developed for Tug Program 2 in Study Contract NAS8-29676, except that it reflects a more relaxed, lower funding level approach due to the 1975-78 advanced technology activities. Under this approach, all long-lead development hardware would be available for Tug installation prior to completion of vehicle final assembly and checkout, rather than after delivery to the flight site as was the case under STSS Program 2.

The total Tug vehicle inventory of 15 Tugs (instead of the 17 under Program 2) was derived from the later NASA mission model dated August 1974 showing a total payload traffic model through 1991 of 255. These were reduced to 168 individual Tug flights, including operations at both ETR and WTR and taking into consideration those Tugs lost to attrition and through Tug expendable missions.

SECTION 4

PROGRAM COSTS

4.1 GROUND RULES AND ASSUMPTIONS

1. Costs are in 1975 dollars, without prime contractor fee/profit.
2. Costs represent the expected value total cost to the Government (less prime contractor fee/profit) at program completion. Therefore, allowances for cost growth are included as discussed in Section 5.2.
3. 1978 technology is utilized in some subsystems.
4. Costs and funding are predicated on the program plans described in Section 4.2.
5. Costs herein are for budgetary and planning purposes. They do not represent a commitment on the part of General Dynamics Corporation, since such a commitment would require more specific contractual arrangements.
6. Costs are those specifically associated with Tug onboard Avionics only. They do not include costs associated with ground checkout and servicing since these areas were a part of the Tug Fleet and Ground Operations Schedules and Control Study.

4.2 PROGRAM PLAN

Although no program definition task was included, a study requirement was that costs be presented in accordance with NASA Documentation Requirements Document (DRD) MF003M. To comply with the cost reporting of MF003M, the program plan described in Section 3 was used. The overall program plan was illustrated in Figure 3-1.

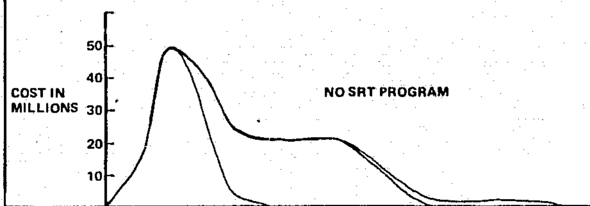
4.3 COST SUMMARY

Tug onboard avionics costs are influenced by the development approach. As previously noted, pre-Tug avionics studies and advanced development could (while not necessarily reducing schedule times) significantly reduce uncertainties associated with time-critical developments. This is particularly true of the avionics subsystems because they represent the most significant new technologies and functions critical to the Tug program. For this reason the study examined two approaches to the DDT&E program: 1) assuming no technology funding is available during 1975-78 (this minimizes the funds required for pre Phase C/D activities but results in Phase C/D activities of research, technology, development, procurement, testing and validation that are all on critical paths of the schedule), or 2) assuming that research and technology funding is available during 1976-78 (this will enable all critical technologies to be modelled/simulated/ demonstrated prior to procurement, testing, and validation of flight hardware).

Thus a comparison of these two programs costs shows the likely benefits to be gained by a selective SRT funding prior to 1978. Summary costs for these two programs are:

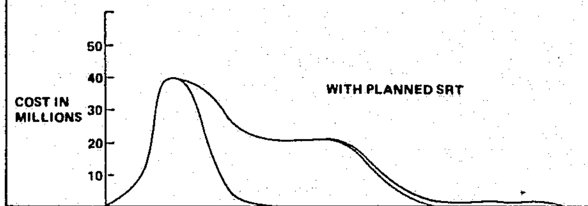
	COST IN THOUSAND DOLLARS NO SRT PROGRAM	WITH PLANNED SRT
DDT&E	92,856	74,172
PRODUCTION	116,364	116,364
OPERATIONS	5,488	5,488
TOTAL	214,708	196,024

Summary annual funding requirements are shown in Figures 4-1 and 4-2.



FY	79	80	81	82	83	84	85	86	87	88	89	90	91	92
DDT&E	11.7	49.1	29.0	3.0										
PRODUCTION			12.4	21.2	21.2	21.2	21.2	14.2	5.0					
OPERATION								0.2	0.9	1.1	1.1	1.0	1.0	0.2
TOTAL	11.7	49.1	41.4	24.2	21.2	21.2	21.2	14.4	5.9	1.1	1.1	1.0	1.0	0.2

Figure 4-1. Onboard Tug Avionics Annual Funding with No SRT Program



FY	79	80	81	82	83	84	85	86	87	88	89	90	91	92
DDT&E	9.2	39.2	23.4	2.4										
PRODUCTION			12.4	21.2	21.2	21.2	21.2	14.2	5.0					
OPERATION								0.2	0.9	1.1	1.1	1.0	1.0	0.2
TOTAL	9.2	39.2	35.8	23.6	21.2	21.2	21.2	14.4	5.9	1.1	1.1	1.0	1.0	0.2

Figure 4-2. Onboard Tug Avionics Annual Funding with Planned SRT

4.4 WBS COSTS

DDT&E costs consist of tasks, services, hardware and software costs of performing the Tug development tasks described in the WBS (Appendix A). One complete set of avionics hardware is dedicated to TAIL/SAIL integration testing. This set of avionics hardware constitutes the Theoretical First Unit (TFU). Therefore DDT&E costs consist of a subsystem Engineering Design and Development (ED&D), other development and integration tasks, and the one set of integration hardware (one TFU). Space Tug avionics DDT&E costs are summarized for with and without SRT in Tables 4-1 and 4-2. More detailed costs factors and programmatics are shown in Appendix B.

Production costs are for the avionics portion of Tug vehicles required to accomplish the missions in the National Mission Model. Fifteen Tug vehicles are required for the operational program beginning at IOC in December 1983 and continuing through 1991. Twelve of these 15 vehicles are used on missions from which the Tug is not returned. Two Tugs are allowed for other mission losses (reliability). Summary

Production costs by WBS category are shown in Table 4-3. Cost improvement factors, initial spares, and other production cost details are shown in Appendix B.

Operations costs are for spares and repairable units to maintain and refurbish Tug airborne subsystems only, during the 1983 through 1991 operational period. Tug Airborne Avionics operations costs are summarized in Table 4-4. Further details are presented in Appendix B.

Table 4-1. DDT&E Summary Costs by WBS Element — Minimum SRT Program

WBS NUMBER	WBS ELEMENT	TFU*	DDT&E Costs in Thousand Dollars		
			EDD	OTHER	TOTAL
320-03-03-01	DATA MANAGEMENT	1,514	10,189		10,189
320-03-03-02	GUID, NAVIGATION & CONTROL	1,500	23,033		23,033
320-03-03-03	RENDEZVOUS & DOCKING	1,195	13,134		13,134
320-03-03-04	COMMUNICATIONS	2,143	9,108		9,108
320-03-03-05	INSTRUMENTATION	1,605	7,338		7,338
320-03-03-06	ELECTRIC POWER	286	7,280		7,280
320-03-03-07	ELEC. PWR DISTRIBUTION & CONTROL	275	2,196		2,196
320-03-03	AVIONICS SUBSYSTEMS TOTAL		(72,278)		(72,278)
320-15-01	TUG ONBOARD SOFTWARE			(5,828)	(5,828)
320-08-01	GROUND TEST HARDWARE (TAIL/SAIL)			(8,518)	(8,518)
320-08-02	GROUND TEST OPERATIONS (TAIL/SAIL)			(6,232)	(6,232)
	TOTAL DDT&E		72,278	20,578	92,856

*SUBSYSTEM BREAKDOWN SHOWN FOR REFERENCE ONLY

Table 4-2. DDT&E Summary Costs by WBS Element — Recommended SRT Program

WBS NUMBER	WBS ELEMENT	TFU*	DDT&E Costs in Thousand Dollars		
			EDD	OTHER	TOTAL
320-03-03-01	DATA MANAGEMENT	1,437	7,918		7,918
320-03-03-02	GUID, NAVIGATION & CONTROL	1,395	18,193		18,193
320-03-03-03	RENDEZVOUS & DOCKING	1,106	10,649		10,649
320-03-03-04	COMMUNICATIONS	2,007	7,154		7,154
320-03-03-05	INSTRUMENTATION	1,397	5,830		5,830
320-03-03-06	ELECTRIC POWER	265	5,461		5,461
320-03-03-07	ELEC. PWR DISTRIBUTION & CONTROL	275	1,803		1,803
320-03-03	AVIONICS SUBSYSTEMS TOTAL		(57,008)		(57,008)
320-15-01	TUG ONBOARD SOFTWARE			(4,662)	(4,662)
320-08-01	GROUND TEST HARDWARE (TAIL/SAIL)			(7,882)	(7,882)
320-08-02	GROUND TEST OPERATIONS (TAIL/SAIL)			(4,620)	(4,620)
	TOTAL DDT&E		57,008	17,164	74,172

*SUBSYSTEM BREAKDOWN SHOWN FOR REFERENCE ONLY

Table 4-3. Production Summary Costs by WBS Element

WBS NUMBER	WBS ELEMENT	Production Cost in Thousand Dollars
320-03-03-01	DATA MANAGEMENT	20,768
32-03-03-02	GUID, NAVIGATION & CONTROL	20,153
320-03-03-03	RENDEZVOUS & DOCKING	15,428
320-03-03-04	COMMUNICATIONS	32,698
320-03-03-05	INSTRUMENTATION	18,989
320-03-03-06	ELECTRIC POWER	4,593
320-03-03-07	ELEC. PWR DISTRIBUTION & CONTROL	3,735
320-03-03	AVIONICS TOTAL	116,364

Table 4-4. Operations Summary Costs by WBS Element

WBS NUMBER	WBS ELEMENT	Operations Cost in Thousand Dollars
320-03-03-01	DATA MANAGEMENT	724
320-03-03-02	GUID, NAVIGATION & CONTROL	553
320-03-03-03	RENDEZVOUS & DOCKING	985
320-03-03-04	COMMUNICATION	263
320-03-03-05	INSTRUMENTATION	2,652
320-03-03-06	ELECTRIC POWER	294
320-03-03-07	ELEC. PWR DISTRIBUTION & CONTROL	17
320-03-03	AVIONICS TOTAL	5,488

SECTION 5

COST APPROACH AND METHODOLOGY

5.1 DATA BANK

During 1973 General Dynamics Convair Division performed a Centaur Cost, Technical, and Programmatic Data Study (Contract NAS8-29075) for NASA's Marshall Space Flight Center. This study covered original Centaur development and initial operations through 1966. The approach developed in that study resulted in some improved techniques for advanced system costing, particularly where there are the many similarities that exist between the Space Tug and the Centaur stage. Convair continued these analyses through the latest Centaur D-1A (upper stage with Atlas) and D-1T (upper stage with Titan III). Thus an extensive data bank of historical data has been developed for predicting expected value costs of advanced systems.

In addition to the Centaur cost, technical and programmatic data bank, Convair obtained cost data from subcontractors/vendors for all major Tug components and/or subsystem elements. Specific ground rules and technical guidance was provided so that subcontractor/vendor quotes and technical information would be closely oriented toward Tug requirements. Fifteen of these major item quotes (e.g., computer, IMU) were obtained. In addition, costs of smaller items were obtained from current catalog price data and from recent Convair material buy experience data.

Convair has assembled a sizable cost, technical and programmatic data bank that is directly applicable to Space Tug Avionics. This data has been developed at the lowest practicable level to provide as much component level data as possible.

5.2 GROWTH ALLOWANCES

Costs required in this study represent expected value total costs to the Government at program completion. Therefore, estimated costs must include allowances for program and hardware changes. There are three basic uncertainties that contribute to cost growth during a program. The first factor is uncertainty in the stated requirements of the system, i.e., Requirements Uncertainty. The second factor is Technology Uncertainty. The third factor is the degree of Concurrency in the development program. In cases where subsystems are being simultaneously developed according to a tight schedule, costs (and schedules) can be severely impacted.

Based on past studies, particularly the Centaur program, the range of possible cost uncertainty percentages depicted in Figure 5-1 were developed. The results of the technology assessment shown in Table 5-1, and similar assessments of requirements

*TYPICAL COST UNCERTAINTY FACTORS	REASON FOR UNCERTAINTY FACTOR
90%	ADVANCED STATE OF ART CONCURRENT DEVELOPMENT & INTEGRATION OF ALL TUG SYSTEMS
30%	MEDIUM/LOW STATE OF ART CONCURRENT DEVELOPMENT & INTEGRATION OF ALL TUG SYSTEMS
10%	OFF THE SHELF COMPONENTS SOME PREVIOUS EXPERIENCE WITH INTEGRATION LOW CONCURRENCY OF TUG SYSTEMS

*BASED ON PAST PROGRAMS. TYPICAL NUMBERS DEVELOPED IN CONTRACTS NAS8 - 29676 & NAS8 - 30290

REASONS FOR UNCERTAINTY – CHANGING REQUIREMENTS, ADVANCED TECHNOLOGY, QUALITY OF COST/SCHEDULE ESTIMATES, & FUNDING CONSTRAINTS

Figure 5-1. Sources of Uncertainty and Their Effects on DDT&E Cost

Table 5-1. Technology Assessments

Subsystem	Current Technology Status
Data Management System	Simplex testing of SUMC modules in 1976-77 for Spacelab application. Data bus is current technology. Fault tolerance memories being breadboarded.
Guidance, Navigation and Control	Simplex laser gyro being tested, dodecahedron in design. Star, sun and ILT sensors essentially state of art.
Communications	Phased array hardware being developed. Techniques for optimum signal processing for network compatibility being pursued for Shuttle.
Electrical Power	Orbiter fuel cell under development. Advance lightweight technology cell units built and tested. Other hardware is approximately state of art.
Rendezvous and Docking	Scanning laser radar units exist. Simplified LADARS are practical. Close in ranging limited by timing circuitry. TV is current state of art. Feasibility of manned remote control docking has been demonstrated.
Instrumentation	Industry efforts on maintenance/trend analysis. Sensor requirements.

uncertainties and potential schedule problems were used to develop cost growth factors for each subsystem. These cost growth allowance percentages are shown in Table 5-2.

Table 5-2. Subsystem Uncertainty Cost Allowances

	Cost Uncertainty Factor (Percent Added DDT&E Cost)	
	Minimum Technology Funding 1975-78	Recommended Technology Funding 1975-78
Data Management		
Digital Computer	70	30
Digital Data Bus	30	10
Tape Recorder	30	10
Guidance, Nav. & Control		
IMU	70	30
Guidance Update	50	20
Rate Gyros	70	20
Control Electronics	40	10
Rendezvous and Docking		
Laser Radar	70	30
TV Camera and Ele ct.	20	10
Electrical Power		
Power Source	60	20
Thermo/Product Water	50	20
Power Distribution	40	10
Communications	60	20
Instrumentation		
Transducers + Wiring	50	20
Signal Conditioners/Mix	40	10
System Integration		
Software	140	70

5.3 COST METHODOLOGY

Subsystem hardware costs were developed using the component cost-build-up approach. The cost-build-up begins with a tabulation of buy costs (vendor quoted costs and purchased parts/materials) as shown in Table 5-3. The cost growth allowance for uncertainties (see Section 5.2) is added to the buy estimates to get an expected value total buy cost for both the Engineering Design & Development (ED&D) and the Theoretical First Unit (TFU) costs for subsystems. Next the Convair "in-hours" Engineering

Table 5-3. Example Guidance Update Buy Cost Worksheet

Study: Tug Avionics Definition — Date: 1/14/75

Subsystem: GN&C — Avionics Cost Worksheet

Component/Part	Total Wt. (lb)	Avg. Power (watts)	Total Volume (ft^3)	Data Source	Units Per Shipset	Cost ($ Million) Unit	Shipset	ED&D
Guid. Update								
Star Tracker (w/power & shade)	25	22	.14	Ball Brothers	2	.140	.280	.258
Sun Sensor	9	5	.08	Adcole	2	.077	.154	.196
Interferometer Land Tracker	20	15		IBM	1	.099	.099	1.650
Subtotal							.533	2.104
Growth (20%/20%)							.107	.421
Total Buy Cost							.640	2.525

Design is estimated, using Centaur or other analogous task historical cost data, and appropriate cost growth allowances added to get the expected value design cost. The buy ED&D and TFU costs, along with the Engineering Design estimate are entered on the total subsystem cost worksheet shown in Table 5-4. Total subsystem costs are derived on this worksheet by adding percentages of the design estimate for design supporting functions and progressive percentages to derive estimated costs of other tasks (e.g., tooling, test). The cost-build-up add-on percentages shown in Table 5-4 were derived for each subsystem from the most appropriate Centaur experience data. This cost build-up approach assumes a Tug make or buy policy consistent with current Convair practices. Total DDT&E costs of each subsystem were developed by adding one complete shipset of equipment (1 TFU) to the subsystem ED&D cost.

Production costs were developed as shown in Table 5-4, using the required quantities of Tug production units and initial spare units times the TFU and times a cost improvement factor. Operational replacement spares costs were determined in a similar manner.

Table 5-4. Tug Avionics Definition Study (GN&C-Guidance Update Cost Build Up Worksheet (Thousand 1974 Dollars)

ED&D (Subsystem)				TFU		
Buy Cost (see details)			2,525	Buy Cost (see details)		
Eng. Design Estimate			655	Production	.11% of Buy	640
Eng. Analysis	2.6%	Design	17	Tooling	.03% Above	1
Des. Services	- %	Design	—	Reliability	2.4% Above	—
Integration	- %	Design	—	Integration	3.1% Above	15
Test/Qual.	0.3%	Above	1	Other	—% Above	20
Tooling	.1%	Above	3	Corp. Exp.	.1% Above	—
Reliability	.4%	Above	13		Total	677
Other	- %	Above	—			
Corp. Exp.	.2%	Above	6			
	Total		3,220			

DDT&E		
ED&D (Subsystem)	3,220	
System Test Hardware (1 equiv. units × 677)	677	
Total		3,897
Production		
Tug Vehicle (15 Units × 677 TFU Cost × .8728)	8,863	
Spares (3.00 Equiv. Units × 677 TFU Cost × 1.0)	1,131	
		9,994
Operations		
Spares (.0252 Equiv. Units × 677 TFU Cost × 1)		17
TOTAL SUBSYSTEM PROGRAM COST		13,908

SECTION 6

TRADE STUDY COSTS

6.1 ELECTRIC POWER

Tug mission durations and power requirements are such that a fuel cell electric power source is required. Three alternative fuel cell concepts were analyzed, two versions of a Space Shuttle Orbiter modified for Space Tug and an integrated lightweight fuel cell. The total system evaluation of these alternatives involves much more than different fuel cells. They require differing amounts of peripheral fuel cell supporting equipments (e.g., electrical controls, reactant storage provisions, product water and coolant provisions), which are elements of WBS elements outside Electrical Power (320-03-03-06). In addition, redundancy management development is a major task in the Tug Avionics Integration Laboratory (TAIL). Summary total DDT&E cost comparisons of the three fuel cell alternatives are shown in Table 6-1. Total program costs are shown in Table 6-2. The lightweight thermally integrated fuel cell was selected on the basis of total program cost.

Tug avionics costs are sensitive to the development approach. Two alternative approaches have been used by personnel involved in fuel cell selection. The first approach is the unitary development plan, in which the fuel cell unit is fully developed and qualified as a component then integrated into the avionics system in the TAIL. The other approach is the system development plan, which utilizes TAIL system tests more extensively to test and qualify the fuel cell as a part of the overall Tug system. Costs in the trade study are for the unitary approach, since that is the worst case for the lightweight integrated fuel cell. The power source costs presented in Sections 6.3 and 6.4 are for the system approach. If the systems approach is used for each of three candidates expected system DDT&E cost comparison is shown in Table 6-3.

6.2 GUIDANCE, NAVIGATION & CONTROL

Four alternative approaches to Tug position/velocity update were considered. Comparative DDT&E costs of these alternatives are shown in Table 6-4. Although not the lowest DDT&E cost, the Interferometric Landmark Tracker (ILT) was selected due to superior accuracy. The Horizon Scanner accuracy penalty was too great to meet requirements and the satellite update has the problem that it may not always be in view of the Tug when updates are required.

Four alternative guidance reference units suitable for Tug use were considered. One of these is the advanced technology dedecahedron laser gyro IMU with six gyros, six accelerometers, and triple redundancy. Another advanced technology candidate is the 3 ESG (MICRON) strapdown IMU. The two current technology reference units considered were the Duel DIGS strapdown platform and a triple Space Shuttle KT-70 system. Summary program costs for these four alternatives are shown in Table 6-5.

Table 6-1. Electric Power Source (DDT&E) Cost Comparison
(1975 Dollars)

	Cost in Thousand $
LIGHTWEIGHT-THERMALLY INTEGRATED	
FUEL CELL	8,670
PERIPHERAL EQUIPMENT	1,261
INTEGRATION	3,700
TOTAL	13,631
ORBITER WITH SUPERCRITICAL STORAGE	
FUEL CELL	3,947
PERIPHERAL EQUIPMENT	3,788
INTEGRATION	4,710
TOTAL	12,445
ORBITER LOW PRESSURE	
FUEL CELL	6,868
PERIPHERAL EQUIPMENT	2,454
INTEGRATION	3,700
TOTAL	13,022

Table 6-2. Electric Power Source Cost Comparison
(Costs in Thousand 1975 Dollars)

	LIGHTWEIGHT INTEGRATED	MOD. ORBITER SUPERCRITICAL SOURCE	ORBITER LOW PRESSURE
DDT&E	13,631	12,445	13,022
PROD/OPER	11,398	18,766	16,046
TOTAL	25,029	31,211	29,068

Table 6-3. Electric Power DDT&E System Development Cost

	DDT&E Cost in Thousand Dollars		
	Lightweight Integrated	Mod. Orbiter Low Pressure	Orbital Super-Orbital Storage
FUEL CELL	5,762	5,500	3,344
THERMAL/WATER	856	1,949	3,104
ELEC. CONTROLS	405	505	684
SYSTEM TEST	2,355	2,495	3,355
TOTAL	9,378	10,449	10,487

Table 6-4. Position/Velocity Update Trade DDT&E Cost Summary

CANDIDATE APPROACH	DDT&E Cost in Thousand Dollars		
	EDD	TFU	TOTAL
HORIZON SCANNER	1,044	207	1,251
INTERFEROMETRIC LANDMARK TRACKER	2,893	126	3,019
SATELLITE (GPS)	1,096	142	1,238
ONE-WAY DOPPLER	3,785	153	3,938

Table 6-5. Guidance Unit Trade Total Program Cost Summary

	Cost in Thousand Dollars			
	Dodecahedron Laser Gyro IMU	ESG IMU	Strapdown Platform	KT-70
DDT&E	7,579	8,485	3,675	3,624
PRODUCTION	5,920	6,277	9,345	8,736
OPERATIONS	651	690	1,027	960
TOTAL PROGRAM	14,150	15,452	14,047	13,320

6.3 DATA MANAGEMENT

Data management approaches using three different computer approaches were analyzed during the study. One was a fault-tolerant, single SUMC computer, the technology for which is being developed under NASA Supporting Research and Technology funding. The other two concepts considered utilized the Rockwell International (RI) Autonetics DF 224 and D 232 computers. Both RI approaches utilize two 48,000 word and two 8000 word processors. The DF 224 has been developed and is currently completing qualification testing. A prototype of the D 232 is currently undergoing engineering evaluation.

Summary total program costs of the three computer alternatives are shown in Table 6-6. Total subsystems DDT&E costs consist of Engineering Design and Development (EDD) plus one shipset for TAIL/SAIL testing. This shipset cost is the theoretical first unit (TFU) cost. Although either the DF 224 or D 232 concepts offer about $2.7 million in DDT&E savings, their expected production and operating costs are higher than for the SUMC. The total program costs of these alternatives are within about 10% of each other.

A cost analysis was also made of the hardwire versus data bus concepts for data transmission. Nonrecurring and recurring costs for these alternatives are summarized in Table 6-7.

6.4 COMMUNICATIONS

The preferred communication antennas approach is the multiple phased array transmit, omnidirectional receive concept. Two alternative concepts were also evaluated. The evaluation included a full evaluation of suitability and effectiveness in addition to costs; however, a summary comparison is shown in Table 6-8.

6.5 AUTONOMY LEVEL

An autonomy level analysis was performed during the study to establish some of the Tug airborne avionics effects of autonomy. These studies did not address all the ground control considerations involved in autonomy level.

Convair's previous Tug avionics studies and analyses developed by this study show that the extreme autonomy levels (Level I — all airborne control, and Level IV — all ground control) are not preferred alternatives. Therefore, Convair concentrated on identifying airborne avionics sensitivities for autonomy Levels II and III.

Table 6-6. Data Management Computer Trade Summary Costs

	TOTAL PROGRAM COST ($1000)		
	SUMC	DF 224	D 232
DDT&E	6,962	4,267	4,297
PRODUCTION			
15 TUGS	4,154	6,373	5,406
INITIAL SPARES (1.36 UNITS)	377	578	490
OPERATIONS (.003 × TFU × 243 FLTS = SPARES)	266	408	346
TOTAL PROGRAM COST	11,759	11,626	10,539

Table 6-7. Hardwire Versus Data Bus Cost Summary

	COST IS THOUSAND DOLLARS	
	HARDWIRE	DATA BUS
DDT&E	4,010	3,125
PRODUCTION	4,170	6,000
OPERATIONS	606	550
TOTAL PROGRAM	8,786	9,675

Table 6-8. Antenna Concepts Trade Study Summary Costs

CANDIDATE	DDT&E COST IN THOUSAND DOLLARS		
	EDD	TFU	TOTAL
1. Omnidirectional Receive/Transmit (Low Power Transmit Mode)	1,539	444	1,983
2. Multiple Directive Transmit, Omni-Receive (Low Power Omni-Transmit)	2,884	884	3,768
3. Multiple Phased Array Transmit, Omni-Receive (Low Power Omni-Transmit	3,610	820	4,430

The Tug avionics baseline developed during the study is close to autonomy level II. For level III autonomy the Interferometric Landmark Tracker (ILT) and the Scanning Laser Radar can be omitted from our level II baseline. In addition, there are some airborne software savings going from level II to level III. Table 4-9 summarizes airborne associated cost differences only when going from autonomy level II to level III.

Table 6-9. Autonomy Level II Versus III Cost Summary, Airborne Associated Costs Only

	Costs in Thousand Dollars					
	Level II Autonomy			Level III Autonomy		
	DDT&E	Prod/Ops	Total	DDT&E	Prod/Ops	Total
Guidance Update	3,897	9,761	13,658	1,241	7,944	9,185
Rendezvous & Docking	11,755	16,223	27,978	1,614	5,368	6,932
Software	4,663	5,666	10,329	3,637	4,419	8,056
Total	20,315	31,650	51,965	6,492	17,731	24,173
Program Difference	Baseline			-27,792		

It must be emphasized that this was not a complete trade study. Costs included show only Tug vehicle associated differences. Inclusion of ground control costs would give a considerably different comparison. (Ref. parallel study by MMC on "Tug Fleet and Ground Operations Schedules and Controls Study".)

APPENDIX A

SPACE TUG PROJECT

WORK BREAKDOWN STRUCTURE

AND

DICTIONARY

GENERAL DYNAMICS CONVAIR DIVISION

San Diego, California

SPACE TUG PROJECT

WORK BREAKDOWN STRUCTURE

AND

DICTIONARY

TABLE OF CONTENTS

I - INTRODUCTION

The Space Tug Project Work Breakdown Structure (WBS) provides a consistent, subsystem oriented framework for technical, programmatic and cost analyses required by the several Space Tug definition studies. As the Tug project moves into later program phases this WBS will be revised to provide for more detailed or different tasks required in those phases.

The Space Tug Project consists of all tasks, material, hardware and services required to design, develop, test, produce and operate Space Tugs with the Space Shuttle to accomplish NASA and DoD missions. Therefore the project includes Tug/Shuttle interfaces and payload interfaces.

The Tug vehicle is considered as a payload with respect to the Space Shuttle. At the same time the Tug will have its respective payloads (spacecraft) for the several missions. For the purposes of this WBS, payload refers to the Tug payloads.

The following sections present the details of the WBS structure. Section II lists the WBS Identification Number Sequence. This numbering sequence consists of nine digits, which identify the WBS elements to level 3 (Assembly). Section III defines the Subdivisions of Work (SOW) which comprise the basic functional tasks within each WBS element. Section IV consists of definitions for each element displayed in the WBS. Section V consists of a master chart display of the titles of each WBS element and their build up to the total Tug project level.

The level of detail described herein (to level 6) is the minimum required. In specific studies lower level details will be required. For example, a detailed Tug Avionics definition study would require at least the next lower level of detail (level 7).

II - WBS IDENTIFICATION NUMBER SEQUENCE

IDENTIFICATION NUMBER	ELEMENT	LEVEL
320	SPACE TUG PROJECT	3
320-01	Project Management	4
320-01-01	Cost/Performance Management	5
320-01-02	Project Direction	5
320-01-03	Information Management	5
320-02	Systems Engineering and Integration	4
320-02-01	Tug Systems Engineering	5
320-02-02	Shuttle Interface	5
320-02-03	Payload Interface	5
320-02-04	Sustaining Engineering	5
320-03	Tug Vehicle Main Stage	4
320-03-01	Structure and Mechanical	5
320-03-01-01	Fuel Tank and Supports	6
320-03-01-02	Oxydizer Tank and Supports	6
320-03-01-03	Body Structure	6
320-03-01-04	Thrust Structure	6
320-03-01-05	Meteoroid Shield	6
320-03-01-06	Payload Interface	6
320-03-02	Thermal Control	5
320-03-02-01	Fuel Tank Insulation	6
320-03-02-02	Oxydizer Tank Insualtion	6
320-03-02-03	Insulation Purge System	6
320-03-02-04	Thermal Control System	6
320-03-03	Avionics	5
320-03-03-01	Data Management	6
320-03-03-02	Guidance, Navigation and Control	6
320-03-03-03	Rendezvous and Docking	6
320-03-03-04	Communications	6
320-03-03-05	Instrumentation	6
320-03-03-06	Electric Power	6
320-03-03-07	Electric Power Distribution & Control	6
320-03-04	Propulsion	5
320-03-04-01	Main Engine	6
320-03-04-02	Feed, Fill and Drain	6
320-03-04-03	Pressurization, Vent and Purge	6
320-03-04-04	Thrust Vector Control	6
320-03-04-05	Propellant Utilization and Propellant Loading Instrumentation	6
320-03-04-06	ACPS Engine	6
320-03-04-07	ACPS Support	6
320-03-05	Integration Assembly and Checkout	5

IDENTIFICATION NUMBER	ELEMENT	LEVEL
320-03-05-01	Final Assembly	6
320-03-05-02	Checkout	6
320-05	Logistics	4
320-05-01	Transportation and Handling	5
320-05-02	Training	5
320-05-02-01	Simulators and Equipment	6
320-05-02-02	Ground Crew	6
320-05-02-03	Flight Operations Crew (NASA)	6
320-05-02-04	Flight Operations Crew (DOD)	6
320-05-03	Logistics Operations	5
320-06	Facilities	4
320-06-01	Manufacturing	5
320-06-02	Test	5
320-06-03	Maintenance and Refurbishment	5
320-06-04	ETR Launch	5
320-06-05	WTR Launch	5
320-07	Ground Support Equipment (GSE)	4
320-07-01	Manufacturing and Test (GSE)	5
320-07-02	Eastern Test Range GSE	5
320-07-03	Western Test Range GSE	5
320-08	Vehicle Test	4
320-08-01	Ground Test Hardware	5
320-08-02	Ground Test Operations	5
320-08-03	Flight Test Hardware	5
320-08-04	Flight Test Operations	5
320-09	Launch Operations	4
320-09-01	Launch Operations, ETR	5
320-09-02	Launch Operations, WTR	5
320-10	Flight Operations	4
320-10-01	Flight Operations, ETR	5
320-10-02	Flight Operations, WTR	5
320-11	Refurbishment and Integration	4
320-11-01	Refurbishment and Integration, ETR	5
320-11-02	Refurbishment and Integration, WTR	5
320-15	Software	4
320-15-01	On Board Software	5
320-15-01-01	Tug	6
320-15-01-02	Shuttle	6
320-15-02	Mission Control Software	5
320-15-03	Ground Support Equipment Software	5

IDENTIFICATION NUMBER	ELEMENT	LEVEL
320-16	Orbiter Interface	4
320-16-01	Structural and Mechanical	5
320-16-01-01	Deployment, Rendezvous and Docking	6
320-16-01-02	Tug/Orbiter Supports	6
320-16-01-03	Interface Panels	6
320-16-01-04	Peripheral Equipment	6
320-16-02	Fluids	5
320-16-02-01	Main Propellant Fill, Drain & Dump	6
320-16-02-02	Vent	6
320-16-02-03	Purge	6
320-16-02-04	ACPS Provisions	6
320-16-02-05	Pressurization	6
320-16-03	Avionics	5
320-16-03-01	Data Management	6
320-16-03-02	Guidance, Navigation & Controls	6
320-16-03-03	Rendezvous and Docking	6
320-16-03-04	Communications	6
320-16-03-05	Instrumentation	6
320-16-03-06	Electrical Power	6
320-16-03-07	Electric Power Distribution & Control	6
320-16-03-08	Peripheral Equipment	6
320-16-04	Environmental	5
320-16-04-01	Thermal Control	6
320-16-04-02	Contamination Control	6
320-16-05	Integration, Assembly and Checkout	5

III - SUBDIVISIONS OF WORK (SOW)

The following definitions apply to the six SOW's. Additional SOW's should be avoided.

1. Engineering is the design, development, analysis, evaluation, and redesign of hardware, GSE, and associated planning and analysis activities. It includes such activities as configuration management, the preparation of specifications, drawings, parts lists, wiring diagrams, technical coordination between engineering and other activities, facilities engineering, vendor coordination, test planning and scheduling, analysis of test results, safety analysis, data reduction and engineering report preparation. It also includes the engineering activities required to support Production and the Operational phases. Materials and subcontracts associated with the above activities are included.

2. Manufacturing includes product and materials receiving, warehousing, fabrication, processing, assembly installation, reworking, modifications, experimental production, shop support to engineering checkout, preparation of hardware for shipping and preparation of necessary manufacturing associated paper work. Includes quality control and inspection activities. This SOW also includes technicians who support various test operations as well as launch operations and refurbishment activities. Materials and subcontracts associated with the above activities are included.

3. Tooling & STE includes planning, design, fabrication, quality control and inspection, modification, maintenance, and rework of all tools, dies, jigs, fixtures, gauges, handling equipment, work platforms, and test equipment and Special Test Equipment (STE) in support of the manufacturing process. It also includes writing and planning tool orders, certification of welding operations, maintaining tool and STE records, preparation of templates, scheduling and controlling all tool and STE orders, programming and preparation of tapes for all numerically controlled machine parts, and calibration and periodic maintenance of production and test tooling. It also includes the necessary tooling maintenance for the Production and Operational phases. Materials and subcontracts associated with the above activities are included.

4. Quality and Reliability Assurance (Q&RA) includes the establishment of Q&RA policies, procedures and requirements; Q&RA review of procurement requests and plans; test plans from a Q&RA standpoint and Q&RA report preparation. Develops Q&RA training plans and certification of quality control personnel. Also includes failure review, analysis and reporting. Materials and subcontracts associated with the above activities are included.

5. Testing involves the investigations on all components, assemblies, subsystems, and systems to determine operational characteristics, verify the suitability in meeting the required criteria, and assure compatibility with the overall system and its intended operational/nonoperational environment. Such tests include design feasibility tests, qualification tests, design verification tests, reliability tests, and

bench functional and environmental tests. Monitoring tests, data reduction, and report preparation are also included. Materials and subcontracts associated with the above activities are included.

6. Management/Other includes all management and administrative effort for planning, organizing, coordinating, directing, controlling, and approving that is required to accomplish the program objectives. Other items not included in the preceding subdivisions should be included in this item where possible. Materials and subcontracts associated with the above activities are included.

IV - WBS DEFINITIONS

320 SPACE TUG PROJECT

This element summarizes the direct and indirect (G&A and burden) effort to provide hardware, software, services, and facilities that are required to develop, produce, operate, and maintain a Space Tug Project, including the associated Tug/Shuttle interfaces.

320-01 PROJECT MANAGEMENT

This element summarizes the management activities of planning, organizing, directing, coordinating, controlling and approval actions required to accomplish overall Space Tug Project objectives which are not associated with specific hardware elements.

320-01-01 COST/PERFORMANCE MANAGEMENT

This element includes those activities which assure the integrated planning, scheduling, budgeting, work authorization and cost accumulation of all tasks performed during the Space Tug Program. Also included are project performance planning, preparation and maintenance of the Project Management Plan, project schedules, resource status reports, change controls, data summary analysis, procurement management, and safety management. This element should implement a low-cost plan to assure adherence to the Government's low-cost Tug philosophy and keyed to the project WBS.

320-01-02 PROJECT DIRECTION

This element pertains to the continuous monitoring of all functional management disciplines to provide central direction and control of the overall project. Included are the decision making for management, timely resolution of problem areas to meet established schedules, and overall surveillance of project progress and goals.

320-01-03 INFORMATION MANAGEMENT

This element refers to the overall management process and activities required to ensure proper information and documentation flow and control. Included are information coordination; identification, control and monitor of the preparation and maintenance of documentation; establishment, implementation and maintenance of the Data Management Plan and Procedures; acquisition of data from subcontractors, vendors and others; preparation, maintenance and submittal of the data, data schedules and accession list; establishment, operation, and maintenance of a project level information file; and public relations.

320-02 SYSTEMS ENGINEERING AND INTEGRATION

This element summarizes the Space Tug systems engineering task of directing and controlling a totally integrated engineering effort, including requirements analysis and integration, system definition, system test definition, interfaces, safety reliability, maintainability, configuration management, quality engineering, technology utilization and logistics support analysis.

320-02-01 TUG SYSTEMS ENGINEERING

This element consists of the systems engineering and integration effort to design, develop, produce and test the Space Tug and associated Tug/Shuttle interfaces. Included are analyses required to verify compatibility of designs with requirements; to meet mission model requirements; to control and direct the engineering activities; to assure proper Space Tug systems integration with both the Shuttle and spacecraft; and to make cost/performance tradeoffs. Also included are engineering planning, studies, technology utilization, technical risk assessment, reliability engineering, safety engineering, quality control, configuration requirements analysis, and associated support required to perform the Tug systems engineering task. Logistics planning and management are also included.

320-02-02 SHUTTLE INTERFACE

This element provides for that engineering effort required to define and maintain a standard Tug interface with the Shuttle, including analysis and identification of Tug test and checkout operations affecting that interface, analysis and identification of Tug systems configuration changes affecting the interface, and evaluation/coordination of recommended changes to the interface.

320-02-03 PAYLOAD INTERFACE

This element includes all systems engineering and integration effort associated with the Tug/Payload interface. Included are system analysis, design, test, and evaluation to ensure the efficient integration of the Tug to the various payloads of the Mission Model; implementation and maintenance of a system to accomplish the Tug/Payload integration; preparation, submittal and maintenance of Interface Control Documents; studies and analyses for system optimization, cost effectiveness and compatibility; technical risk assessment to identify potential major problems; and failure mode and effect analysis on interface hardware, mechanisms and panels which affect payload delivery, retrieval or mission.

320-02-04 SUSTAINING ENGINEERING

This element consists of sustaining engineering effort required for the Space Tug and associated Tug/Shuttle interfaces after the completed, assembled Tug and interface subsystems have been checked out for full flight certification and delivered. A principal effort includes normal product improvement and engineering changes that may occur as a result of user recommendations and/or operational experience. Also included are in-plant engineering liaison support of operational activities and the sustaining engineering support required at the launch sites during the operations phase. Activities would include further allocation of performance requirements for the vehicle into subsystem requirements, evaluation of vehicle and GSE performance, maintainability analysis, etc. Excluded are those activities that pertain to major hardware modification required to meet new performance specifications.

320-03 TUG VEHICLE MAIN STAGE

This element summarizes tasks, hardware and services required to design, develop, test, produce, install and checkout all subsystems and the complete Tug vehicle. The subsystems within this element are those that comprise the total Tug and remain with it during all mission phases. Included are all engineering design and analysis, tooling, manufacture, reliability and quality assurance, test and evaluation, assembly installation, checkout and procurement efforts required for a completed Space Tug. Production and operational spare for the Tug are included.

320-03-01 STRUCTURE AND MECHANICAL

This element summarizes all work associated with the design, development, test, and production of the Tug structural and mechanical subsystem elements. Included are the initial production and operational spares.

320-03-01-01 FUEL TANK AND SUPPORT

This element covers the structural details, structural subassemblies, brackets and supports of the fuel tank. It encompasses subordinate items such as baffles, level sensors supports, tank supports, basic tank shell, feedline supports, access covers, attachment mechanisms for wiring, etc. Specific inclusions are detail design and analysis; tool engineering and manufacture; procurement of materials and services; development and qualification tests; development and qualification of test fixtures, rigs and set-ups; and manufacture of components, subassemblies, assemblies, and spares.

320-03-01-02 OXIDIZER TANK AND SUPPORT

Same as Fuel Tank and Support (320-03-01-01), plus thrust structure attachment provisions.

320-03-01-03 BODY STRUCTURE

This element is the principal structural entity upon which the propellant tank(s) mount. It consists of the shell structure (comprised of forward skirt, main shell and intertank skirt), forward interface ring, manipulator attach point, access provisions, stage-side umbilicals, and support bracketry for avionics, fuel cell and ACPS components. The portion that remains in the Orbiter is excluded here but included under Orbiter Interface (320-16-01-01).

320-03-01-04 THRUST STRUCTURE

This element is composed of all structural members and subassemblies comprising the interface between the engine and the oxidizer tank. It includes thrust struts, engine mounting provisions, feed line supports, actuator attach points, and mounting supports for engine fluid and electrical interface lines.

320-03-01-05 METEOROID SHIELD

This item is comprised of any special meteoroid or micrometeoroid protection that may be deemed necessary beyond that provided by the body structure sidewall and the propellant tank insulation.

320-03-01-06 PAYLOAD INTERFACE

This element is comprised of all mechanical devices, electrical power and signal interfaces, pyrotechnics, etc., associated with attachment of the Tug to its payload. The structural interface ring, backup fittings and manipulator attach points are covered in the Body Structure element.

320-03-02 THERMAL CONTROL

This element includes the development, test, fabrication, installation, and checkout of the insulation for the fuel tank, oxidizer tank, and associated bracketry; the insulation purge system; and the vehicle thermal control system. Included are initial production and operational spares.

320-03-02-01 FUEL TANK INSULATION

This element includes the development, test and production of the insulation for the fuel tank. Also included are the procurement and evaluation of mockups and other supporting engineering activities.

320-03-02-02 OXIDIZER TANK INSULATION

Same as Fuel Tank Insulation.

320-03-02-03 INSULATION PURGE SYSTEM

This element includes the insulation purge system including bottles, valves, disconnects, plumbing, regulators, and control provisions.

320-03-02-04 THERMAL CONTROL SYSTEM

This element includes the development, test and production of the vehicle thermal control system. Included are such items as heat pipes, cold plates and active louvres, which are not an inherent part of the components of any subsystem. Thermal control devices or provisions which are an inherent part of a component of another subsystem are included within that subsystem and are excluded from this element.

320-03-03 AVIONICS

This element summarizes tasks, hardware and services to design, develop, test, produce, install and check out the Tug electronic and electrical equipments and the completed avionics subsystems. Tasks include qualification test of components and subsystems, manufacturing and tooling for development, production and operational spares.

320-03-03-01 DATA MANAGEMENT

This element consists of tasks, hardware and services required to provide equipment for the Tug data management subsystem, including data acquisition, computer operation and data processing. Included are such items as central processor, memory units, buffer/formatter, tape recorder and associated interface units. Thermal control provisions are included only if they are inherently part of a component of this subystem. Included are all engineering design and analysis, tooling, manufacturing reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment.

320-03-03-02 GUIDANCE, NAVIGATION AND CONTROL

This element consists of tasks, hardware and services to provide Tug guidance, navigation and electronic/electrical control functions. Included are such items as star trackers, horizon sensors, auto-collimators, IUMs, thermal conditioning systems, rate stabilization systems, and control interfaces for main engine actuators and ACPS actuators. Thermal control provisions are included only when they are an inherent part of a component of this subsystem. Included are engineering design and analysis, tooling, manufacture, reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment.

320-03-03-03 RENDEZVOUS AND DOCKING

This element consists of tasks, hardware and services required to design, develop, test and produce electronic/electrical Tug equipment necessary to provide Tug/Shuttle and Tug/payload rendezvous and docking functions. Included are items such as a laser radar unit, TV gimbal mounts, camera lights. Thermal control provisions are included only when they are an inherent part of a component of this subsystem. Included are engineering design and analysis, tooling, manufacture, reliability and quality assurance, test and evaluation and associated supporting tasks for this equipment.

320-03-03-04 COMMUNICATIONS

This element consists of tasks, hardware and services required to provide Tug communications equipment, such as FM transmitter, PM transponder, antenna, RF multiplexer, power amplifier and associated thermal conditioning. Thermal control provisions are included only when they are an inherent part of a component of this subsystem. Included are all engineering design and analysis, tooling, manufacturing, reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment.

320-03-03-05 INSTRUMENTATION

This element consists of tasks, hardware and services required to provide Tug instrumentation equipment, such as sensors, transducers, signal conditioning and circuitry. Thermal control provisions are included only when they are an inherent part of a component of this subsystem. Included are all engineering design and analysis, tooling, manufacturing, reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment.

320-03-03-06 ELECTRIC POWER

This element consists of tasks, hardware and services to provide Tug electric power sources (e.g., batteries and fuel cells). Thermal control provisions are included only when they are an inherent part of a component of this subsystem. Included are engineering design and analysis, tooling, manufacturing, reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment.

320-03-03-07 ELECTRIC POWER DISTRIBUTION AND CONTROL

This element consists of tasks, hardware and services to provide for the distribution and control of electric power in the Tug. This equipment typically consists of power distribution wiring and connectors, distribution harnesses, power control units, etc. Thermal control provisions are included only when they are an inherent part of a component of this subsystem. Included are engineering design and analysis, tooling, manufacturing reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment.

320-03-04 PROPULSION

This element covers the design, development, test, production and maintenance of the main and auxiliary propulsion systems. Included are all propulsion contractor costs incurred in these activities such as direct and indirect labor costs. Integrated testing at the vehicle system level is not included. Initial production and operational spares are also included.

320-03-04-01 MAIN ENGINE (GFE)

This element includes all deliverable main engines required for DDT&E activities, production and operational spare engines. All main engine DDT&E and/or DDT&E required to modify existing engines are included.

320-03-04-02 FEED, FILL AND DRAIN

This level 6 element is comprised of all lines, valves, ducts, bellows and other components that transfer the main engine oxidizer/fuel from the tanks to the main engine. Also included are all lines, ducts, valves, and other components required to fill and drain the main propellant tanks between the interface panel with the Orbiter or deployment adapter and the main tanks which are filled and drained.

320-03-04-03 PRESSURIZATION, VENT AND PURGE

This level 6 element is composed of all lines, valves, ducts, bellows and other components that take pressurization gases from the engine to the main fuel tank, and the lines, valves, ducts, bellows, storage tank and other components which provide pressurization gas to the oxidizer tanks. It also consists of those components that are required to provide for propellant vent and for carrying pressurization gas for the main oxidizer and main fuel tanks for dumping propellant overboard. Also included are those provisions required to provide gas purge of required vehicle areas.

320-03-04-04 THRUST VECTOR CONTROL

This element consists of the thrust vector control power conversion and distribution system elements and such other mechanisms or components as are required to orient and control the thrust vector of the main engine. It includes engine actuators and the associated valve controls or switches.

320-03-04-05 PROPELLANT UTILIZATION (PU) AND PROPELLANT LOADING INSTRUMENTATION SYSTEM (PLIS)

The PLIS senses liquid level in the propellant tanks and senses propellant mass during tanking and prior to flight. Propellant utilization consists of the controls of propellant use so as to minimize residual weight of one at depletion of the other. It includes the engine mixture ratio controls. Also included are provisions for electrical signals of proportional to simulated mass through vehicle umbilicals to ground monitoring equipment.

320-03-04-06 ACPS ENGINE

This element covers tasks, hardware and services necessary to design, develop, test, produce and maintain the entire ACPS except the plumbing and tanks. Included are all test hardware, test operations and test propellants. Installation and testing at the Space Tug vehicle level is not included.

320-03-04-07 ACPS ENGINE SUPPORT

This element covers the tanks (including their internal propellant acquisition devices), propellant and pressurization lines and valves of the ACPS. This element is a separate item due to the large amount of lines included in some Space Tug ACPS concepts. Also included are thermal conditioning provisions.

321-03-05 INTEGRATION, ASSEMBLY AND CHECKOUT

This element consists of tasks, material and services required for integrated Tug subsystems manufacture, and the assembly, checkout and acceptance of these subsystems. Items are included herein only if they are in the nature of overall manufacturing integration of interface WBS elements and/or involve two or more subsystems and hence are not identifiable to a single subsystem WBS element.

320-03-05-01 FINAL ASSEMBLY

This element covers the "prime" contractor activities in integrating and assembling the Space Tug elements and subsystems into an operational vehicle. Included are those activities required for packaging and preparation to ship.

320-03-05-02 CHECKOUT

This element includes all system calibration and checkout, as well as necessary acceptance testing, to validate the vehicle operational capability and readiness.

320-05 LOGISTICS

This element provides the effort to implement, operate, and maintain a logistics management for support of the Tug and Tug/Shuttle interfaces and related ground support equipment, including transportation, handling, factory warehousing, and inventories, systems orientation, and familiarization, training of ground and flight crew personnel and the design, development and manufacture of those distinctive end-items required specifically to meet the training objectives. Included are operational maintenance trainers, cutaways, models and any facilities constructed or modified for training purposes.

320-05-01 TRANSPORTATION AND HANDLING

This element refers to the preparation for and transportation of major items of Tug and interface equipment and hardware which have special requirements due to their size, weight, shape, or environmental control. Transportation of items not requiring such special considerations is included within the specific interface or ground subsystem element.

320-05-02 TRAINING

This element consists of training services, training materials, training aids and training equipment required for Tug factory, technical, flight and ground crew training. It includes instructor and student services, and the development and maintenance of lesson plans, study guides, training manuals, and training aids for classroom and trainer instruction in preparation for and during the Tug test and operations program phases.

320-05-02-01 SIMULATORS AND EQUIPMENT

This element refers to the cost for the design, development and manufacture of those distinctive end items required specifically to meet training objectives. Included are operational maintenance trainers, cutaways, and models.

320-05-02-02 GROUND CREW

This element includes the cost of instruction, audio-visual teaching aids and accessories required to train the personnel to support and maintain the Tug and Tug/Shuttle interface subsystems. Also included are training information, documentation, and the effort to determine the training requirements.

320-05-02-03 FLIGHT OPERATIONS CREW (NASA)

This element includes the cost of instruction, audio-visual teaching aids and accessories required to train the personnel to operate and/or maintain the Tug and equipment required to support flight operations at tracking stations and flight operations center.

320-05-02-04 FLIGHT OPERATIONS CREW (DOD)

Same as 320-05-02-03, except for DOD.

320-05-03 LOGISTICS OPERATIONS

This element refers to development of integrated logistic support (ILS) of the Tug, and the management of spares and repair parts and other specialized logistics in support of the Tug system during development and operations. This element includes the determination and management of spares quantity, procurement, warehousing, distribution and transportation. It also includes maintenance of spares status and logistics of repairable items to support servicing and maintenance of the Tug Vehicle and Tug support equipment during development. The cost of spares and repair parts (S&RP) and rework costs are not included. S&RP are included under each Tug Subsystem element and the ground support equipment element.

320-06 FACILITIES

This element covers facilities (new or modification to existing) for manufacture, test, maintenance, refurbishment, and launch support of an operational program. Note that the basic launch and operations facilities are charged to the Shuttle. However, those launch site facilities built specifically for Tug and Tug/Shuttle interfaces are included here. This effort includes facilities planning, acquisition or modification, and maintenance. Amortization of adequate existing facilities will not be included.

320-06-01 MANUFACTURING

This element includes all additional and modifications to existing government facilities and private facilities which are needed for Tug and Tug/Shuttle interfaces. It includes new facilities and equipment for the manufacture and checkout of subsystems, and intersite transportation facilities, such as docks, ramps, pads, air strips, etc.

320-06-02 TEST

This element includes all additional or modifications to existing facilities required for testing the Tug and Tug/Shuttle interface subsystems, and major test items as well as those required for development of new technology.

320-06-03 MAINTENANCE AND REFURBISHMENT

This element includes all additional or modifications to existing facilities required for maintenance and refurbishment of the operational Tug and Tug/Shuttle interface subsystems. Maintenance and refurbishment facilities include those necessary to accomplish on-site maintenance and repair, field site modifications, post-maintenance checkout, refurbishment, and equipment storage.

320-06-04 ETR LAUNCH

This element includes all additional or modification to existing launch facilities at the Eastern Test Range for the Tug and Tug/Shuttle interface equipments. Only the additional facilities built or modified specifically to configure the launch facilities for Tug/Shuttle interface acceptance are included.

320-06-05 WTR LAUNCH

This element includes all additions or modifications to existing launch facilities at the Western Test Range for Tug and Tug/Shuttle interface equipment. Only the additional facilities built or modified specifically to configure the launch facilities for interface acceptance are included.

320-07 GROUND SUPPORT EQUIPMENT (GSE)

This element includes all GSE required for the Tug and Tug/Shuttle interface subsystems test and operations. Included are all ground-based equipment required to support the ground test program and launch, recovery and maintenance phases during flight test operations and flight operations. The GSE element includes design, fabrication, documentation, and qualification of Tug and Tug/Shuttle interface peculiar test and operational GSE. GSE items included are hardware, site activation, and maintenance peculiar to interface ground operations for manufacturing and launch. All common DDT&E GSE costs will be charged to ETR since it will be the first activated. Therefore, the only DDT&E charged to WTR will be that for GSE which is peculiar to WTR. GSE spares are also included.

320-07-01 MANUFACTURING AND TEST GSE

This element is composed of all factory support equipment required to support the Tug system manufacturing operations and checkout, and the peculiar GSE which is required only for the R&D test program. This element also includes design, fabrication, integration, documentation, and qualification of all ground support equipment for manufacturing and test. Items included are hardware, site activation of GSE, maintenance, and any non-deliverable support equipment as well as associated spares.

320-07-02 EASTERN TEST RANGE GSE

This element includes all ground-based equipment required to support launch, flight, recovery and maintenance of the Space Tugs during both flight tests and operations. This element also includes design, modification, fabrication, integration, documentation, and qualification of the launch site and Tug GSE associated with flight hardware. Items included are hardware, site activation of GSE, and maintenance. The first set of launch site GSE produced can be used during the vehicle test program (Element #320-08).

320-07-03 WESTERN TEST RANGE GSE

Same as 320-07-02

320-08 VEHICLE TEST

This element includes the effort to plan and perform integrated system and subsystem level tests on the Tug and Tug/Shuttle interface equipment for both ground and flight testing. Included are ground test hardware, ground test operations, flight test hardware, and flight test operations. Included are major hardware articles such as fuel tank, oxidizer tank, thrust structure, battleship vehicle, flight test vehicles, mockups, etc. Hardware for subsystem test and qualification is excluded from this element, but is included with their design and development cost. Propellants and gases are included under the appropriate test operations.

320-08-01 GROUND TEST HARDWARE

This element includes the fabrication, assembly, installation, quality assurance, and checkout of major test articles, and mockups. The subsystem hardware installed on the test articles is included.

320-08-02 GROUND TEST OPERATIONS

This element includes the test management, requirements development and test planning activities for the vehicle level test programs. The preparation of the test articles for test; design of test fixtures; set-up, performance of tests and teardown; and data reduction/analysis and report generation are included. Propellants and gases required for ground test activities are also included.

320-08-03 FLIGHT TEST HARDWARE

This element includes the fabrication, assembly, installation, quality assurance, and checkout of all test hardware used for flight tests. Refurbishment of test articles for another major test is also included.

320-08-04 FLIGHT TEST OPERATIONS

This element includes dedicated vehicle test flights and associated activities only. A dedicated test flight is a vehicle flight for test purposes only and does not carry an operational payload. It includes all activities that support such test flight programs from the planning to launch, actual flight and return. All Tug and Tug/Shuttle interface systems launch support, operations support (i.e., countdown, tracking, etc.) data analysis and evaluation are included. Propellants and gases are also included. Excluded are activities associated with flights that carry an operational payload. These are to be included under the appropriate operational elements even though the flight may, as a secondary purpose, serve as a test flight.

320-09 LAUNCH OPERATIONS

This element summarizes services and operations required to perform those activities that comprise pre-launch and launch tasks for Tug and Tug/Shuttle interface elements. These activities include launch site services/support, mating and checkout, propellants and gases, pre-launch checkout, countdown, and post flight safing.

320-09-01 LAUNCH OPERATIONS, EASTERN TEST RANGE

This element consists of services and launch tasks which support Tug and Tug/ Shuttle interface subsystems during pre-launch and launch operations.

320-09-02 LAUNCH OPERATIONS, WESTERN TEST RANGE

Same as 320-09-01

320-10 FLIGHT OPERATIONS

This element summarizes flight operations tasks and services directly related to Tug and Tug/Shuttle interface equipment aspects of missions. These activities include mission planning, flight control and flight evaluation related to interface subsystems.

320-10-01 FLIGHT OPERATIONS, EASTERN TEST RANGE

This element consists of tasks and services required to support Tug and Tug/ Shuttle interface aspects of flight operations.

320-10-02 FLIGHT OPERATIONS, WESTERN TEST RANGE

Same as 320-10-01

320-11 REFURBISHMENT AND INTEGRATION

This element summarizes efforts for restoring the reusable Tug and Tug/ Shuttle interface subsystems after each mission to a readiness condition for subsequent missions. This activity is completed when the Tug and interface equipment are ready for launch operations. It includes both refurbishment and normal turnaround maintenance and checkout between flights, both scheduled and unscheduled. Also included are preflight requirement planning efforts, such as inspection requirements, reliability vs. refurbishment trade offs, Tug-to-Payload mating and checkout. Hardware costs for spares are excluded from this element but are included under interface subsystem elements.

320-11-01 REFURBISHMENT AND INTEGRATION, EASTERN TEST RANGE

This element consists of refurbishment and integration tasks to make Tug and Tug/Shuttle interface equipment used for one mission fully ready for the subsequent mission at ETR.

320-11-02 REFURBISHMENT AND INTEGRATION, WESTERN TEST RANGE

Same as 320-11-01, except at WTR.

320-15 SOFTWARE

This element summarizes all tasks and services required to analyze, develop, verify and implement Tug and Tug/Shuttle interface software. It includes design, processing and implementation of software (computer languages, computer programs, program verification, debugging, etc.) for ground and airborne subsystems related to Tug/Shuttle interface.

320-15-01 ONBOARD SOFTWARE

This element consists of tasks and services required to analyze, design, develop, simulate, verify, and maintain software for use onboard the Shuttle or Tug to support Tug and Tug/Shuttle interface requirements.

320-15-01-01 TUG ONBOARD SOFTWARE

This element consists of tasks and services for software which is required for Tug onboard subsystems.

320-15-01-02 SHUTTLE ONBOARD SOFTWARE

This element consists of tasks and services for software which are generated by Tug requirements, but which is for Shuttle subsystems or subsystems which remain with the Shuttle during the Tug flight portion of the missions.

320-15-02 MISSION CONTROL SOFTWARE

This element consists of tasks and services required to analyze, design, develop, simulate, verify, and maintain Tug and Tug/Shuttle interface software used in ground mission control systems.

320-15-03 GROUND SUPPORT EQUIPMENT SOFTWARE

This element consists of tasks and services required to analyze, design, develop, simulate, verify and maintain Tug and Tug/Shuttle interface software for GSE at the manufacturing, refurbishment and launch site.

320-16 ORBITER INTERFACE

This element summarizes tasks and services required to design, develop, test, produce, install and checkout all hardware required to mate the Tug with the Shuttle, link with and separate from it. Hardware includes that which remains in the Shuttle during the Tug flight portion of the mission. Included is the equipments for operational docking/undocking of the Tug and Shuttle, abort provisions, alignment and energy absorption, retraction/extension support, reentry purge, avionics interface, and umbilical disconnects in the fluid/electrical interface. Initial production and operational spares are included.

320-16-01 STRUCTURE AND MECHANICAL

This element summarizes tasks, hardware and services required to design, develop, test, produce, install and checkout structural and mechanical Tug/Shuttle interface equipments. These equipments consist of structural/mechanical portions of items required for Tug deployment, rendezvous and docking; interface panels, Tug/Orbiter supports, and supports for interfacing subsystems. Tasks include qualification test of components and subsystems, manufacturing and tooling for development, production and operational spares.

320-16-01-01 DEPLOYMENT, RENDEZVOUS AND DOCKING

This element consists of tasks, hardware and services required to design, develop, test and produce structural and mechanical hardware for Tug/Shuttle deployment, rendezvous and docking interfaces. Included are all engineering design and analysis, tooling, manufacture, reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment. Equipment within this element may consist of such items as deployment position control mechanisms and locks, Tug/adapter alignment/attenuation provisions, Tug/adapter separation latches and actuators, attachment fittings for Orbiter Remote Manipulation System, and deployment adapter structure.

320-16-01-02 INTERFACE PANELS

This element consists of tasks, hardware and services required to design, develop, test and produce structural and mechanical interface panels for the Tug/Shuttle interfaces. Engineering design and analysis, tooling, manufacture, reliability and quality assurance, test and evaluation, and associated support for structural and mechanical interface panels is included. Interface panels typically consist of such items as electrical, fuel and oxydizer umbilical panels; and panel position control mechanisms.

320-16-01-03 TUG/ORBITER SUPPORTS

This element consists of tasks, hardware and services required to design, develop, test and produce structural and mechanical supports for the Tug/Orbiter interface. Engineering design and analysis, tooling, manufacture, reliability and quality assurance, test and evaluation, and associated support for Tug/Orbiter supports is included. These supports typically consist of structural interface fittings, load balancing system elements, and deployment adapter.

320-16-01-04 PERIPHERAL EQUIPMENT

This element consists of tasks, hardware and services required to design, develop, test and produce structural and mechanical items required for Tug/Shuttle interface, but which may not be included in other structure/mechanical elements. Typical of this element are the various structural and mechanical support provisions required by other interface subsystems (e.g., fluids, avionics, etc.).

320-16-02 FLUIDS

This element summarizes tasks, hardware and services required to design, develop, test, produce, install and checkout Tug/Shuttle interface fluid subsystems. These items consist of main propellant fill, drain, dump, vent and purge provisions between the Tug and Shuttle and through the Shuttle and similar Attitude Control propellant provisions as required. Tasks include qualification test of components and subsystems, manufacturing and tooling for development, production and operational spares.

320-16-02-01 MAIN PROPELLANT FILL, DRAIN AND DUMP

This element consists of tasks, hardware and services required to design, develop, test and produce Tug/Shuttle main propellant fill, drain and dump interface equipments. Included are all engineering design and analysis, tooling, manufacture, reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment. Equipment within this element typically consists of lines, valves, ducts, bellows and other components between the Tug and Orbiter and within the Orbiter that are required to fill, drain and dump Tug main propellants from Tug tanks overboard through the Orbiter. Also included are special propulsion interfaces of these types necessary to mate/demate fill and drain functions when the Tug is entering or leaving the payload bay.

320-16-02-02 VENT

This element consists of tasks, hardware and services required to design, develop, test and produce Tug/Shuttle interface equipments for venting of Tug propellants and/or gases overboard through the Orbiter. Included are all engineering design and analysis, tooling, manufacture, reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment. Equipment within this element typically consists of lines, valves, ducts, bellows, and other components required between the Tug and Orbiter and within the Orbiter to provide for carrying pressurization gas from Tug main propellant tanks for dumping propellants overboard. Also included are special vent interface provisions of the above types to accomplish mate/demate when the Tug is entering or leaving the Orbiter payload bay.

320-16-02-03 PURGE

This element consists of tasks, hardware and services required to design, develop, test and produce Tug/Shuttle equipments for purging propellants and gases from Tug tanks and lines overboard through the Orbiter. Included are all engineering design and analysis, tooling, manufacture, reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment. Equipment within this element typically consists of lines, valves, ducts, bellows, storage tank and other components installed between the Tug and Orbiter and within the Orbiter to provide gas purge of required vehicle areas. Also included are the provisions for purge required for mate/demate when the Tug is leaving and/or entering the Orbiter payload bay.

320-16-02-04 ATTITUDE CONTROL PROPULSION SYSTEM (ACPS) PROVISIONS

This element consists of tasks, hardware and services required to design, develop, test and produce Tug/Shuttle interface equipment to accommodate the Tug ACPS within the Orbiter and while linking with or separating from it during the mission. Included are all engineering design and analysis, tooling, manufacture, reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment. Equipment within this element typically consists of lines, valves, flex joints, couplings, etc., installed between Tug and Orbiter and within the Orbiter to provide for fill and drain of Tug ACPS propellants and gases when the Tug is in the Orbiter payload bay. Also included are interfaces for handling ACPS propellants and gases mate/demate when the Tug is entering or leaving the payload bay.

320-16-02-05 PRESSURIZATION

This element consists of tasks, hardware and services required to design, develop, test and produce Tug/Shuttle interface equipment to provide for pressurization of Tug main propellant tanks and/or vehicle areas while the Tug is within the Orbiter and for mate/demate during the mission. Included are all engineering design and analysis, tooling, manufacture, reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment. Equipment in this element typically consists of lines, valves, ducts, bellows and other components between the Tug and Orbiter and within the Orbiter that provide pressurization gas to Tug tanks and vehicle areas while the Tug is in the Orbiter. Also included are these items required for mate/demate when the Tug is entering or leaving the Orbiter payload bay.

320-16-03 AVIONICS

This element summarizes tasks, hardware and services to design, develop, test, produce, install and check out the electronic and electrical equipments that provide Tug/Shuttle interfaces while the Tug is in the Orbiter payload bay and while it is entering or leaving it during a mission. Tasks include qualification test of components and subsystems, manufacturing and tooling for development, production and operational spares.

320-16-03-01 DATA MANAGEMENT

This element consists of tasks, hardware and services required to provide equipment for Tug/Shuttle hardware data exchange and processing while the Tug is in the Orbiter bay and when it is entering or leaving it during a mission. Included are all engineering design and analysis, tooling, manufacturing reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment.

320-16-03-02 GUIDANCE, NAVIGATION AND CONTROL

This element consists of tasks, hardware and services to provide guidance, navigation and electronic/electrical control functions between the Tug and Shuttle while the Tug is in the Orbiter payload bay and while it is leaving or entering the bay during a mission. Included are engineering design and analysis, tooling, manufacture, reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment.

320-16-03-03 RENDEZVOUS AND DOCKING

This element consists of tasks, hardware and services required to design, develop, test and produce electronic/electrical interface equipment necessary to provide Tug/Shuttle and Tug/Payload rendezvous and docking functions in addition to the functions provided by standard on board Shuttle and Tug equipments. Included are engineering design and analysis, tooling, manufacture, reliability and quality assurance, test and evaluation and associated supporting tasks for this equipment.

320-16-03-04 COMMUNICATIONS

This element consists of tasks, hardware and services required to provide communications equipment for the Tug/Shuttle interface during all launch and flight mission phases. Included are all engineering design and analysis, tooling, manufacturing, reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment.

320-16-03-05 INSTRUMENTATION

This element consists of tasks, hardware and services required to provide instrumentation equipment for the Tug/Shuttle interface provisions. Included are all engineering design and analysis, tooling, manufacturing, reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment.

320-16-03-06 ELECTRIC POWER

This element consists of hardware, tasks and services to design, develop, test and produce electrical power sources (e.g., batteries and fuel cells) and/or associated provisions within the Tug/Shuttle interface. In the case of a fuel cell the associated reactant supply and storage, venting, product water, purge, and thermal control provisions are included. Included are the associated Tug/Orbiter mate/demate provisions.

320-16-03-07 ELECTRIC POWER DISTRIBUTION AND CONTROL

This element consists of tasks, hardware and services to provide for the distribution and control of electric power in the Tug/Shuttle interface. This equipment typically consists of power distribution wiring and connectors, distribution harnesses, etc. Included are engineering design and analysis, tooling, manufacturing reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment.

320-16-03-08 PERIPHERAL EQUIPMENT

This element consists of tasks, hardware and services required to design, develop, test and produce electronic and electrical equipments required for Tug/Shuttle interface, but which may not be included in other avionics elements.

320-16-04 ENVIRONMENTAL

This element summarizes tasks, hardware and services required to design, develop, test, produce, install and checkout Tug/Shuttle interface environmental control equipment. This equipment typically includes thermal control items, such as heat dissipation devices and insulation, and equipment required to control/prevent contamination in critical areas of the vehicle. Tasks include qualification test of components and subsystems, manufacturing and tooling for development, production, and operational spares.

320-16-04-01 THERMAL CONTROL

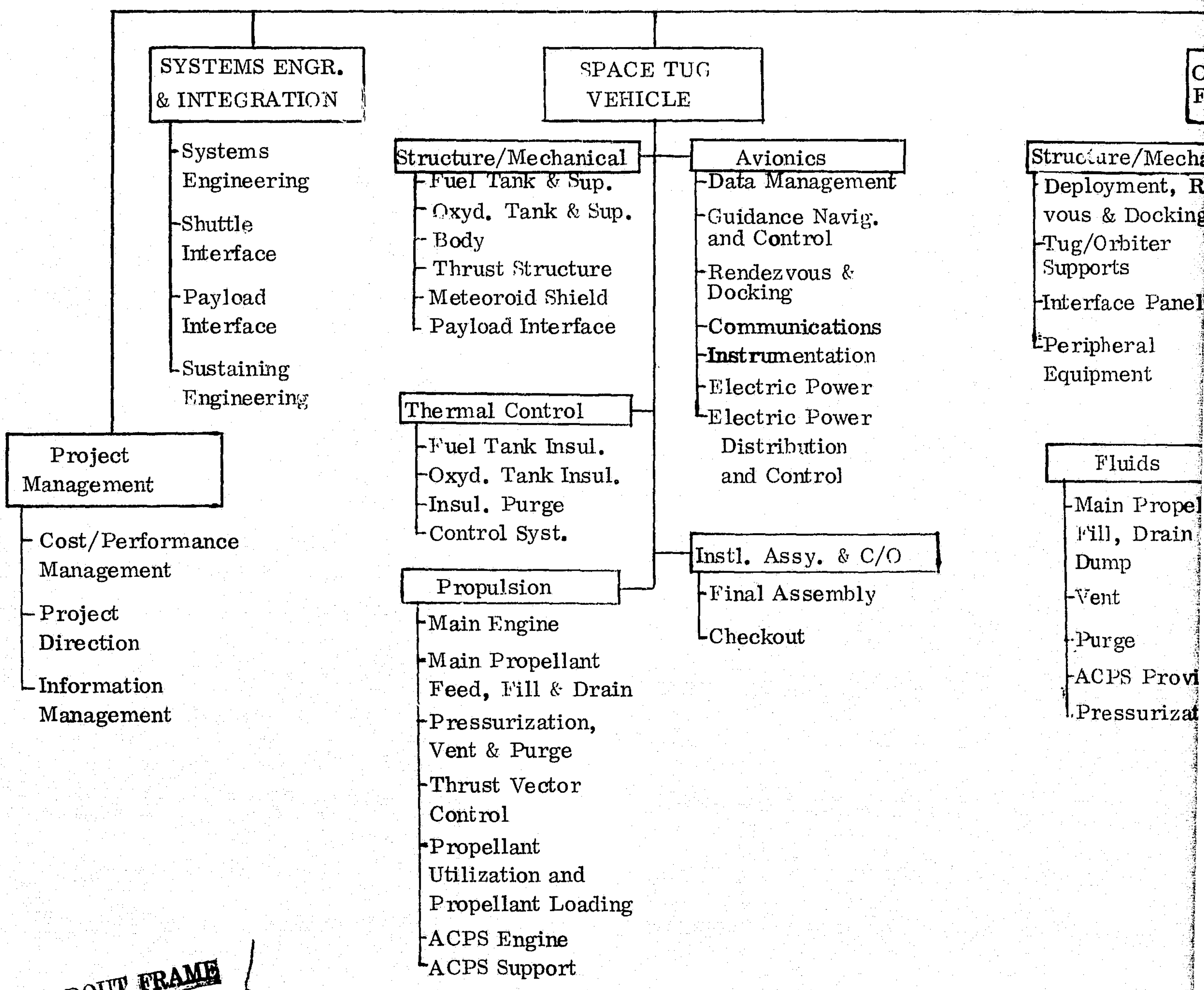
This element consists of active subsystems hardware and passive (e.g., insulation) provision for control of temperature in critical Tug/Shuttle interface areas. Thermal control devices or provisions which are an inherent part of a component of another subsystem are included within that subsystem element and are excluded from this element. Included are all engineering design and analysis, tooling, manufacture, reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment.

320-16-04-02 CONTAMINATION CONTROL

This element consists of tasks, hardware and services required to provide subsystems for control of contamination in critical vehicle areas of the Tug/Shuttle interface. Included are engineering design and analysis, tooling, manufacturing, reliability and quality assurance, test and evaluation, and associated supporting tasks for this equipment.

320-16-05 INTEGRATION, ASSEMBLY AND CHECKOUT

This element consists of tasks, material and services required to integrated Tug/Shuttle interface subsystems manufacture, and the assembly, checkout and acceptance of these subsystems. Items are included herein only if they are in the nature of overall manufacturing integration of interface WBS elements and/or involve two or more subsystems and hence are not identifiable to a single subsystem WBS element.



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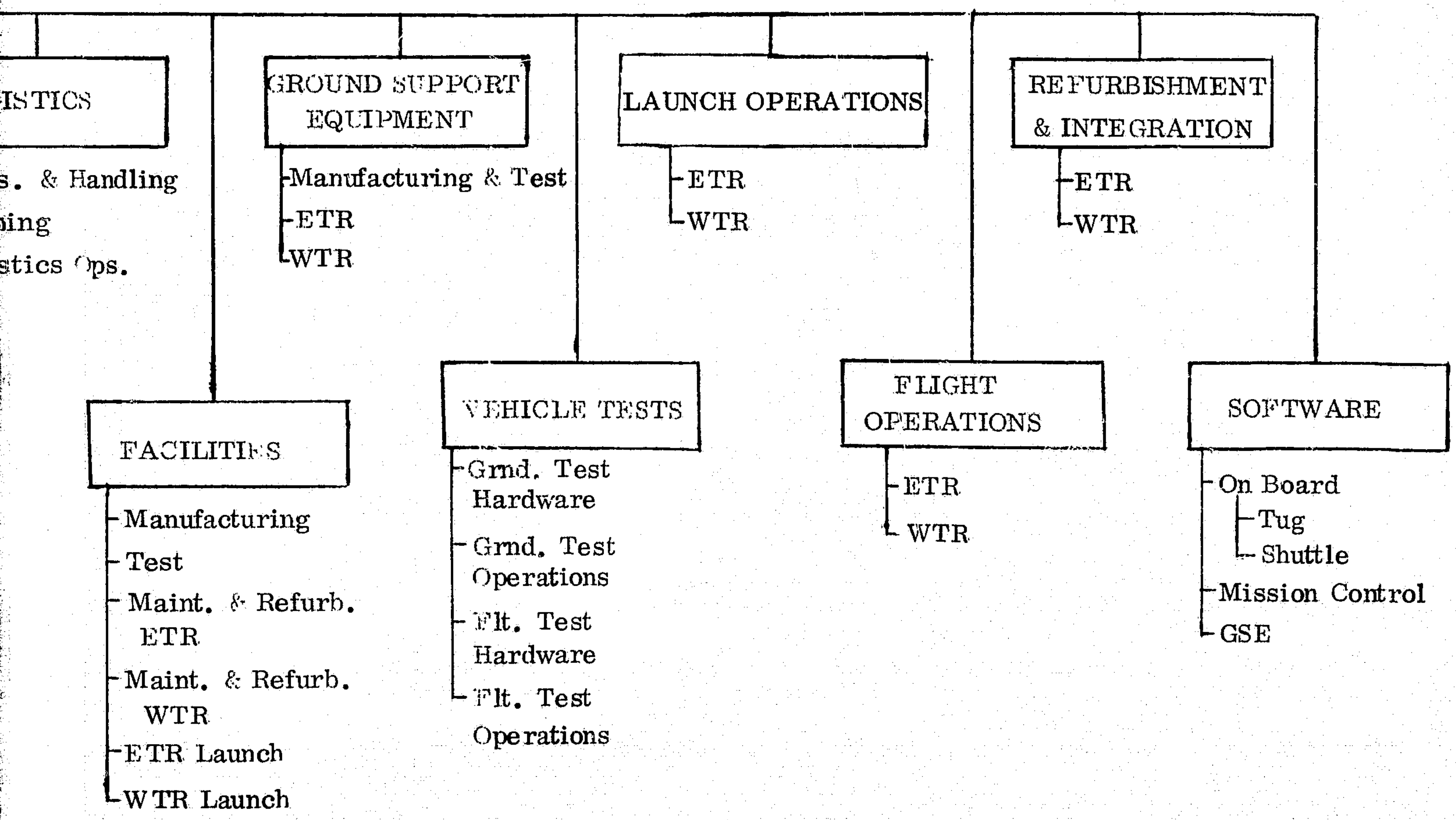

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APPENDIX B

NASA DETAILED COST REPORT FORMS

Space Tug Avionics Definition Study

Contract Number - NAS8-31010

COST DATA FORM – A(1)
NON-RECURRING (DDT&E)
(MINIMUM SRT PROGRAM)

Date ____________

IDENTIFICATION NUMBER	WBS IDENTIFICATION	WBS LEVEL	EXPECT. COST	CONFID. RATING	T_d	T_s	SPREAD FUNCT.
320-03-03	Tug Avionics	5	(72,278)				
320-03-03-01	Data Management	6	10,189	2	42	12/78	4
320-03-03-02	Guidance, Navigation & Control	6	23,032	2	32	12/78	3
320-03-03-03	Rendezvous & Docking	6	13,734	2	43	12/78	4
320-03-03-04	Communications	6	9,108	3	26	12/78	3
320-03-03-05	Instrumentation	6	7,338	3	30	1/79	4
320-03-03-06	Electric Power	6	7,280	3	32	12/78	3
320-03-03-07	Elect. Power Dist. & Control	6	2,196	3	32	12/78	3
320-15-01-01	Tug On Board Software	6	5,828	3	37	12/78	3
320-08-01	Ground Test Hardware	5	8,518	3	27	7/79	4
320-08-02	Ground Test Operations	5	6,232	3	24	1/80	4

Space Tug Avionics Definition Study

Contract Number - NAS8-31010

COST DATA FORM – A(1)

• NON-RECURRING (DDT&E)

(RECOMMENDED SRT PROGRAM)

Date__________

Page 1 of 1

IDENTIFICATION NUMBER	WBS IDENTIFICATION	WBS LEVEL	EXPECT. COST	CONFID. RATING	T_d	T_s	SPREAD FUNCT.
320-03-03	Tug Avionics	5	(57,008)				
320-03-03-01	Data Management	6	7,918	2	42	12/78	4
320-03-03-02	Guidance, Navigation & Control	6	18,193	2	32	12/78	3
320-03-03-03	Rendezvous & Docking	6	10,649	2	43	12/78	4
320-03-03-04	Communications	6	7,154	3	26	12/78	3
320-03-03-05	Instrumentation	6	5,830	3	30	1/79	4
320-03-03-06	Electric Power	6	5,461	3	32	12/78	3
320-03-03-07	Elect. Power Dist. & Control	6	1,803	3	32	12/78	3
320-15-01-01	Tug On Board Software	6	4,662	3	37	12/78	3
320-08-01	Ground Test Hardware	5	7,882	3	27	7/79	4
320-08-02	Ground Test Operations	5	4,620	3	24	1/80	4

Space Tug Avionics Definition Study

Contract Number - NAS8 -31010

COST DATA FORM - A(2)

RECURRING (PRODUCTION)

IDENTIFICATION NUMBER	WBS IDENTIFICATION	WBS LEVEL	NO. OF UNITS	1st UNIT COST T_1	EXPECTED COST	REF. UNIT	REF. UNIT COST	CONFID. RATING	T_d	T_s	SPREAD FUNCT	LEARN INDEX
320-03-03	Tug Avionics	5	—	(7,882)	(116,364)							
320-03-03-01	Data Management	6	15	1,437	18,814	1	See Column Titled 1st Unit Cost T_1	2	66	10/80	6	0.95
320-S3-03-01	" Spares	6	1.36		1,954	1		2				1.00
320-03-03-02	GN&C	6	—	(1,395)	(20,153)							
320-03-03-02-01	G&N	7	15	496	6,494	1		2	64	10/80	6	0.95
320-S3-03-02-01	" Spares	7	0.73		362	1		2				1.00
320-03-03-02-02	Guidance Update	7	15	677	8,863	1		3	64	10/80	6	0.95
320-S3-03-02-02	" Spares	7	3		1,131	1		3				1.00
320-03-03-02-03	Flight Control	7	15	222	2,906	1		2	64	10/80	6	0.95
320-S3-03-02-03	" Spares	7	1.79		397	1		2				1.00
320-03-03-03	Rend. & Docking	6	—	(1,106)	(15,428)							
320-03-03-03-01	SLADAR	7	15	740	8,424	1		2	54	7/81	6	0.90
320-S3-03-03-01	" Spares	7	2		1,480	1		2				1.00
320-03-03-03-02	LLLTV	7	15	366	4,792	1		3	54	7/81	6	0.95
320-S3-03-03-02	" Spares	7	2		732	1		3				1.00
320-03-03-04	Communications	6	15	2,007	26,276	1		3	69	10/81	6	0.95
320-S3-03-04	" Spares	6	3.2		6,422	1		3				1.00

Space Tug Avionics Definition Study

Contract Number - NAS8 -31010

COST DATA FORM - A(2)
RECURRING (PRODUCTION)

Date______________

IDENTIFICATION NUMBER	WBS IDENTIFICATION	WBS LEVEL	NO. OF UNITS	1st UNIT COST T_1	EXPECTED COST	REF. UNIT	REF. UNIT COST	CONFID. RATING	T_d	T_S	SPREAD FUNCT	LEARN INDEX
320-03-03-05	Instrumentation	6	15	1,397	18,290	1	See Column Titled 1st Unit Cost T_1	3	72	10/80	6	0.95
320-S3-03-05	" Spares	6	0.5		699	1		3				1.00
320-03-03-06	Electric Power	6	15	265	3,469	1		3	78	1/81	6	0.95
320-S3-03-06	" Spares	6	4.24		1,124	1		3				1.00
320-03=03-07	EP D&C	6	15	275	3,600	1		3	70	4/81	6	0.95
320-S3-03-07	" Spares	6	0.49		135	1		3				1.00

Space Tug Avionics Definition Study

Contract Number - NAS8 -31010

COST DATA FROM – A (3)

RECURRING (OPERATIONS)

Date________

INDENTIFICATION NUMBER	WBS IDENTIFICATION	WBS LEVEL	NO. OF UNITS	EXPECT COST	REF. UNIT	REF UNIT COST	CONFID. RATING	T_d	T_s	SPREAD FUNCT	LEARN INDEX
320-S3-03	Tug Avionics	5		(5,488)							
320-S3-03-01	Data Management	6	.504	724	1	1,437	2	68	4/86	21	1.0
320-S3-03-02-01	GN&C (IMU)	7	.9072	450	1	496	2	70	2/86	21	1.0
320-S3-03-02-02	GN&C (Guid. Update)	7	.0252	17	1	677	3	70	2/86	21	1.0
320-S3-03-02-03	GN&C (Flt. Cntl.)	7	.3864	86	1	222	2	70	2/86	21	1.0
320-S3-03-03	Rendezvous & Docking	6	.8904	985	1	1,106	2	71	1/86	21	1.0
320-S3-03-04	Communications	6	.131	263	1	2,007	3	58	7/87	21	1.0
320-S3-03-05	Instrumentation	6	1.8984	2,652	1	1,397	3	62	10/86	21	1.0
320-S3-03-06	Electric Power	6	1.1088	294	1	265	3	53	7/87	21	1.0
320-S3-03-07	Elect. Power D&C	6	.0622	17	1	275	3	59	2/87	21	1.0

TECHNICAL CHARACTERISTICS DATA FORM B

Study Title - Space Tug Avionics Definition Study

Date 4-3-75

Contract Number - NAS 8-301010

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Configuration - Baseline

WBS IDENTIFICATION NUMBER	WBS IDENTIFICATION	VALUE	UNIT OF MEASURE	CHARACTERISTICS	NOTES
320-03-03	Avionics Hardware				
320-03-03-01	Data Management				
	Computer			Dual Modular SUMC; 48K, 32 bit, semi-conductor memory, CMOS Logic	
		(25.4 × 35.6 × 24.1)	cm	Dimensions	
		10.0 × 14.0 × 9.5	in		
		34 (15.4)	lb (kg)	Weight	
		60	watts	Power	
	Computer Interface Unit (CIU) (2) per unit			Micro Programmable; CMOS Logic	
		(12.7 × 12.7 ×16.5)	cm	Dimensions	
		5 × 5 × 6.5	in		
		6.5 (2.9)	lb (kg)	Weight	
		7	watts	Power	
	Digital Interface Unit ((DIU) (8) per unit			Micro Programmable; CMOS Logic	
		(12.7 × 12.7 × 16.5)	cm	Dimensions	
		5 × 5 × 6.5	in		
		5 (2.3)	lb (kg)	Weight	
		5	watts	Power	

TECHNICAL CHARACTERISTICS DATA FORM B

Study Title - Space Tug Avionics Definition Study

Date 4-3-75

Contract Number - NAS 8-301010

Configuration - Baseline

WBS IDENTIFICATION NUMBER	WBS IDENTIFICATION	VALUE	UNIT OF MEASURE	CHARACTERISTICS	NOTES
320-03-03-01 (Cont.)	Tape Recorder			NASA Standard Recorder.	
		(25.4 × 20.3 × 12.7)	cm	Dimensions	
		10 × 8 × 5	in		
		13 (5.9)	lb (kg)	Weight	
		20	watts	Power (Intermittent)	

TECHNICAL CHARACTERISTICS DATA FORM B

Study Title - Space Tug Avionics Definition Study

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Configuration - Baseline

WBS IDENTIFICATION NUMBER	WBS IDENTIFICATION	VALUE	UNIT OF MEASURE	CHARACTERISTICS	NOTES
320-03-03-02	G, N, & C Inertial Measurement Unit			Strapdown System with 6 Ring Laser Gyros and 6 Accelerometers in a Dodecahedron Configuration	
	Inertial Instruments	(22.9 × 22.90) 9 × 9 Diameter	cm	Dimensions	
		25 (11.3)	in (kg)	Weight	
		100	watts	Power	
	IMU Electronics	(25.4 × 50.8 × 12.7) 10 × 20 × 5	cm	Dimensions	
		30 (13.6)	lbs (kg)	Weight	
		100	watts	Power	
	Rate Gyros			6 Laser Gyros in a Dodecahedron Configuration	
		(25.4 × 25.4 × 15.2) 10 × 10 × 6	cm in	Dimensions	
		20 (9.1)	lbs (kg)	Weight	
		100	watts	Power	

TECHNICAL CHARACTERISTICS DATA FORM B

Study Title - Space Tug Avioni·s Definition ´tudy

Contract Number - NAS 8-31010

Configuration - Baseline

Date 4-3-75

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WBS IDENTIFICATION NUMBER	WBS IDENTIFICATION	VALUE	UNIT OF MEASURE	CHARACTERISTICS	NOTES
320-03-03-02 (Cont.)	Control Electronics			Redundant TUC servo-Amplifiers and APS control	
		(30.5 × 30.5 × 45.7)	cm	Dimensions	
		12 × 12 × 18	in		
		50 (22.7)	lbs (kg)	Weight	
		50	watts	Power	
	Interferometric Landmark Tracker (ILT)			4 Antennas Plus a Redundant Receiver Electronics Package	
		(5.1 × 15.2)	cm	Dimensions	
	4 Antennas (Each)	2 × 6 Diameter	in		
		1 (.45)	lbs (kg)	Weight	
		0	watts	Power	
	1 Receiver Electronics	(30.5 × 25.4 × 22.9)	cm	Dimensions	
		12 × 10 × 9	in		
		20 (9.1)	lbs (kg)	Weight	
		15	watts	Power	

TECHNICAL CHARACTERISTICS DATA FORM B

Study Title - Space Tug Avionics Definition Study

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WBS IDENTIFICATION NUMBER	WBS IDENTIFICATION	VALUE	UNIT OF MEASURE	CHARACTERISTICS	NOTES
320-03-03-02 (Cont.)	Star Trackers (2)			Two Bendix Strapped Down, Image Dissector Star Trackers	
		(15.2 × 20.3 × 30.5)	cm	Dimensions	
		6 × 8 × 12	in		
		16 (7.3)	lbs (kg)	Weight	
		12	watts	Power	
	Sun Sensors (2)			Two Two-Axis Digital Sun Sensors	
		(17.5 × 16.5 × 7.6)	cm	Dimensions	
		6.9 × 6.5 × 3	in		
		4.5 (2.1)	lbs (kg)	Weight	
		5	watts	Power	
	Control Electronics			Redundant TUC Servo-Amplifiers and APS Control	
		(30.5 × 30.5 × 45.7)	cm	Dimensions	
		12 × 12 × 18	in		
		50 (22.7)	lbs (kg)	Weight	
		50	watts	Power	

TECHNICAL CHARACTERISTICS DATA FORM B

Study Title - Tug Avionics Definition Study

Contract Number - NAS8-301010

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WBS IDENTIFICATION NUMBER	WBS IDENTIFICATION	VALUE	UNIT OF MEASURE	CHARACTERISTICS	NOTES
320-03-03-03	Rendezvous & Docking				
	Scanning Laser Radar (1)	6 x 8 x 20	inches	Dimensions	
		(15.2x20.3x50.8)	(cm)	Dimensions	
		10	watts	Operating Power	
		28 (12.7)	lbs (Kg)	Weight	
	LADAR Electronics (1)	9 x 9 x 11	inches	Dimensions	
		(22.9x22.9x27.9)	(cm)	Dimensions	
		30	watts	Operating Power	
		11 (5.0)	lbs (Kg)	Weight	
	TV Camera and Electronics (2)	6 x 6 x 15	inches	Dimensions (ea.)	
		(15.2x15.2x38.1)	(cm)	Dimensions (ea.)	
		10	watts	Operating Power (ea.)	
		8 (3.6)	lb (Kg)	Weight (ea.)	
	TV Strobe Lamps (4)	3.5x3.5x3.5	inches	Dimensions (ea.)	
		(8.9x8.9x8.9)	(cm)	Dimensions (ea.)	
		Negligible	watts	power	
		1 (0.45)	lb (Kg)	Weight (ea.)	

TECHNICAL CHARACTERISTICS DATA FORM B

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Configuration - Baseline

WBS IDENTIFICATION NUMBER	WBS IDENTIFICATION	VALUE	UNIT OF MEASURE	CHARACTERISTICS	NOTES
320-03-03-04	Communications Phased Array Antenna (3) Per Unit			Electronically Steerable; 25 transmit modules Integrated Beam Steering Logic	
		(8.6 × 38.1)	cm	Dimensions	
		3.4 × 15.0 Diameter	in		
		16 (7.3)	lb (kg)	Weight	
		93	watts	Power (one unit powered at a time)	
	Hemispherical Antenna (2) Per Unit			Cavity Backed Planar Spiral	
		(11.7 × 15.2 × 5.1)	cm	Dimensions	
		4.6 × 6.0 × 2.0	in		
		1 (.45)	lb	Weight	
	RF Network Assembly			Ring Coupler and Dual Diplexer	
		(8.4 × 9.7 × 2.5)	cm	Dimensions	
		3.3 × 3.8 × 1.0	in		
		2 (.91)	lb	Weight	

TECHNICAL CHARACTERISTICS DATA FORM B

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WBS IDENTIFICATION NUMBER	WBS IDENTIFICATION	VALUE	UNIT OF MEASURE	CHARACTERISTICS	NOTES
320-03-03-04 (cont.)	RF Switch Assembly			Multiple Path Switching Matrix	
		(12.7 × 12.7 × 15.9)	cm	Dimensions	
		5.0 × 5.0 × 6.3	in		
		7.3 (3.3)	lb (kg)	Weight	
		3.0	watts	Power	
	Transponder (2) per unit			Compatible with STDN, TDRS and AFSCF Networks	
		(38.1 × 17.8 × 15.2)	cm	Dimensions	
		15 × 7 × 6	in		
		16.5 (7.5)	lb	Weight	
		16	watts	Power	
	Signal Processor (2) per unit			Convolutional Encoder, Decoder, Command Decoder, Switchable	
		(34.3 × 15.2 × 14.2)	cm	Dimensions	
		13.5 × 6.0 × 5.6	in		
		11.1 (5)	lb (kg)	Weight	
		18	watts	Power	

TECHNICAL CHARACTERISTICS DATA FORM B

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WBS IDENTIFICATION NUMBER	WBS IDENTIFICATION	VALUE	UNIT OF MEASURE	CHARACTERISTICS	NOTES
320-03-03-04 (Cont.)	Command Distribution Unit			Redundant Relay Command Drivers; Serial Output	
		(12.7 × 12.7 × 10.2)	cm	Dimensions	
		5 × 5 × 4	in		
		18 (8.2)	lb (kg)	Weight	
		35	watts	Power (Active)	
		7	watts	Power (Passive)	
	Encryption Device (2) per unit			GFE	
		(14.7 × 10.9 × 13.5)	cm	Dimensions	
		5.8 × 4.3 × 5.3	in		
		4.3 (2.0)	lb (kg)	Weight	
		7	watts	Power	
	Decryption Device			GFE	
		(15.2 × 9.1 × 14.7)	cm	Dimensions	
		6.0 × 3.6 × 5.8	in		
		4.1 (1.9)	lb	Weight	
		2.4	watts	Power	

TECHNICAL CHARACTERISTICS DATA FORM B

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WBS IDENTIFICATION NUMBER	WBS IDENTIFICATION	VALUE	UNIT OF MEASURE	CHARACTERISTICS	NOTES
320-03-03-05	Instrumentation				
	Transducers	243	No. Units	Transducers (various)	
		248	No. Units	Simple Data Measurements	
		160	No. Units	Passive Detectors	
		20 (9.1)	lbs (Kg)	Seight (total)	
	Wire	612	ft	Length (#22 AWG Kapton Insul)	
	Connectors	330	No. Units		
	Signal Conditioners/ Multiplexers (3)	12 x 10 x 6	inches	Dimensions (ea.)	
		(30.5X25.4X15.2)	(cm)	Dimensions (ea.)	
		22	watts	Operating Power (ea.)	
		18 (8.2)	lb (Kg)	Weight (ea.)	

TECHNICAL CHARACTERISTICS DATA FORM B

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WBS IDENTIFICATION NUMBER	WBS IDENTIFICATION	VALUE	UNIT OF MEASURE	CHARACTERISTICS	NOTES
	Strobe Electronics (2)	2 x 3.5 x 2.5	inches	Dimensions (ea.)	
		(5.1x8.9x6.4)	(cm)	Dimensions (ea.)	
		2 (0.9)	lb (Kg)	Weight (ea.)	
		Negligible	watts	Power	

TECHNICAL CHARACTERISTICS DATA FORM B

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WBS IDENTIFICATION NUMBER	WBS IDENTIFICATION	VALUE	UNIT OF MEASURE	CHARACTERISTICS	NOTES
320-03-03-06	Electrical Power				
	Fuel Cell Power Plant (2)			Dual Redundant Thermally integrated lightweight PUD, United Aircraft	
		(30.5 × 15.2 × 38.1) 12 × 6 × 15	cm in	Dimensions	
		42.4 (19.2)	lb (kg)	Weight	
	Emergency Battery			AG-Zn (50 ah)	
		(20.3 × 27.9 × 17.8) 8 × 11 × 7	cm in	Dimensions	
		36 (16.3)	lb (kg)	Weight	
		8	watts	Power	
For Ref. Only: (Components located in WBS: 320-03-04-02 320-03-04-03 320-03-04-07	(Heat Rejection Exchanger; Reactant Feed & Vent Plumbing	[91 (41.3)]	lbs (kg)	Weight – Includes water storage	

TECHNICAL CHARACTERISTICS DATA FORM B

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WBS IDENTIFICATION NUMBER	WBS IDENTIFICATION	VALUE	UNIT OF MEASURE	CHARACTERISTICS	NOTES
320-03-03-07	Power Distribution and Control			Centralized, Solid State	
	Fwd Power Control Unit			Solid State & Hybrid Switches	
		(25.4 × 15.2 × 20.3)	cm	Dimensions	
		10 × 6 × 8	in		
		10 (4.5	lb (kg)	Weight	
	Aft Power Control Unit			Solid State & Hybrid Switches	
		(30.5 × 38.1 × 20.3)	cm	Dimensions	
		12 × 15 × 8	in		
		24 (10.9)	lb (kg)	Weight	
	Harnesses & Connectors	1000' 22 ga	ft	Length	
		400' 10 ga			
		100' 8 ga			
		130 (59)	lb (kg)	Weight	
		60 connectors			
	Power Processing Unit (2)	(22.9 × 22.9 × 20.3)	cm	Dimensions	
		9 × 9 × 8	in		
		8 (4)	lb (kg)	Weight	

TECHNICAL CHARACTERISTICS DATA FORM B

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WBS IDENTIFICATION NUMBER	WBS IDENTIFICATION	VALUE	UNIT OF MEASURE	CHARACTERISTICS	NOTES
320-03-03-07 (Cont.)	Remote Power Controller (59)	(1.3 × 2.5 × 2.5) 1/2 × 1 × 1	cm in	Dimensions	
		.2 (.09)	lb (kg)	Weight	
	Arm/Safe Switches (2)	5 (2.3)	lb (kg)	Weight	

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FUNDING SCHEDULE DATA FORM C 04/13/75

(NO SRT PROGRAM)

SPACE TUG AVIONICS DEFINITION STUDY

TUG AVIONICS SUBSYSTEMS COSTS (1975 $)

(ALL COSTS SHOWN IN THOUSANDS OF DOLLARS)

SUBSYSTEMS	TOTAL	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87
NON-RECURRING (DDT+E)											
NO SIM/DIM											
DDT+E											
DATA MANAGEMENT	10189.000	0.000	675.404	3810.692	4557.071	1145.834	0.000	0.000	0.000	0.000	0.000
GUIDANCE, NAV., + CNTL.	23033.000	0.000	4146.079	14740.842	4146.079	0.000	0.000	0.000	0.000	0.000	0.000
RENDEZVOUS + DOCKING	13134.000	0.000	817.942	4692.816	5855.234	1768.008	0.000	0.000	0.000	0.000	0.000
COMMUNICATIONS	9108.000	0.000	2652.359	6195.814	259.827	0.000	0.000	0.000	0.000	0.000	0.000
INSTRUMENTATION	7330.000	0.000	886.019	4530.422	1921.558	0.000	0.000	0.000	0.000	0.000	0.000
ELECTRIC POWER	7230.000	0.000	1310.444	4659.112	1310.444	0.000	0.000	0.000	0.000	0.000	0.000
ELECT PWR DIST + CNTL	2196.000	0.000	395.293	1405.414	395.293	0.000	0.000	0.000	0.000	0.000	0.000
TUG ON BOARD SOFTWARE	5828.000	0.000	734.552	3188.730	1877.308	27.410	0.000	0.000	0.000	0.000	0.000
GROUND TEST HARDWARE	8518.000	0.000	68.693	4147.103	4302.204	0.000	0.000	0.000	0.000	0.000	0.000
GROUND TEST OPERATIONS	6232.000	0.000	0.000	1715.093	4416.869	100.038	0.000	0.000	0.000	0.000	0.000
TUG AVIONICS DDT+E	92856.000	0.000	11686.786	49086.038	29041.887	3041.289	0.000	0.000	0.000	0.000	0.000

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FUNDING SCHEDULE DATA FORM C 04/04/75

(WITH PLANNED SRT)

SPACE TUG AVIONICS DEFINITION STUDY

TUG AVIONICS SUBSYSTEMS COSTS (1975 $)

(ALL COSTS SHOWN IN THOUSANDS OF DOLLARS)

SUBSYSTEMS	TOTAL	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87
NON-RECURRING (DDT+E)											
DDT+E											
DATA MANAGEMENT	7918.000	0.000	524.865	2961.336	3541.357	890.442	0.000	0.000	0.000	0.000	0.000
GUIDANCE, NAV., + CNTL.	18193.000	0.000	3274.850	11643.301	3274.850	0.000	0.000	0.000	0.000	0.000	0.000
RENDEZVOUS + DOCKING	10649.000	0.000	663.185	3804.918	4747.403	1433.494	0.000	0.000	0.000	0.000	0.000
COMMUNICATIONS	7154.000	0.000	2083.331	4866.584	204.085	0.000	0.000	0.000	0.000	0.000	0.000
INSTRUMENTATION	5830.000	0.000	703.939	3599.395	1526.667	0.000	0.000	0.000	0.000	0.000	0.000
ELECTRIC POWER	5461.000	0.000	983.013	3494.974	983.013	0.000	0.000	0.000	0.000	0.000	0.000
ELECT PWR DIST + CNTL	1803.000	0.000	324.551	1153.898	324.551	0.000	0.000	0.000	0.000	0.000	0.000
TUG ON BOARD SOFTWARE	4662.000	0.000	587.591	2550.765	1501.718	21.926	0.000	0.000	0.000	0.000	0.000
GROUND TEST HARDWARE	7882.000	0.000	63.564	3837.458	3980.978	0.000	0.000	0.000	0.000	0.000	0.000
GROUND TEST OPERATIONS	4620.000	0.000	0.000	1271.459	3274.380	74.161	0.000	0.000	0.000	0.000	0.000
TUG AVIONICS DDT+E	74172.000	0.000	9208.837	39184.089	23359.001	2420.024	0.000	0.000	0.000	0.000	0.000

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FUNDING SCHEDULE DATA FORM C 04/14/75

SPACE TUG AVIONICS DEFINITION STUDY

TUG AVIONICS SUBSYSTEMS COSTS (1975 $)

(ALL COSTS SHOWN IN THOUSANDS OF DOLLARS)

SUBSYSTEMS	TOTAL	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87
RECURRING PRODUCTION											
DATA MANAGEMENT	18814.000	0.000	0.000	0.000	3420.727	3420.727	3420.727	3420.727	3420.727	1710.364	0.000
DATA MANAGEMENT SPARES	1954.000	0.000	0.000	0.000	355.273	355.273	355.273	355.273	355.273	177.636	0.000
GUIDANCE + NAVIGATION	6494.000	0.000	0.000	0.000	1217.625	1217.625	1217.625	1217.625	1217.625	405.875	0.000
GUIDANCE+NAVIGATION SPARE	362.000	0.000	0.000	0.000	67.875	67.875	67.875	67.875	67.875	22.625	0.000
GUIDANCE UPDATE	8863.000	0.000	0.000	0.000	1661.812	1661.812	1661.812	1661.812	1661.812	553.937	0.000
GUIDANCE UPDATE SPARES	1131.000	0.000	0.000	0.000	212.062	212.062	212.062	212.062	212.062	70.687	0.000
FLIGHT CONTROL	2906.000	0.000	0.000	0.000	544.875	544.875	544.875	544.875	544.875	181.625	0.000
FLIGHT CONTROL SPARES	397.000	0.000	0.000	0.000	74.437	74.437	74.437	74.437	74.437	24.812	0.000
SLADAR	8424.000	0.000	0.000	0.000	468.000	1872.000	1872.000	1872.000	1872.000	468.000	0.000
SLADAR SPARES	1480.000	0.000	0.000	0.000	82.222	328.889	328.889	328.889	328.889	82.222	0.000
LLLTV	4792.000	0.000	0.000	0.000	266.222	1064.889	1064.889	1064.889	1064.889	266.222	0.000
LLLTV SPARES	732.000	0.000	0.000	0.000	40.667	162.667	162.667	162.667	162.667	40.667	0.000
COMMUNICATIONS	26276.000	0.000	0.000	0.000	0.000	4569.739	4569.739	4569.739	4569.739	4569.739	3427.304
COMMUNICATIONS SPARES	6422.000	0.000	0.000	0.000	0.000	1116.870	1116.870	1116.870	1116.870	1116.870	837.652
INSTRUMENTATION	18290.000	0.000	0.000	0.000	3048.333	3048.333	3048.333	3048.333	3048.333	3048.333	0.000
INSTRUMENTATION SPARES	699.000	0.000	0.000	0.000	116.500	116.500	116.500	116.500	116.500	116.500	0.000
ELECTRIC POWER	3469.000	0.000	0.000	0.000	400.269	533.692	533.692	533.692	533.692	533.692	400.269
ELECTRIC POWER SPARES	1124.000	0.000	0.000	0.000	129.692	172.923	172.923	172.923	172.923	172.923	129.692
EP DISTRIBUTION+CONTROL	3600.000	0.000	0.000	0.000	308.571	617.143	617.143	617.143	617.143	617.143	205.714
EP D+C SPARES	135.000	0.000	0.000	0.000	11.571	23.143	23.143	23.143	23.143	23.143	7.714
TUG AVIONICS REC. PROD.	116364.000	0.000	0.000	0.000	12426.736	21181.475	21181.475	21181.475	21181.475	14203.017	5008.347

SPACE TUG AVIONICS DEFINITION STUDY

TUG AVIONICS SUBSYSTEMS COSTS (1975 $)

(ALL COSTS SHOWN IN THOUSANDS OF DOLLARS)

SUBSYSTEMS	TOTAL	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87
RECURRING OPERATIONS											
DATA MANAGEMENT	724.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	63.882	127.765
GUIDANCE+NAVIGATION	450.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	51.429	77.143
GUIDANCE UPDATE	17.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.943	2.914
FLIGHT CONTROL	86.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	9.829	14.743
RENDEZVOUS+DOCKING	985.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	124.859	166.479
COMMUNICATIONS	263.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	14.887
INSTRUMENTATION	2652.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	513.290
ELECTRIC POWER	294.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	16.542
ELECT. POWER DIST. + CNTL	17.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.345
TUG AVIONICS REC. OPNS.	5438.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	251.942	936.207

SPACE TUG AVIONICS DEFINITION STUDY

TUG AVIONICS SUBSYSTEMS COSTS (1975 $)

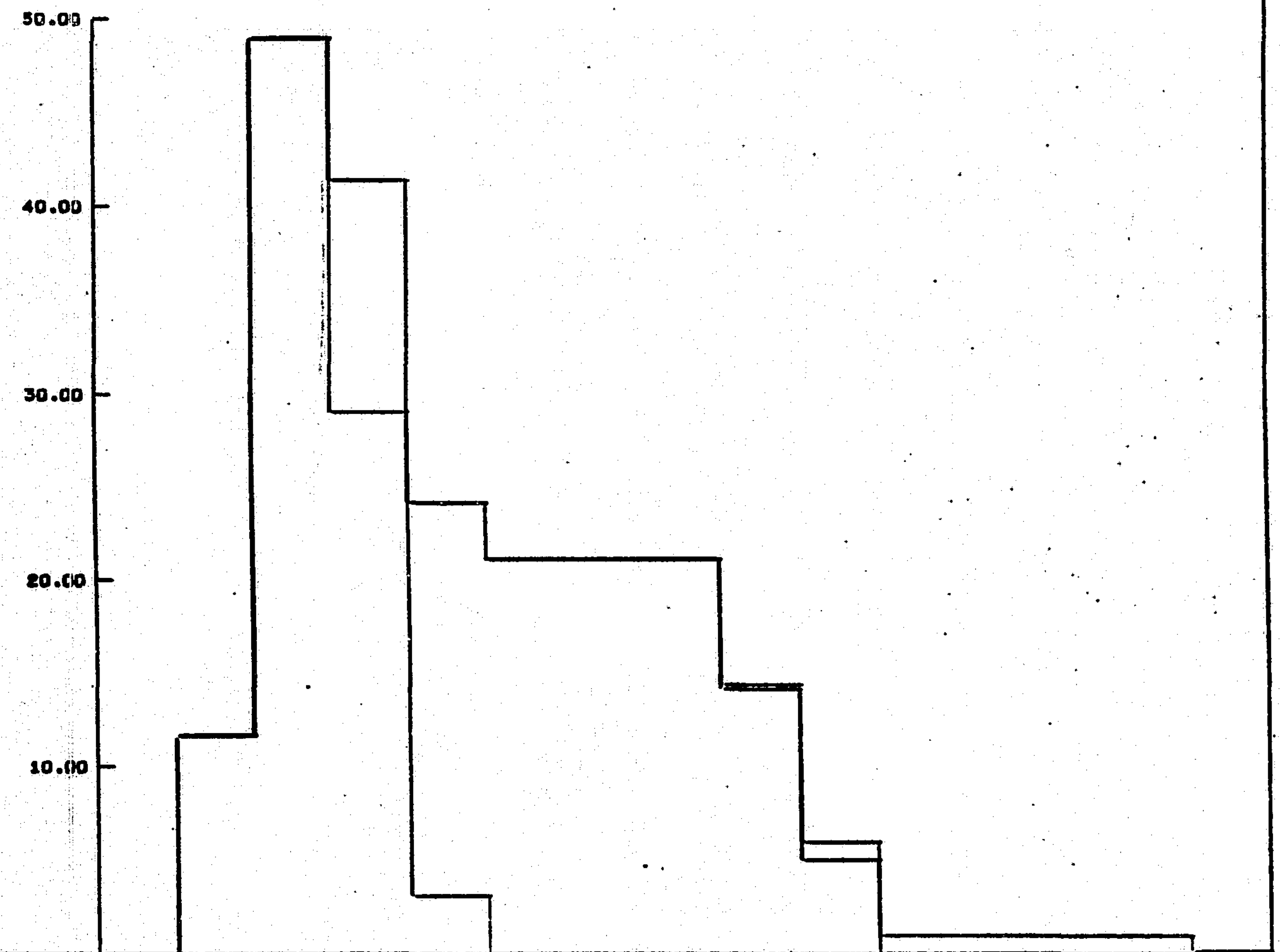
(ALL COSTS SHOWN IN THOUSANDS OF DOLLARS)

SUBSYSTEMS	TOTAL	FY88	FY89	FY90	FY91	FY92
RECURRING OPERATIONS						
DATA MANAGEMENT	724.000	127.765	127.765	127.765	127.765	21.294
GUIDANCE+NAVIGATION	450.000	77.143	77.143	77.143	77.143	12.857
GUIDANCE UPDATE	17.000	2.914	2.914	2.914	2.914	.486
FLIGHT CONTROL	86.000	14.743	14.743	14.743	14.743	2.457
RENDEZVOUS+DOCKING	985.000	166.479	166.479	166.479	166.479	27.746
COMMUNICATIONS	263.000	59.547	59.547	59.547	59.547	9.925
INSTRUMENTATION	2652.000	513.290	513.290	513.290	513.290	85.548
ELECTRIC POWER	294.000	66.566	66.566	66.566	66.566	11.094
ELECT. POWER DIST. + CNTL	17.000	3.517	3.517	3.517	3.517	.586
TUG AVIONICS REC. OPNS.	5438.000	1031.964	1031.964	1031.964	1031.964	171.994

C-2

FUNDING SCHEDULE DATA FORM C

ANNUAL EXPENDITURE PROFILE

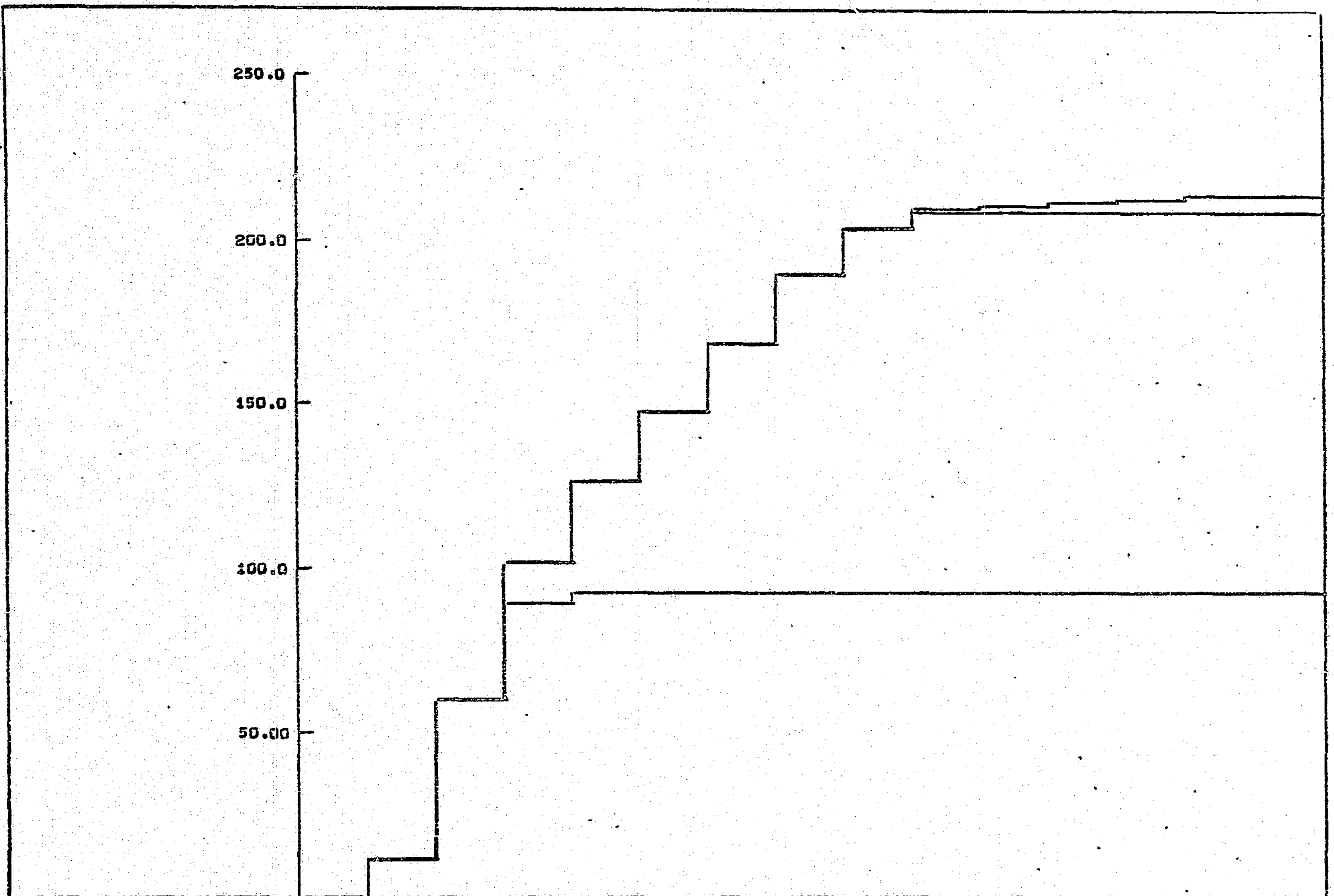


SUBSYSTEMS	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87	FY88	FY89	FY90	FY91	FY92
TUG AVIONICS DDT+E		11.69	49.09	29.04	3.041										
TUG AVIONICS REC. PROD.				12.43	21.18	21.18	21.18	21.18	14.20	5.008					
TUG AVIONICS REC. OPNS.									.2519	.9362	1.032	1.032	1.032	1.032	.1720
TOTAL		11.69	49.09	41.47	24.22	21.18	21.18	21.18	14.45	5.945	1.032	1.032	1.032	1.032	.1720

04/18/75

FUNDING SCHEDULE DATA FORM C

CUMULATIVE EXPENDITURE PROFILE

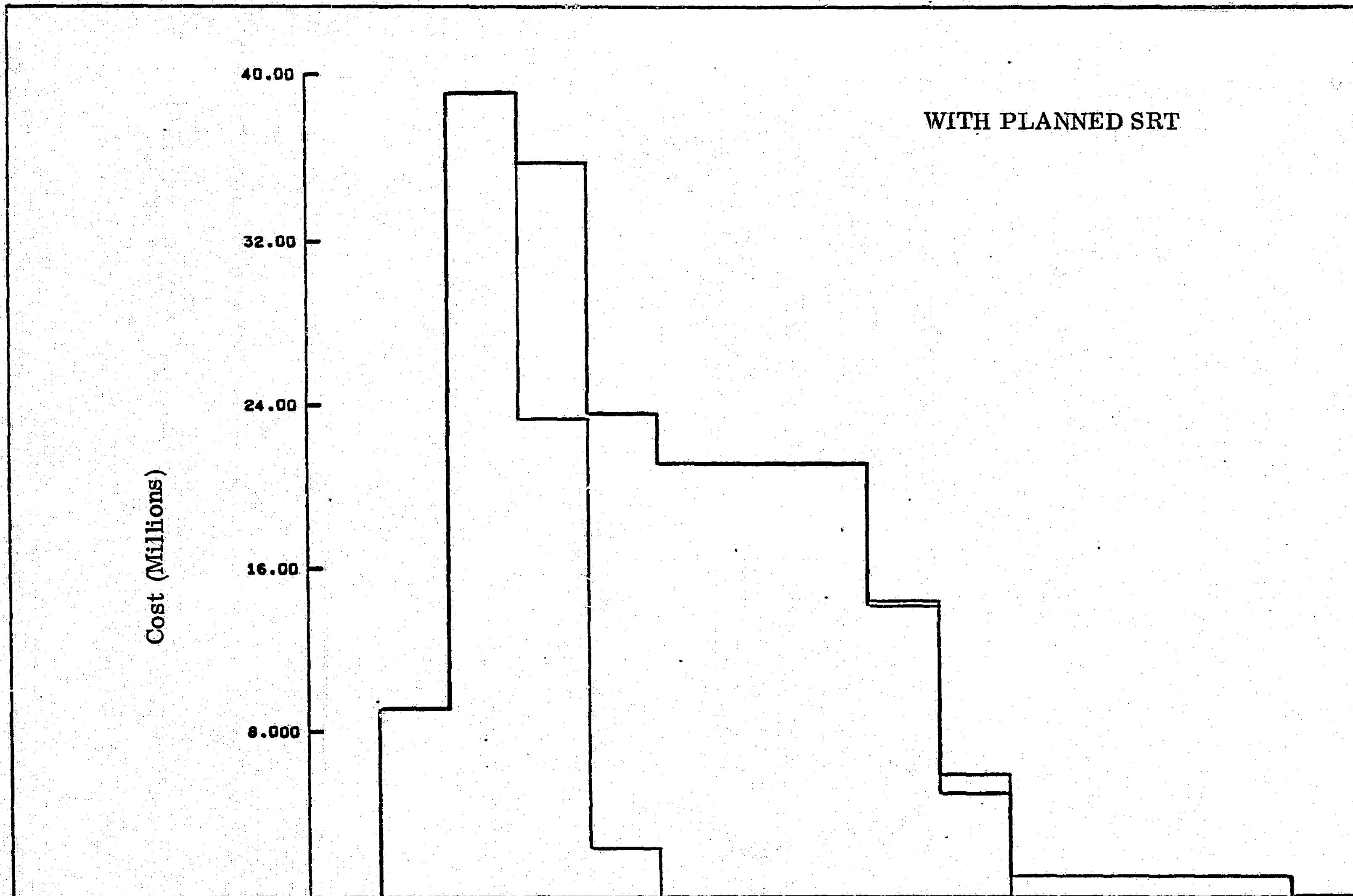


SUBSYSTEMS	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87	FY88	FY89	FY90	FY91	FY92
TUG AVIONICS DDT+E		11.69	60.77	89.81	92.86	92.86	92.86	92.86	92.86	92.86	92.86	92.86	92.86	92.86	92.86
TUG AVIONICS REC. PROD.				12.43	33.61	54.79	75.97	97.15	111.4	116.4	116.4	116.4	116.4	116.4	116.4
TUG AVIONICS REC. OPNS.									.2519	1.188	2.220	3.252	4.284	5.316	5.400
TOTAL		11.69	60.77	102.2	126.5	147.6	168.8	190.0	204.5	210.4	211.4	212.5	213.5	214.6	214.7

04/19/78

FUNDING SCHEDULE DATA FORM C

ANNUAL EXPENDITURE PROFILE

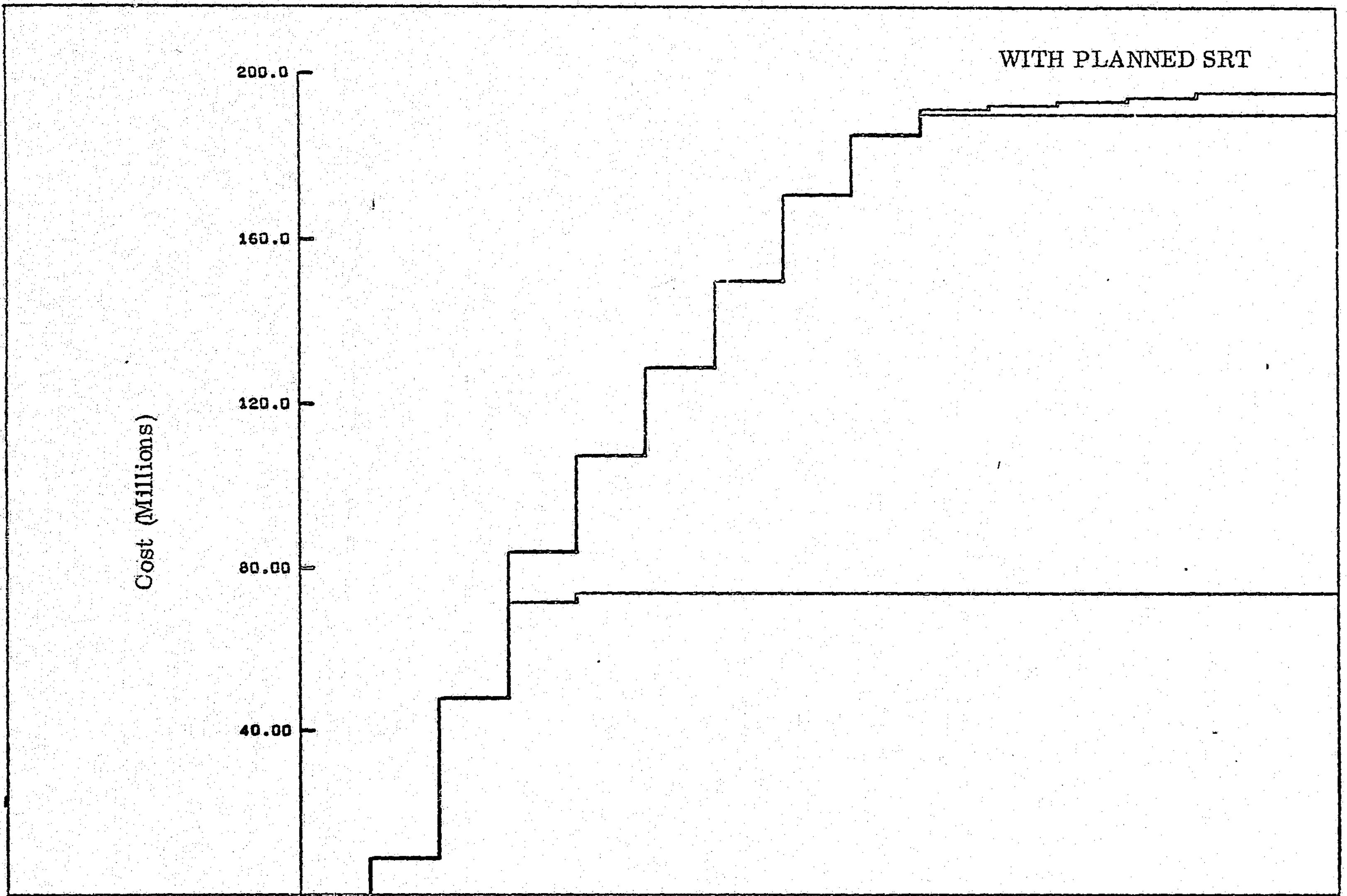


SUBSYSTEMS	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87	FY88	FY89	FY90	FY91	FY92
TUG AVIONICS DDT+E		9.209	39.18	23.36	2.420										
TUG AVIONICS REC. PROD.				12.43	21.18	21.18	21.18	21.18	14.20	5.008					
TUG AVIONICS REC. OPNS.									.2519	.9362	1.032	1.032	1.032	1.032	.1720
TOTAL		9.209	39.18	35.79	23.60	21.18	21.18	21.18	14.45	5.945	1.032	1.032	1.032	1.032	.1720

04/07/75

FUNDING SCHEDULE DATA FORM C

CUMULATIVE EXPENDITURE PROFILE



SUBSYSTEMS	FY78	FY79	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87	FY88	FY89	FY90	FY91	FY92
TUG AVIONICS DDT?E		9.209	48.39	71.75	74.17	74.17	74.17	74.17	74.17	74.17	74.17	74.17	74.17	74.17	74.17
TUG AVIONICS REC. PROD.				12.43	33.61	54.79	75.97	97.15	111.4	116.4	116.4	116.4	116.4	116.4	116.4
TUG AVIONICS REC. OPNS.									.2519	1.188	2.220	3.252	4.284	5.316	5.488
TOTAL		9.209	48.39	84.18	107.8	129.0	150.1	171.3	185.8	191.7	192.8	193.8	194.8	195.8	196.0

04/07/78

COST ESTIMATE DATA FORM T

DATE 15 April 1975

PROGRAM PHASE NONRECURRING (DDT&E) NO SRT PROGRAM

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-03-03-01 WBS NAME DATA MANAGEMENT

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	104,437	5,823
INTEGRATION		75
TOOLING	2,678	916
PRODUCTION		353
TEST & EVALUATION	134	2,386
RELIABILITY & QUALITY	12,854	353
TRANSPORTATION		
PROGRAM MANAGEMENT		3
OTHER		280
TOTAL	120,102	10,189

COST ESTIMATE DATA FORMAT

DATE 15 April 1975

PROGRAM PHASE NONRECURRING (DDT&E) NO SRT PROGRAM

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-03-03-02 WBS NAME Guidance, Navigation & Control

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	222,677	12,110
INTEGRATION	1,676	192
TOOLING	24,777	2,297
PRODUCTION	3,019	906
TEST & EVALUATION	39,428	6,097
RELIABILITY & QUALITY	20,853	630
TRANSPORTATION		
PROGRAM MANAGEMENT	67	101
OTHER	27	600
TOTAL	312,524	22,933

COST ESTIMATE DATA FORM T

DATE 15 April 1975

PROGRAM PHASE NONRECURRING (DDT&E) NO SRT PROGRAM

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-03-03-03 WBS NAME Rendezvous & Docking

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	68,614	6,021
INTEGRATION	1,429	148
TOOLING	18,011	1,523
PRODUCTION	2,573	617
TEST & EVALUATION	33,450	4,150
RELIABILITY & QUALITY	2,859	328
TRANSPORTATION		
PROGRAM MANAGEMENT	57	5
OTHER	22	342
TOTAL	127,015	13,134

COST ESTIMATE
DATA FORM T

DATE 15 April 1975
PAGE 4 OF 10

PROGRAM PHASE NONRECURRING (DDT&E) NO SRT PROGRAM

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-03-03-04 WBS NAME Communications

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	137,812	6,056
INTEGRATION	13,299	292
TOOLING	18,216	647
PRODUCTION	2,732	109
TEST & EVALUATION	72,864	1,658
RELIABILITY & QUALITY	728	14
TRANSPORTATION		
PROGRAM MANAGEMENT	638	14
OTHER		318
TOTAL	246,289	9,108

COST ESTIMATE
DATA FORM T

DATE 15 April 1975
PAGE 5 OF 10

PROGRAM PHASE NONRECURRING (DDT&E) NO SRT PROGRAM

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-03-03-05 WBS NAME Instrumentation

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	198,126	3,742
INTEGRATION	14,676	234
TOOLING	44,028	726
PRODUCTION	1,468	94
TEST & EVALUATION	88,056	2,186
RELIABILITY & QUALITY	6,604	125
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		230
TOTAL	352,958	7,338

COST ESTIMATE DATA FORM T

DATE 15 April 1975

PROGRAM PHASE NONRECURRING (DDT&E) NO SRT PROGRAM

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 32-03-03-06 WBS NAME Electrical Power

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	19,904	3,309
INTEGRATION	853	79
TOOLING	3,791	803
PRODUCTION		305
TEST & EVALUATION	17,061	2,386
RELIABILITY & QUALITY	1,896	185
TRANSPORTATION		
PROGRAM MANAGEMENT	189	17
OTHER	19	196
TOTAL	43,713	7,280

COST ESTIMATE
DATA FORM T

PROGRAM PHASE NONRECURRING (DDT&E) NO SRT PROGRAM

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-03-03-07 WBS NAME Elec. Power Distribution & Control

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	54,900	1,122
INTEGRATION	13,176	246
TOOLING	26,352	397
PRODUCTION	878	16
TEST & EVALUATION	10,992	312
RELIABILITY & QUALITY	1,756	30
TRANSPORTATION		
PROGRAM MANAGEMENT	66	1
OTHER		72
TOTAL	108,121	2,196

COST ESTIMATE
DATA FORM T

PROGRAM PHASE NONRECURRING (DDT&E) NO SRT PROGRAM

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-15-01 WBS NAME Tug On Board Software

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	242,445	4,720
INTEGRATION		
TOOLING		
PRODUCTION		
TEST & EVALUATION		
RELIABILITY & QUALITY		
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		1,108
TOTAL	242,445	5,828

COST ESTIMATE
DATA FORM T

PROGRAM PHASE NONRECURRING (DDT&E) NO SRT PROGRAM

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-08-02 WBS NAME Ground Test Ops (TAIL/SAIL)

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	18,696	480
INTEGRATION	24,928	326
TOOLING	1,246	31
PRODUCTION	37,392	804
TEST & EVALUATION	211,888	4,380
RELIABILITY & QUALITY	1,870	24
TRANSPORTATION		
PROGRAM MANAGEMENT	499	12
OTHER		174
TOTAL	296,519	6,232

COST ESTIMATE
DATA FORM T

DATE 15 April 1975

PROGRAM PHASE NONRECURRING (DDT&E) NO SRT PROGRAM

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-08-01 WBS NAME Ground Test Hardware (TAIL/SAIL)

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING		
INTEGRATION	107,876	1,293
TOOLING	15,764	323
PRODUCTION	63,056	3,870
TEST & EVALUATION	1,576	552
RELIABILITY & QUALITY	28,375	1,214
TRANSPORTATION	2,365	24
PROGRAM MANAGEMENT	473	32
OTHER	788	574
TOTAL	220,273	7,882

COST ESTIMATE DATA FORM T

PROGRAM PHASE NONRECURRING (DDT&E) PLANNED SRT

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-03-03-01 WBS NAME DATA MANAGEMENT

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	81,159	4,525
INTEGRATION		58
TOOLING	2,081	712
PRODUCTION		274
TEST & EVALUATION	104	1,854
RELIABILITY & QUALITY	9,989	274
TRANSPORTATION		
PROGRAM MANAGEMENT		2
OTHER		219
TOTAL	93,333	7,918

COST ESTIMATE
DATA FORM T

DATE 3 April 1975

PROGRAM PHASE NONRECURRING (DDT&E) PLANNED SRT

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-03-03-02 WBS NAME Guidance, Navigation & Control

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	176,652	9,607
INTEGRATION	1,330	152
TOOLING	19,656	1,822
PRODUCTION	2,395	719
TEST & EVALUATION	31,279	4,837
RELIABILITY & QUALITY	16,543	500
TRANSPORTATION		
PROGRAM MANAGEMENT	53	80
OTHER	21	476
TOTAL	247,929	18,193

COST ESTIMATE DATA FORM T

DATE 3 April 1975

PROGRAM PHASE NONRECURRING (DDT&E) PLANNED SRT

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-03-03-03 WBS NAME Rendezvous and Docking

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	55,632	4,882
INTEGRATION	1,159	120
TOOLING	14,603	1,235
PRODUCTION	2,086	500
TEST & EVALUATION	27,121	3,365
RELIABILITY & QUALITY	2,318	266
TRANSPORTATION		
PROGRAM MANAGEMENT	46	4
OTHER	18	277
TOTAL	102,983	10,649

COST ESTIMATE
DATA FORM T

PROGRAM PHASE NONRECURRING (DDT&E) PLANNED SRT

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-03-03-04 WBS NAME COMMUNICATIONS

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	108,246	4,757
INTEGRATION	10,446	229
TOOLING	14,308	508
PRODUCTION	2,146	86
TEST & EVALUATION	57,232	1,302
RELIABILITY & QUALITY	572	11
TRANSPORTATION		
PROGRAM MANAGEMENT	501	11
OTHER		250
TOTAL	193,451	7,154

COST ESTIMATE DATA FORM T

DATE 3 April 1975
PAGE 5 OF 10

PROGRAM PHASE NONRECURRING (DDT&E) PLANNED SRT

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-03-03-05 WBS NAME INSTRUMENTATION

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	157,410	2,973
INTEGRATION	11,660	186
TOOLING	34,980	577
PRODUCTION	1,166	75
TEST & EVALUATION	69,960	1,737
RELIABILITY & QUALITY	5,247	99
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		183
TOTAL	280,423	5,830

COST ESTIMATE DATA FORM T

DATE 3 April 1975

PROGRAM PHASE NONRECURRING (DDT&E) PLANNED SRT

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-03-03-06 WBS NAME ELECTRIC POWER

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	14,931	2,482
INTEGRATION	640	59
TOOLING	2,844	602
PRODUCTION		229
TEST & EVALUATION	12,798	1,790
RELIABILITY & QUALITY	1,422	139
TRANSPORTATION		
PROGRAM MANAGEMENT	142	13
OTHER	14	147
TOTAL	32,791	5,461

COST ESTIMATE
DATA FORM T

DATE 3 April 1975
PAGE 7 OF 10

PROGRAM PHASE NONRECURRING (DDT&E) PLANNED SRT

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-03-03-07 WBS NAME Elec. Power Distribution & Control

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	45,075	921
INTEGRATION	10,818	202
TOOLING	21,636	326
PRODUCTION	721	13
TEST & EVALUATION	9,025	256
RELIABILITY & QUALITY	1,442	25
TRANSPORTATION		
PROGRAM MANAGEMENT	54	1
OTHER		59
TOTAL	88,871	1,803

COST ESTIMATE DATA FORM T

DATE 3 April 1975
PAGE 8 OF 10

PROGRAM PHASE NONRECURRING (DDT&E) PLANNED SRT

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-15-01 WBS NAME Tug On-Board Software

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	193,939	3,776
INTEGRATION		
TOOLING		
PRODUCTION		
TEST & EVALUATION		
RELIABILITY & QUALITY		
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		886
TOTAL	193,939	4,662

COST ESTIMATE DATA FORM T

DATE 3 April 1975
PAGE 9 OF 10

PROGRAM PHASE NONRECURRING (DDT&E) PLANNED SRT

CONTRACT NAS-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-08-02 WBS NAME Ground Test Ops (TAIL/SAIL)

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING	13,960	356
INTEGRATION	18,480	242
TOOLING	924	23
PRODUCTION	27,720	596
TEST & EVALUATION	157,080	3,247
RELIABILITY & QUALITY	1,386	18
TRANSPORTATION		
PROGRAM MANAGEMENT	370	9
OTHER		129
TOTAL	219,820	4,620

COST ESTIMATE
DATA FORM T

PROGRAM PHASE NONRECURRING (DDT&E) PLANNED SRT

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-08-01 WBS NAME Ground Test Hardware (TAIL/SAIL)

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING		
INTEGRATION	107,876	1,293
TOOLING	15,764	323
PRODUCTION	63,056	3,870
TEST & EVALUATION	1,576	552
RELIABILITY & QUALITY	28,375	1,214
TRANSPORTATION	2,365	24
PROGRAM MANAGEMENT	473	32
OTHER	788	574
TOTAL	220,273	7,882

COST ESTIMATE DATA FORM T

PROGRAM PHASE RECURRING (PRODUCTION

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-S3-03-01 WBS NAME DATA MANAGEMENT

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING		
INTEGRATION	353,056	6,646
TOOLING	6,230	415
PRODUCTION	83,072	5,794
TEST & EVALUATION	2,077	1,330
RELIABILITY & QUALITY	41,536	6,230
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		353
TOTAL	485,971	20,768

COST ESTIMATE
DATA FORM T

DATE 3 April 1975

PROGRAM PHASE RECURRING (PRODUCTION)

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-S3-03-02 WBS NAME Guidance, Navigation & Control

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING		
INTEGRATION	? 41,536	935
TOOLING	415	955
PRODUCTION	10,384	11,215
TEST & EVALUATION	2,077	3,738
RELIABILITY & QUALITY	2,076	3,102
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		208
TOTAL	56,488	20,153

COST ESTIMATE
DATA FORM T

DATE 3 April 1975

PROGRAM PHASE RECURRING (PRODUCTION)

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-S3-03-03 WBS NAME Rendezvous & Docking

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING		
INTEGRATION	148,109	2,808
TOOLING	20,056	555
PRODUCTION	2,160	7,575
TEST & EVALUATION		2,099
RELIABILITY & QUALITY	11,417	2,283
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		108
TOTAL	181,742	15,428

COST ESTIMATE DATA FORM T

DATE 3 April 1975
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PROGRAM PHASE RECURRING (PRODUCTION)

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-S3-03-04 WBS NAME Communications

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING		
INTEGRATION	294,282	5,232
TOOLING	6,540	65
PRODUCTION	457,772	19,710
TEST & EVALUATION		5,601
RELIABILITY & QUALITY		2,030
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		60
TOTAL	758,594	32,698

COST ESTIMATE
DATA FORM T

PROGRAM PHASE RECURRING (PRODUCTION)

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-S3-03-05 WBS NAME Instrumentation

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING		
INTEGRATION	265,846	3,912
TOOLING	15,000	323
PRODUCTION	1,205,131	12,593
TEST & EVALUATION	105,110	1,098
RELIABILITY & QUALITY	17,240	778
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		285
TOTAL	1,608,327	18,989

COST ESTIMATE DATA FORM T

DATE 3 April 1975

PROGRAM PHASE RECURRING (PRODUCTION)

CONTRACT NAS-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-S3-03-06 WBS NAME Electric Power Source

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING		
INTEGRATION	597	9
TOOLING	1,378	23
PRODUCTION	41,337	3,658
TEST & EVALUATION	4,593	407
RELIABILITY & QUALITY	13,779	464
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		32
TOTAL	61,684	4,593

COST ESTIMATE DATA FORM T

DATE 3 April 1975

PROGRAM PHASE RECURRING (PRODUCTION)

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-S3-03-07 WBS NAME Elec. Power Distribution & Control

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING		
INTEGRATION	29,880	534
TOOLING	4,482	63
PRODUCTION	100,845	2,757
TEST & EVALUATION		
RELIABILITY & QUALITY	11,205	306
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		75
TOTAL	146,412	3,735

COST ESTIMATE DATA FORM T

PROGRAM PHASE RECURRING (OPERATIONS)

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-53-03-01 WBS NAME Data Management

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING		
INTEGRATION	12,308	232
TOOLING	217	14
PRODUCTION	2,896	203
TEST & EVALUATION	72	46
RELIABILITY & QUALITY	1,448	217
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		12
TOTAL	16,941	724

COST ESTIMATE DATA FORM T

PROGRAM PHASE RECURRING (OPERATIONS)

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-53-03-02 WBS NAME Guid, Navigation & Control

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING		
INTEGRATION	1,140	26
TOOLING	11	25
PRODUCTION	285	308
TEST & EVALUATION	57	103
RELIABILITY & QUALITY	57	85
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		6
TOTAL	1,550	553

COST ESTIMATE DATA FORM T

PROGRAM PHASE RECURRING (OPERATIONS)

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-53-03-03 WBS NAME Rendezvous & Docking

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING		
INTEGRATION	9,456	179
TOOLING	1,280	35
PRODUCTION	138	484
TEST & EVALUATION		132
RELIABILITY & QUALITY	729	148
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		7
	11,603	985
TOTAL		

COST ESTIMATE DATA FORM T

DATE ______

PROGRAM PHASE RECURRING (OPERATIONS)

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-53-03-04 WBS NAME. Communications

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING		
INTEGRATION	2,367	42
TOOLING	53	1
PRODUCTION	3,682	158
TEST & EVALUATION		45
RELIABILITY & QUALITY		16
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		1
TOTAL	6,102	263

COST ESTIMATE
DATA FORM T

DATE ____________

PROGRAM PHASE RECURRING (OPERATIONS)

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-53-03-05 WBS NAME Instrumentation

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST $/$1000
ENGINEERING		
INTEGRATION	37,128	546
TOOLING	2,095	45
PRODUCTION	168,308	1,759
TEST & EVALUATION	14,680	153
RELIABILITY & QUALITY	2,808	109
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		40
TOTAL	225,019	2,652

COST ESTIMATE DATA FORM T

DATE ______

PROGRAM PHASE RECURRING (OPERATIONS)

CONTRACT NAS8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-53-03-06 WBS NAME Electric Power

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING		
INTEGRATION	38	1
TOOLING	88	1
PRODUCTION	2,646	234
TEST & EVALUATION	294	26
RELIABILITY & QUALITY	882	30
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		2
TOTAL	3,948	294

COST ESTIMATE DATA FORM T

PROGRAM PHASE RECURRING (OPERATIONS)

CONTRACT NA8-31010 STUDY TUG AVIONICS DEFINITION

WBS NO. 320-53-03-07 WBS NAME Elec. Power Distribution & Control

SUBDIVISION OF WORK	LABOR HOURS	TOTAL COST ($1000)
ENGINEERING		
INTEGRATION	136	2
TOOLING	20	1
PRODUCTION	459	13
TEST & EVALUATION		
RELIABILITY & QUALITY	51	1
TRANSPORTATION		
PROGRAM MANAGEMENT		
OTHER		
TOTAL	666	17