PD-DO-EX

CONTRACT NAS 8-29676

SPACE TUG SYSTEMS STUDY (CRYOGENIC)

DATA DUMP

VOLUME I • PROGRAM 1 SUMMARY

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM MILESTONES

GENERAL DYNAMICS
Convair Aerospace Division

MAJOR MILESTONES	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
ORIENTATION BRIEFING	(7-9) ▼									
REQUIREMENTS ASSESSMENT MEETING		(9-12) ▼								
FIRST REVIEW			(29-1) ▼							
PROGRAM CONCEPT EVALUATION & SELECTION					(16-27) ▬					
SELECTED OPTIONS DATA DUMP							(17-21) ▼			
UPDATE									TBD ▬	
FINAL REVIEW										TBD ▼
FINAL REPORT										▼

09043CVD3086A

The basic objective of this data dump is to supply the government with program definition data on the three programs defined at the conclusion of the Concept Evaluation and Selection Meeting. The data is provided in summary forms in the overview volumes with the details in the backup volumes. The emphasis in generating the data was on the programmatic aspects. The technical were covered to the extent necessary to yield credible programmatic and cost data.

In addition to presenting data on the three baseline programs it is also the objective of this data dump to provide certain configuration and programmatic sensitivity data. These include the four major sensitivities listed on the chart and other sensitivities to various capability features such as payload power, autonomy and design life.

OBJECTIVES

- PROVIDE PROGRAM DEFINITION DATA ON 3 PROGRAMS SELECTED AT CONCEPT EVALUATION & SELECTION MEETING

  EMPHASIS ON PROGRAMMATICS

- PROVIDE SENSITIVITY DATA

  IOC VARIATIONS

  PERFORMANCE LEVEL

  SERVICING MISSION

  ADVANCED ENGINES

  CAPABILITY FEATURES

This chart indicates the documentation for the data dump. This is one of the three summary volumes which have an annotated vugraph format. The introductory material, comparative sensitivity data and conclusions section of each summary volume are identical. The main content of each summary volume consists of the summary material on the baselines and the major sensitivity results for the program being described. Each chart in the summary volume is cross referenced to the section in the detailed data volumes where the subject is discussed.

There are five detailed data volumes. Each of these volumes is arranged by program. Within a volume the section numbers are consistent with the government supplied outline with the applicable program identified by the program number in parentheses. In some cases a volume consists of several books.

DATA DUMP MATERIAL

SUMMARY DATA	DETAILED DATA
	VOLUME 4 - MISSION ACCOMPLISHMENT
VOLUME 1 - PROGRAM 1 SUMMARY	VOLUME 5 - SYSTEMS
VOLUME 2 - PROGRAM 2 SUMMARY	VOLUME 6 - OPERATIONS
VOLUME 3 - PROGRAM 3 SUMMARY	VOLUME 7 - SAFETY
	VOLUME 8 - PROGRAMMATICS/ COST

- SUMMARY VOLUMES REFER TO APPROPRIATE SECTION IN VOLUMES 4 - 8 FOR DETAILED DISCUSSION OF TOPIC
- VOLUMES 4 THROUGH 8 ARE ARRANGED BY PROGRAM

18093CVD4636

Program definition data has been prepared on the three programs which were defined at the conclusion of the Concept Evaluation and Selection Meeting. The basic criteria for these three programs are listed on the chart along with the configuration for these programs.

The emphasis in Program 1 was on minimum DDT&E cost. The selected configuration uses conventional structure and an existing engine. In order to minimize costs maximum use has been made of Centaur components such as astrionics and engine support components.

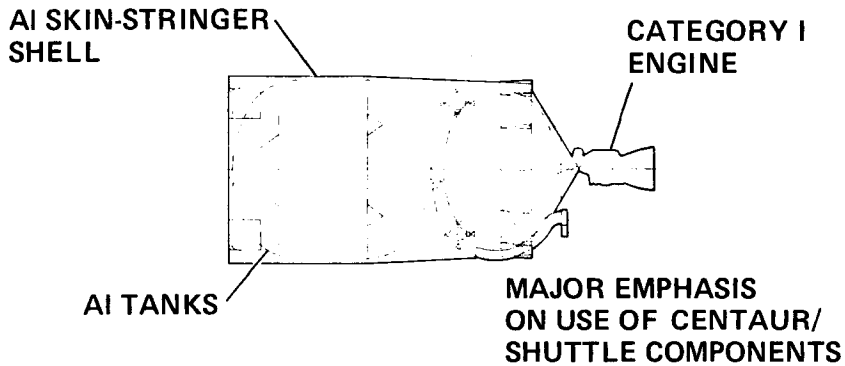
The emphasis in Program 2 was more on total program cost effectiveness which is reflected in the higher performance requirement. The increased performance was obtained by using a RL10 engine Category IIB engine, a composite sandwich shell and more advanced astrionics.

Program 3 is a phased program in which the emphasis for the initial vehicle is on minimizing DDT&E cost while for the final vehicle the emphasis is more on low total program cost. The major configuration phasing in this program is from a low cost astrionics system to an advanced lightweight system with rendezvous and docking capbility.

PROGRAM DEFINITION OPTIONS

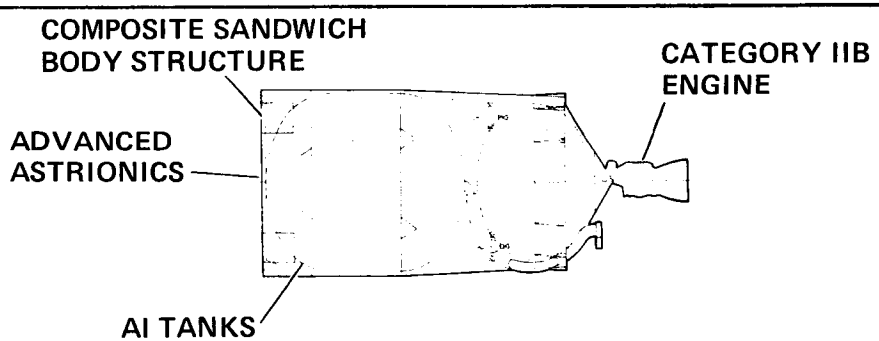
PROGRAM 1

- ≥3,500 LB. PLACEMENT TO SYNCHRONOUS EQUATORIAL
- NO PAYLOAD RETRIEVAL
- MINIMUM DDT&E
- IOC DEC. 1979



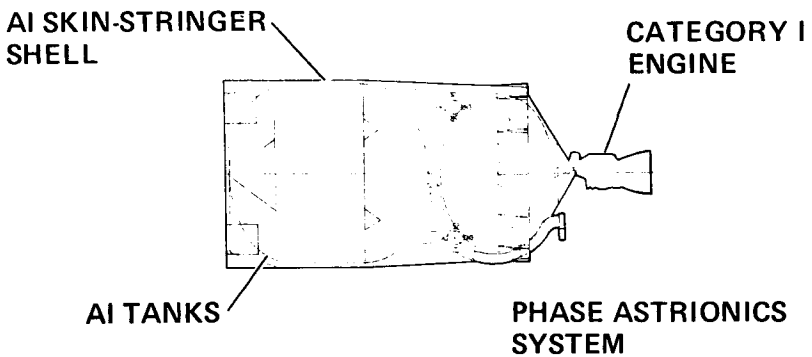
PROGRAM 2

- ≥3,500 LB. RETRIEVAL FROM SYNCHRONOUS EQUATORIAL
- LOW DDT&E/TOTAL PROGRAM COST EFFECTIVENESS
- IOC DEC. 1983



PROGRAM 3

- PHASED
  - INITIAL — ≥3,500 LB. PLACEMENT IOC DEC. 1979
  - FINAL — ≥2,200 LB. RETRIEVAL IOC DEC. 1983 LOW TOTAL PROGRAM COST



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This chart summarizes the payload and cost data for the three baseline programs. The development cost and peak year funding data are consistent and can be compared. The total Tug program cost and total operations cost per payload cannot be compared since the IOC dates are different and the mission models are different.

The parameter of total operations cost per payload is less than the Shuttle launch cost because of the multi-deployment capability.

SUMMARY PROGRAM CHARACTERISTICS

	PAYLOAD (LB.)	COSTS ($ MILLIONS)			
		DDT&E	TOTAL TUG PROGRAM	TOTAL OPS.* COST/PL	PEAK-YEAR FUNDING
PROGRAM 1	5,352 (DEP)	193	597	7.3	89 (77)
PROGRAM 2	5,204 (RET)	291	716	6.3	145 (81)
PROGRAM 3					
INITIAL	5,183 (DEP)	215	382	7.1	103 (78)
FINAL	2,514 (RET)	48	390		66 (85)

EACH PROGRAM HAS A DIFFERENT MISSION MODEL
*INCLUDES SHUTTLE LAUNCH COST AT $10.5-M

18093CVD4674

In order to minimize development costs of the Program 1 Tug, maximum use was made of existing hardware and technology. Where applicable, systems were used which have been developed for the Centaur high-energy upper stage vehicle. The three areas which have components particularly suited for conversion to Tug requirements are: astrionics, propulsion, and insulation.

Astrionics — The Program 1 Tug uses modified versions of the Centaur computer, the Sequence Control Unit (SCU), the Servo Inverter Unit (SIU), and instrumentation system.

Propulsion — The propulsion system is based on the Centaur technology and uses a Category I RL10 engine operating at a 5/1 mixture ratio. Centaur hydraulic actuators, gimbal joints, and modified propellant utilization systems are used. Boost pumps are also used, which although not of the same design as the present Centaur boost pumps, allow reliance on operating modes presently understood.

Thermal Control System — The insulation used on the propellant tanks is based on the multilayer blankets which were developed for the forward bulkhead of the LH_2 tank for the D-1T Centaur.

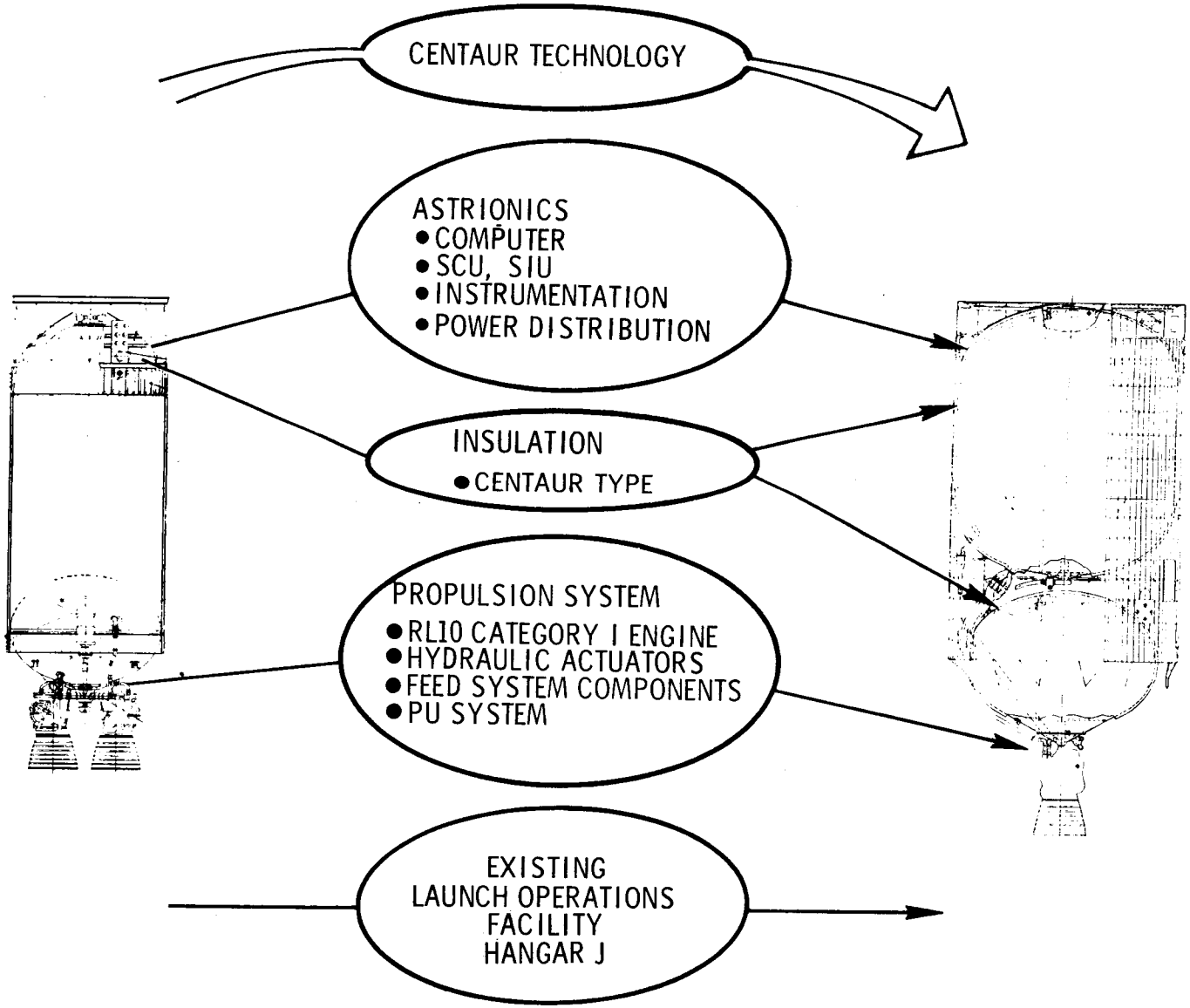
Use of Existing Launch Operations Facility — The Program 1 Tug assumes the use of the existing Hangar J facility in the Cape Kennedy Industrial Area. This eliminates the need for a new Tug Maintenance Facility.

Although the systems in general have been modified for compatibility with the Tug requirements the technology is very similar to that used on the Centaur today. Such factors as main engine operating characteristics, insulation purging and conditioning and vehicle software control provide a broad experience bank from which Tug design and operations can be developed.

Many of the technology development problems that occur in the early phases of such a program have already been addressed and solved. The reliance on this technology background supplies a firm base from which to initiate the Program 1 Tug.

LOW-DDT&E APPROACH TO PROGRAM 1

GENERAL DYNAMICS
Convair Aerospace Division



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In addition to utilizing subsystem components from the Centaur, the Program 1 Tug incorporates hardware from other existing programs. The major items are the Attitude Control Propulsion System (ACPS), the power supply, communications, and guidance and navigation system. In addition simple aluminum structures were used, with no advanced structures of any kind.

The use of these systems, coupled with the Centaur derived systems, provides a minimum cost vehicle with high performance to satisfy the Program 1 requirements.

LOW-DDT&E APPROACH TO PROGRAM 1
Components Based Upon Existing Programs

ACPS

- ENGINES – MODIFIED T III TRANSTAGE ENGINES
- N_2H_4 STORAGE BOTTLES – P-95 PROGRAM, VIKING 75
- HELIUM STORAGE – MAN-RATED SPACECRAFT PROGRAM
- REGULATORS – MODIFIED COMMAND SERVICE MODULE ACS

ASTRIONICS

- POWER – MODIFIED SHUTTLE FUEL CELL
- COMMUNICATIONS – USB, MODIFIED ERTS
  SGLS; MODIFIED FLTSATCOM
- GUIDANCE & NAV. – DIGS STRAPDOWN IMU

STRUCTURES

- LOW-COST APPROACH

18093CVD4692

The main thrust of the safety program has been (1) the systematic identification of Tug hazards, and (2) the implementation of design features that eliminate/minimize each of these hazards.

In the hazard assessment, all mission phases from prelaunch to post-landing operations were evaluated. Particular emphasis was placed on those operations conducted with the Tug in or near the Orbiter. The safety implications associated with aborted missions received equal priority.

Once Tug hazards had been identified, safety features that specifically countered each of the hazards were designed into the Tug candidates. These safety features were not considered tradeable and the weight penalties associated with the implementation of safety were considered to be mandatory.

The safety analysis has indicated that (1) credible design approaches are available for assuring Tug compatibility with manned space operations, and (2) the performance capability permits the Tug design to absorb the resulting weight penalties (~250 pounds) and still achieve the payload delivery/retrieval requirements.

TUG SAFETY CONSIDERATIONS

GENERAL DYNAMICS
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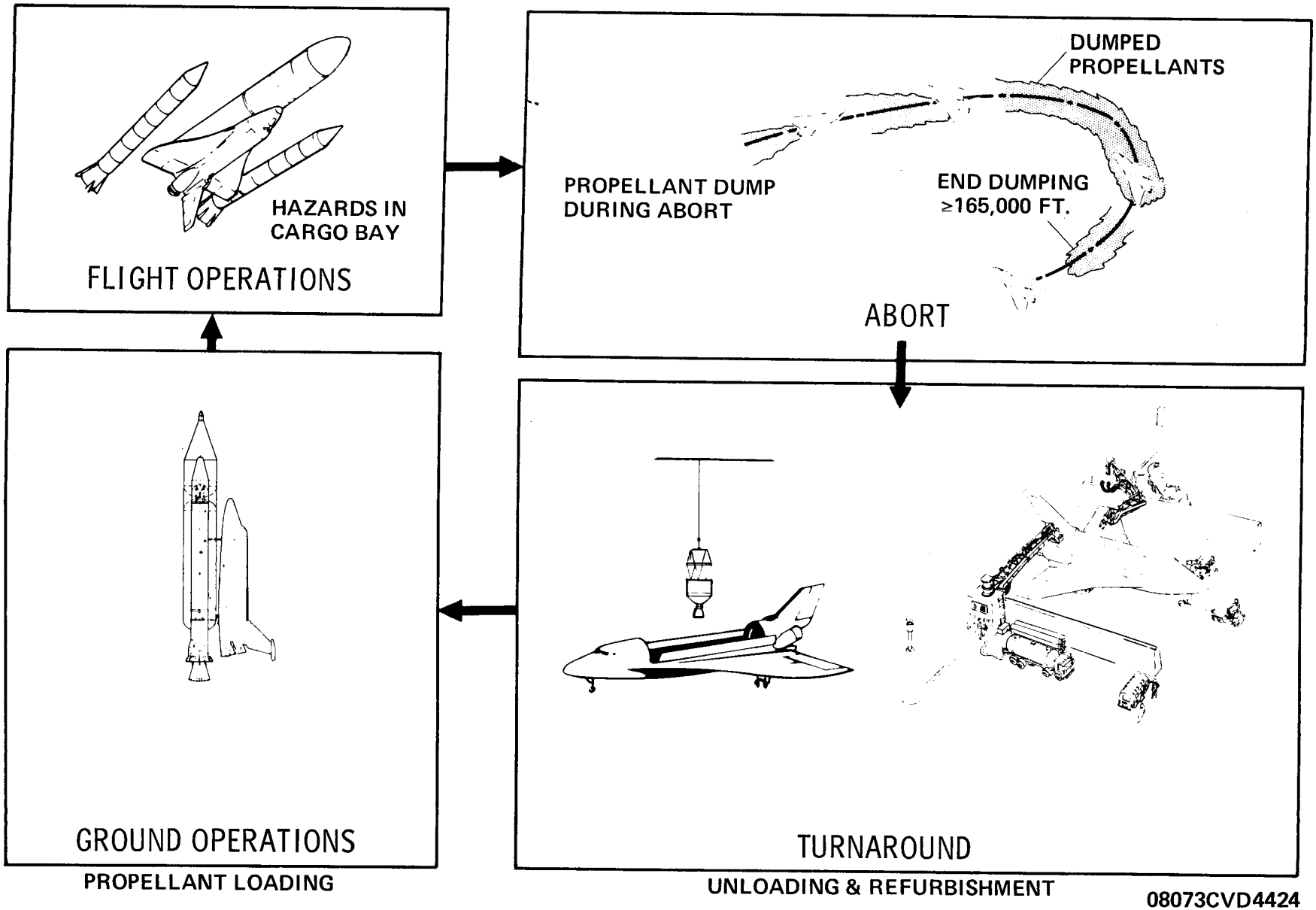

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The major features associated with a cryogenic Tug are as indicated.

Potential safety hazards can be avoided by designing in safety features.

High performance is inherent with cryogenic Tugs, using engines based on present day technology (i.e., RL10 Category I engine). This inherent high performance produces a number of benefits. There are no performance related requirements that drive towards advanced state-of-the-art subsystems. The high performance afforded by the engine allows the use of other existing technology subsystems, and also allows the implementation of redundancy without dropping the performance below the desired level. The high performance also provides a performance margin for both the Tug and the Shuttle.

There are further benefits in terms of low operational complexity, multipayload mission capability and potential payload effects benefits in terms of increased payload mass and possible payload reuse (retrieval).

CRYOGENIC TUG FEATURES

- SAFE
- HIGH INHERENT PERFORMANCE
- LOW RISK
  - NO ADVANCED STATE OF ART SYSTEMS
  - HIGH RELIABILITY
  - PERFORMANCE MARGIN FOR SHUTTLE
- LOW OPERATIONAL COMPLEXITY (NO TWO TUG OPERATION)
- LARGE NUMBER OF MULTI-PAYLOAD MISSIONS
- POTENTIAL FOR PAYLOAD EFFECTS BENEFITS
- < $200M DEVELOPMENT COST POSSIBLE

18093CVD4691

PROGRAM 1

This chart shows the basic objectives of Program 3 as given in NASA/MSFC document PD-TUG-000801(1) dated July 25, 1973.

OBJECTIVES

REQUIRED PERFORMANCE $\geqslant$ 3,500-LB. PAYLOAD PLACEMENT TO SYNCHRONOUS EQUATORIAL ORBIT

36-HOUR MISSION DURATION

NO PAYLOAD RETRIEVAL CAPABILITY

MINIMUM DDT&E COST

IOC DEC. 1979

DIRECT DEVELOPMENT

SENSITIVITY: 2-YEAR DELAY IN IOC

ORDER OF DISCUSSION

CONFIGURATION

SYSTEM DESCRIPTION

- STRUCTURE
- PROPULSION
- ASTRIONICS
- THERMO
- INTERFACES

MASS PROPERTIES & PERFORMANCE

SAFETY & RELIABILITY

MISSIONS

OPERATIONS

- FLIGHT
- GROUND

PROGRAMMATICS

- SCHEDULE
- TESTING
- MANUFACTURE

COST

RISK

TECHNOLOGY

SENSITIVITIES

18093CVD4699

The inboard profile of Program 1 Tug shown has primary emphasis on low DDT&E cost, no growth capability, minimum performance $\geq$ 3500 lbs placement to synchronous equatorial, and without rendezvous and docking. To accomodate these objectives the shell is aluminum skin/stringer with aluminum alloy propellant tanks. The RL10 category 1 engine operating at a mixture ratio of 5:1 is mounted on the conical aft end of oxygen tank. The A.C.P.S. is hydrazene monopropellant with helium pressurized bladder tanks with sixteen A.C.P.S. thrusters, mounted in clusters of four to provide all axis maneuver capability. These thruster modules are mounted circumferentially around the shell between the hydrogen and oxygen tank, along with their fuel supply bottles, the Tug power fuel cell, radiator and plumbing system.

The astrionics system module, at forward end of Tug,relies heavily on Centaur developed components, for data management, guidance and navigation, flight control,instrumentation,and power distribution control.

The main propellant tanks are sized for deployment mission and make a Tug length of approximately 409 inches and overall diameter of 174 inches. The insulation blanket system,Centaur developed, is of dimpled double aluminized Kapton film.

By utilizing many Centaur developed components and techniques with state of the art aluminum structural construction, low DDT&E costs can be maintained.

Further details of all subsystems are contained in Volume 5, Book 1.

CONFIGURATION

GENERAL DYNAMICS
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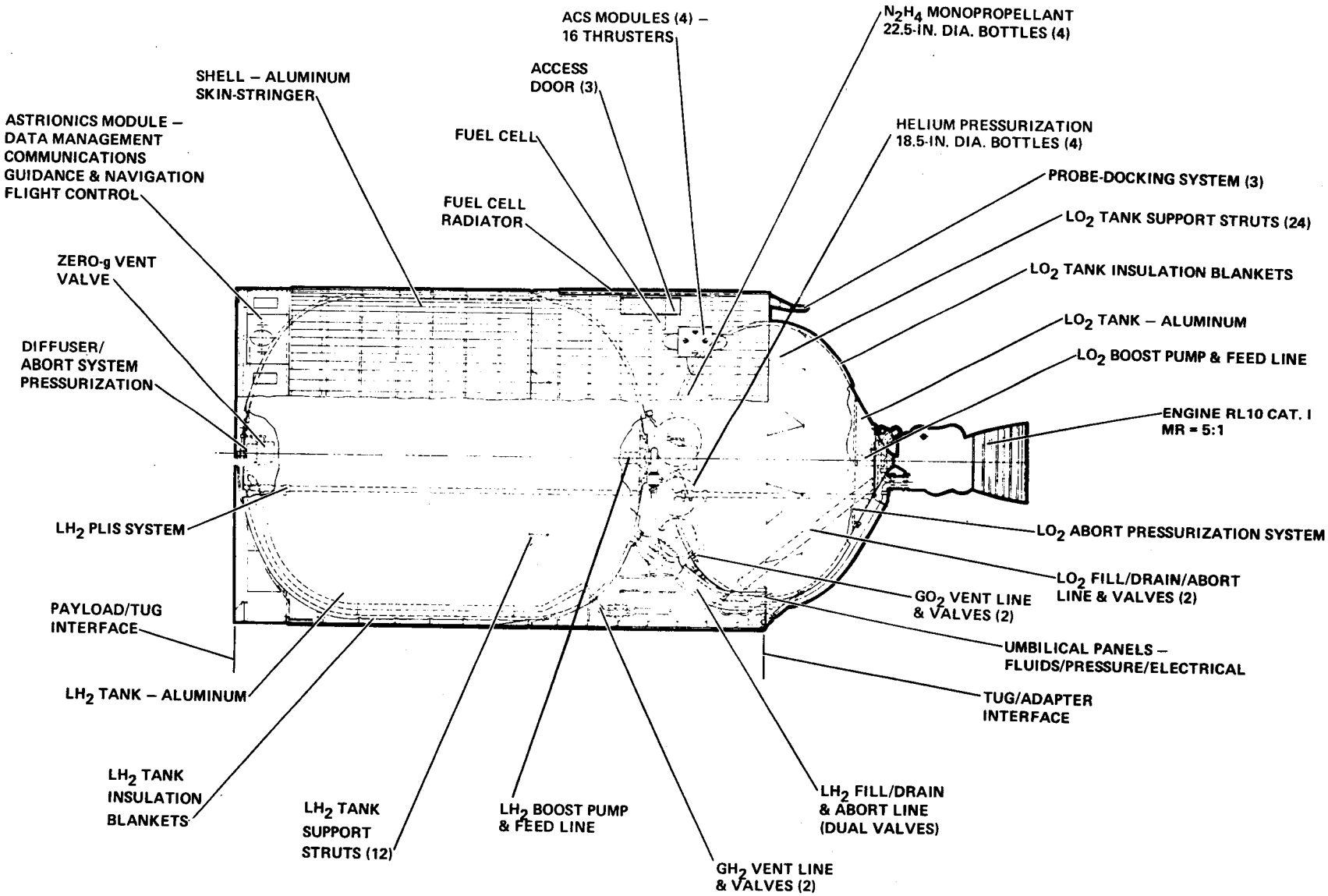
PROGRAM 1



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The combination of suspended monocoque fuel tank and full length body structure is lighter and less expensive than the option featuring an integrally-stiffened load-bearing tank with less body structure. Suspension of both tanks with discrete thermal isolation struts reduces heat input and resultant propellant boiloff.

2219-T87 aluminum was selected as the preferred tank material from among twelve candidates. Its frequent recent use has permitted detailed characterization in the key categories of fracture toughness, stress-corrosion resistance, and weldability, where it is unsurpassed by other aluminum alloys. In addition, it results in one of the lightest tank systems.

Ellipsoidal bulkheads with $a/b = 1.38$ avoid compressive hoop stresses and provide tank lengths compatible with the total vehicle length constraint. Gore construction is used in preference to the 1-piece spin-formed option due to lesser development, higher strength, and a negligible (4 lb) weight penalty.

The body structure is partitioned into three segments (Astrionics, Forward, and Aft Modules) for ease of both initial fabrication and subsystems attachment and subsequent maintenance and refurbishment. Conventional aluminum skin-stringer construction was selected in preference to metallic isogrid or various composite systems for low cost and minimum development.

The integral tank-mounted thrust structure concept is preferred over either the non-integral tank-mounted or body-mounted options since it provides a stiff, low weight, in-line load path into the oxidizer tank aft bulkhead, and also functions as a sump and tank access closure. Its 1-piece construction assures low cost and minimum risk.

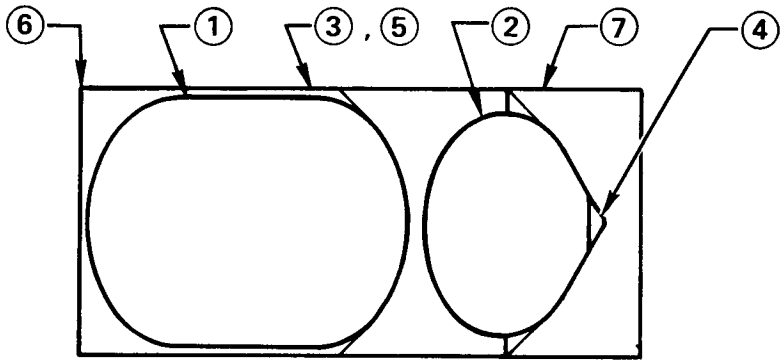
The 0.020 in. body structure skin exceeds the minimum meteoroid bumper thickness required for a 6-day on-orbit synchronous mission during the interval of greatest seasonal meteoroid activity.

Discrete one-shot pyrotechnic latches are provided for payload separation since there is no requirement for payload reattachment. Use of flight qualified hardware assures low cost and risk.

Aluminum skin-stringer construction is selected for the support/deployment adapter for compatibility with the body structure. All mechanisms in the Orbiter interface Subsystem are actuated by multiple electrically powered linear ball screws based on existing hardware designs.

Additional data and selection rationale are presented in Volume 5, Section 5.2.3.2.

STRUCTURE



SUBSYSTEM	CHARACTERISTICS	RATIONALE
1, 2 PROPELLANT TANKS	• MONOCOQUE; SUSPENDED FROM BODY • 2219-T87 ALUMINUM • ELLIPSOIDAL GORE BULKHEADS	• LOW COST; LOW WT; LOW HEAT INPUT • EXISTING; STRONG;TOUGH; GOOD WELD • LOW HEIGHT; MIN DEVEL (LOW COST, RISK)
3 BODY STRUCTURE	• 3 SEGMENTS • ALUMINUM SKIN-STRINGER	• EASE OF MAINT/REFURB • CONVENTIONAL (LOW COST, RISK); MED WT
4 THRUST STRUCTURE	• 1 PC ALUMINUM CONE • OXID TANK AFT CLOSURE (BOLT-ON)	• LOW COST; LOW WT • BI-FUNCTIONAL
5 METEOROID SHIELD	• PROVIDED BY BODY STRUCT SKIN	• EXCESS t FOR 6-DAY, SYNC MISSION
6 PAYLOAD INTERFACE	• DISCRETE PYROTECHNIC LATCHES	• FLIGHT-QUALIFIED; DEPLOY ONLY
7 ORBITER INTERFACE	• ALUMINUM SKIN-STRINGER ADAPTER • ELECT. LINEAR BALL- SCREWS FOR DEPLOY, DOCK, LATCH, UMBIL MECHANISMS	• CONVENTIONAL; MED WT • EXISTING HARDWARE

Characteristics of the Category I engine, as defined for Program 1, are summarized in this chart. It is the existing Centaur Pratt & Whitney RL10A-3-3 engine requalified for the Tug operating conditions and requirements, including the following:

a. Lower engine inlet pressures during cooldown and engine starting. Mimimum Centaur and Tug requirements are compared below:

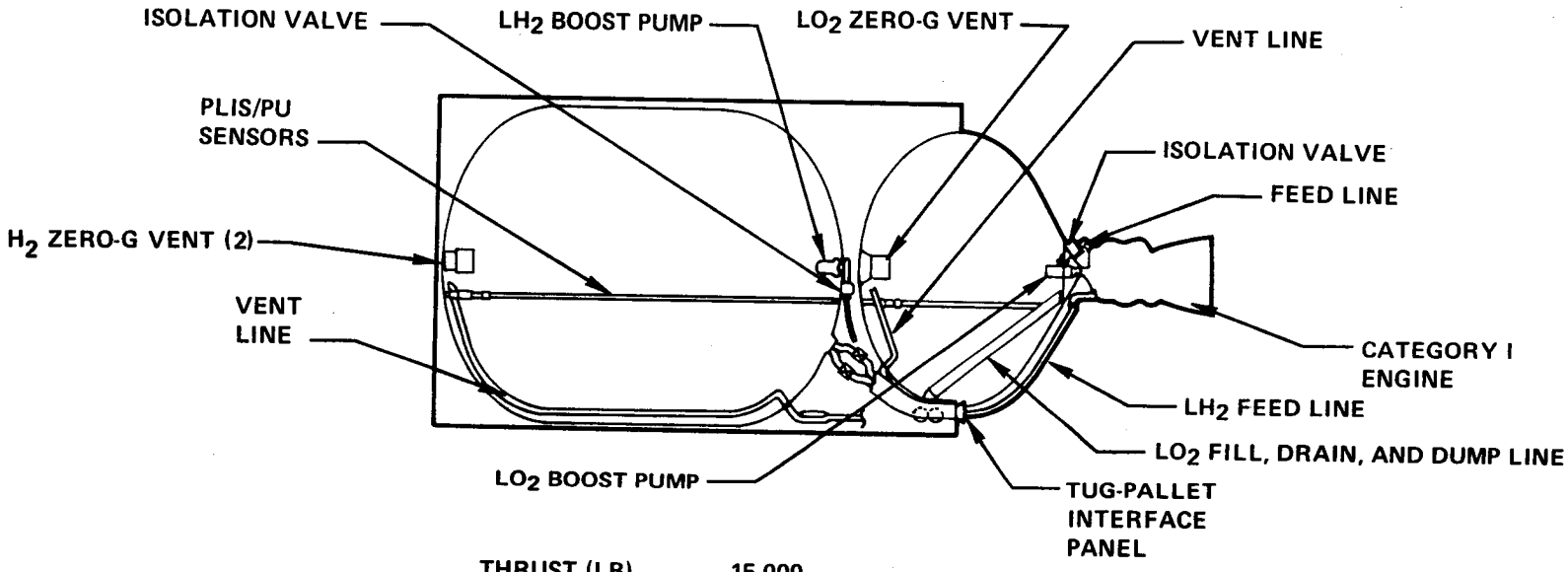
	Centaur	Tug
LH_2 Minimum Inlet Pressure (psia)	40	22
LO_2 Minimum Inlet Pressure (psia)	115	21

b. Modified cooldown sequence and conditions. Flow areas through the cooldown valves are changed to match the above Tug pressures and to minimize cooldown losses. Engine pump housing temperatures for most engine starts will be different than for Centaur, for which the RL10A-3-3 is qualified.

c. Tug feed System Compatibility. Demonstrate that the engines perform to specifications with the Tug propellant feed system hardware including feed ducts and boost pumps.

All specifications shown are the same as for the RL10A-3-3. The $13,000,000 DDT&E cost shown is almost totally for the qualification test program, including cost for reactivation of the required test stands. Further details on the Main engine system are given in Volume 5, Section 5.2.3.1(1).

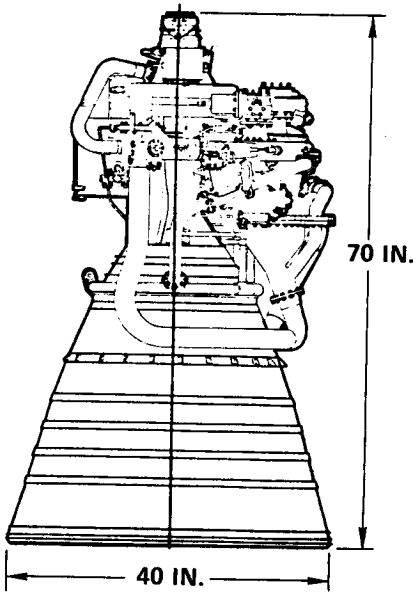
MAIN PROPULSION SYSTEM
RL10 Category I Engine



CENTAUR RL10A-3-3 REQUALIFIED FOR TUG
- LOWER INLET PRESSURES
- TUG FEED SYSTEM COMPATABILITY
- MODIFIED COOLDOWN SEQUENCE

THRUST (LB)	15,000
ISP (SEC)	444
ϵ	57
P_C (PSIA)	400
MIXTURE RATIO	5.0
NPSP (FT)	
LO_2	7.5
LH_2	14
WEIGHT (LB)	293
PRESSURIZATION-ELECTRIC BOOST PUMPS	
LIFE (HR)	5.0
(STARTS)	190
COST (M$)	
DDT&E	13.0
TFU	0.7
SCHEDULE (MONTHS FROM ATP)	
PFC	–
FFC	24

SELECTED FOR MINIMUM DDT&E COST



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This chart is a summary description of the propulsion subsystems with a brief selection rationale for each feature. A more detailed discussion can be found in Volume 5, Section 5.2.3.1.2(1).

PROPULSION SUBSYSTEM

SELECTED FEATURES	DESCRIPTION	RATIONALE FOR SELECTION
ARTICULATED FEED, FILL & VENT LINES (CENTAUR TYPE)	MATERIAL: CRES 321 WALL GAGE: 0.025 IN. FLEX JOINTS – CENTAUR	CENTAUR PROVEN MINIMUM COST & WT. LEAST COMPLEXITY LONG LIFE (FATIGUE RESISTANT)
SELF-PRESSURIZATION WITH BOOST PUMPS	PUMP BHP: LH_2 = 2.2 LO_2 = 1.1 MAX. TANK OPERATING PRESSURE = 20 PSIA	NO ENGINE DEVELOPMENT CENTAUR-PROVEN MINIMUM WEIGHT LOW COST MISSION INSENSITIVE
BATTERY/INVERTER/AC MOTOR BOOST PUMP DRIVE	BATTERY: 28V, 115 A LO_2 INV. 3-PH., 200 Hz, 1,500 VA LH_2 INV. 3 PH., 400 Hz, 2,300 VA	OPERATIONAL SIMPLICITY LOW COST/RISK LOW WEIGHT
INTEGRATED PLIS/PU SENSORS	CAPACITANCE PROBES (MODIFIED CENTAUR)	OFFLOADING (15%) REQUIRED
CLOSED-LOOP PU CONTROL	PLIS/PU SENSORS + VEHICLE COMPUTER	INCREASED PAYLOAD (600 LB.) LOW DEVELOPMENT COST (PU VALVE ACTUATOR ONLY)
BULK HEAT EXCHANGER ZERO-g VENT	LH_2 / LO_2 POWER (W) 10 / 60 WT. (LB.) 9 / 14 CAP. (LB./HR.) 4 / 15	LOW WEIGHT, COST & RISK PRESENT STATE OF ART
HYDRAULIC MAIN ENGINE GIMBAL SYSTEM	ENGINE-DRIVEN HYD. PUMP HYD. SERVO-ACTUATORS (HALF OF CENTAUR SYSTEM)	OFF THE SHELF (CENTAUR) LOW WEIGHT
FOAM/MLI FEED LINE INSULATION	CAST-IN-PLACE FOAM MLI WRAPPED & PURGED	SIMILAR TO CENTAUR INSULATION MINIMUM WEIGHT & COST
ZERO-g PROPELLANT SETTLING BY AXIAL-THRUST WITH ACPS	TYPICAL VALUES: SETTLING TIME 90 SEC. PROPELLANT: 20 LB. ΔV: 3 - 10 FPS	CENTAUR-PROVEN MINIMUM WEIGHT
DRY PROPELLANT LINES DURING ASCENT	TANK ISOLATION VALVES IN FEED, DUMP & VENT LINES	SAFETY

The attitude control propulsion system (ACPS) selected for Tug Program 1 is a monopropellant N_2H_4 system of approximately 180,000 lb/sec total impulse. All major system components are modifications or adaptations of existing hardware.

The 16 engines are modified Titan IIIC Transtage designs with redesigned nozzle, mounting structure, and valving.

The four propellant storage bottles are currently used on a USAF satellite program and for "Viking 75", while the helium storage bottle is qualified for manned vehicle usage. The pressure regulators are modifications of the Apollo Command and Service Module RCS regulator.

In selecting a monopropellant system over a bipropellant ACPS for Program 1, the major driver was low development cost, approximately 30-45% less for the N_2H_4 monopropellant. Potential payload contamination with bipropellant ACPS was also a consideration in the selection. Other factors favoring the choice of N_2H_4 were: higher reliability, minimum complexity, minimum development risk, and availability of engines and tankage requiring minimum modification for Tug usage.

Additional detail on engine and system configurations and selection can be found in Volume 5, Sections 5.2.3.1.3 and 5.2.3.1.4.

ATTITUDE CONTROL PROPULSION SYSTEM

SELECTED FEATURES	DESCRIPTION	RATIONALE FOR SELECTION
N_2H_4 ACPS	~180,000 LB SEC. TOTAL IMPULSE	• MINIMUM DEVELOPMENT COST • NO PAYLOAD CONTAMINATION • RELIABILITY • LOW MAINTENANCE REQUIREMENTS • MINIMUM COMPLEXITY
DIAPHRAGM EXPULSION N_2H_4 BOTTLES	FOUR Ti-6AL-4V SPHERES – 22.14 I.D., EPT-10 DIAPHRAGM, 350 PSIG OPERATING, 700 PSIG BURST, 17.25 LB. WEIGHT	• PROVEN CONCEPT FOR N_2H_4 STORAGE & EXPULSION. • MEETS CYCLIC LIFE REQMTS > 200 EXPULSION CYCLE CAPABILITY • SELECTED BOTTLE QUALIFIED & IN PRODUCTION FOR P95 & VIKING.
QUAD REDUNDANT, REGULATED PRESSURIZATION SUBSYSTEM	• TWO DUAL REGULATOR LEGS WITH ISOLATION VALVES • TWO 15.15 I.D. HELIUM BOTTLES, 23.3 LBS WEIGHT, 4000 PSIG OPERATING, 8000 PSIG BURST	• FAIL OPERATIONAL, FAIL SAFE REQUIREMENT • BASIC CONCEPT SIMILAR TO APOLLO CSM RCS PRESSURIZATION • CONSTANT ENGINE THRUST
16 ENGINES @ 25 LB_f EACH	• FOUR ENGINE QUADS • MODIFIED TRANSTAGE ENGINES • INDIVIDUAL ENGINE AND MODULE ISOLATION VALVES	• MEET TRANSLATION & ROTATIONAL REQUIREMENTS • MINIMUM DEVELOPMENT COST • FAIL OPERATIONAL/FAIL SAFE

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The astrionics configuration for the Program 1 vehicle has the lowest DDT&E cost of the three vehicles studied. The configuration is based on a maximum utilization of existing Centaur equipment design to achieve Level 1 autonomy and minimum required vehicle performance. Redundancy is added selectively to meet reliability and safety requirements.

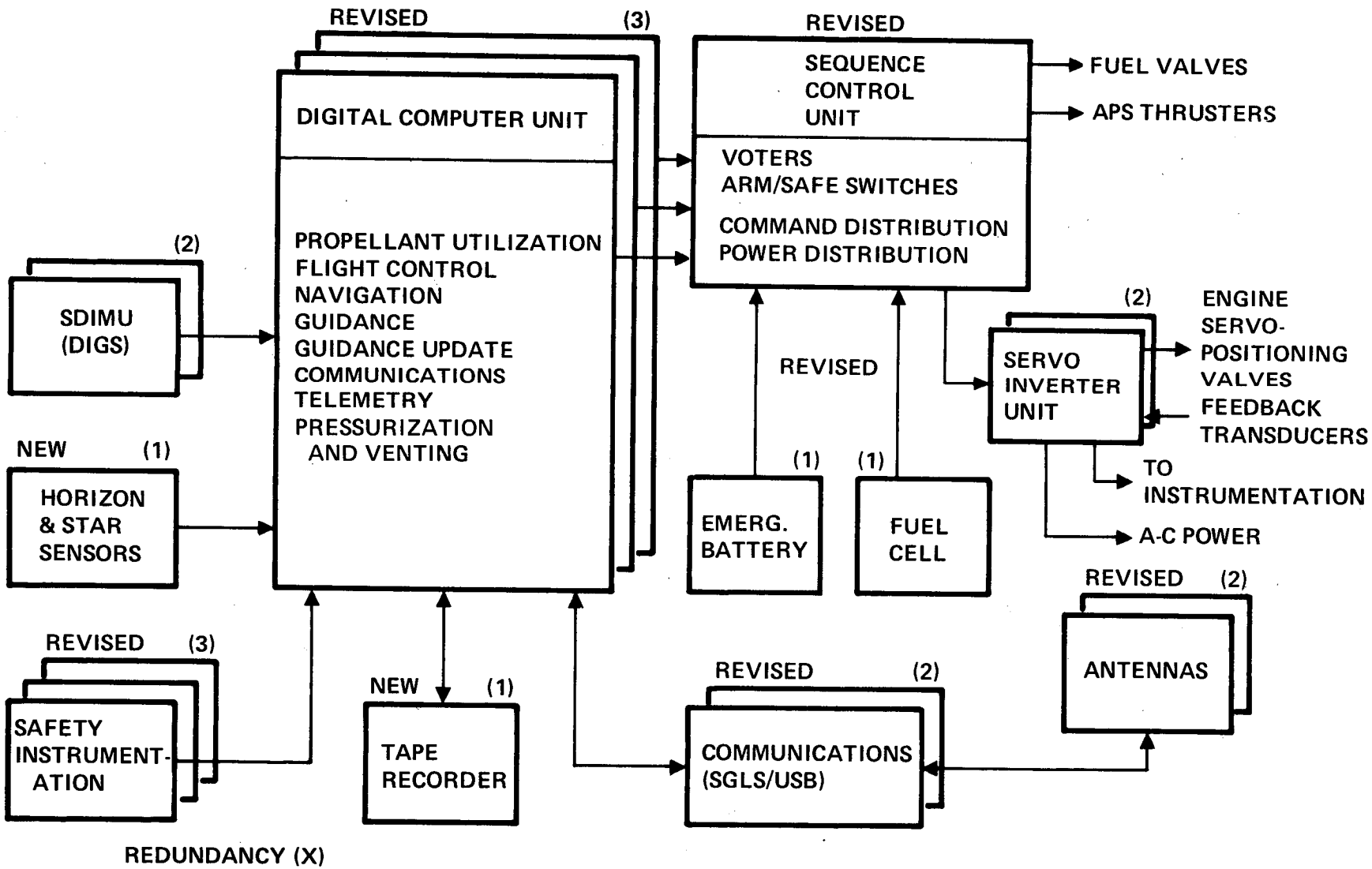
Three digital computer units are included with their outputs voted in the Sequence Control Unit. Dual Strapdown Inertial Measurement Units (SDIMU) provide navigation and attitude reference data. Horizon and star sensor units are used to update the SDIMU data for long term accuracy. Safety instrumentation is selectively redundant to provide the centrol computer with the required vehicle system data. The tape recorder stores formatted telemetry data to be communicated to the ground and can also be used to store data required at preplanned times during the mission. The dual redundant RF communications units provide for Tug/Shuttle or ground communications. The primary source of electrical power for the vehicle is a Fuel Cell. An emergency battery is provided to maintain safety critical functions in the event fuel cell power is lost. The Sequence Control Unit and the Servo Inverter Units provide the interface for command and control outputs from the central computer to the vehicles systems.

For details see Volume 5, Book 1, Section 5.2.3.4(1)

ASTRIONICS FUNCTIONAL SYSTEM

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1



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The Data Management subsystem consists of triple redundant modified Centaur computer units and a new tape recorder in development for the High Energy Astronomical Observatory program. Guidance and navigation is implemented by a dual redundant strapdown IMU used on the Delta launch vehicle. The Flight Control interfaces with the central computer is handled by the sequence control unit and the servo inverter units which are modified Centaur vehicle equipment. Guidance update data to the central computer is provided by star and horizon sensors that have been built and tested. The dual redundant RF communications subsystem utilizes modified ERTS equipment to meet NASA requirements and modified FLTSATCOM equipment for DOD requirements. Triple redundant safety critical instrumentation is a modified Centaur configuration. The primary source of electrical power is a modified Shuttle fuel cell resized to Tug power requirements. An emergency battery provides short term backup in the event of a fuel cell failure. A boost pump battery is a separate power source for driving electrical boost pumps. The electrical power distribution and control is a modification of the existing system used on the Centaur vehicle. New inverters are added to convert the boost pump battery power to AC required by the H_2 and O_2 electric boost pumps.

For details see Volume 5, Book 1, Section 5.2.3.4(1).

ASTRIONICS SYSTEM CHARACTERISTICS

SUBSYSTEM	REDUNDANCY	DEVELOPMENT STATUS	CHARACTERISTICS
DATA MANAGEMENT	TRIPLE SINGLE	CENTAUR (MOD.) IN DEVELOPMENT	48K MEMORY, NO DATA BUS TAPE RECORDERS
GUIDANCE & NAV.	DUAL	IN PRODUCTION	DIGS STRAPDOWN IMU
FLIGHT CONTROL	SINGLE DUAL	CENTAUR (MOD.) CENTAUR (MOD.)	SCU SIU
GUIDANCE UPDATE	SINGLE	IN DEVELOPMENT	LEVEL I AUTONOMY STAR SENSOR & HORIZON SENSOR
COMMUNICATIONS	DUAL	ERTS (MOD.) FLTSATCOM (MOD.)	USB (NASA), NO RF COMMUNICATIONS WITH PAYLOAD SGLS (DOD), SECURE, NO RF COMMUNICATIONS WITH PAYLOAD
INSTRUMENTATION	TRIPLE FOR SAFETY CRITICAL	CENTAUR (MOD.)	REMOTE MULTIPLEXING
ELECTRICAL POWER	SINGLE	SHUTTLE (MOD.)	FUEL CELL, EMERGENCY BATTERY, BOOST PUMP BATTERY
POWER DISTRIBUTION & CONTROL	DUAL FOR SAFETY	CENTAUR (MOD.)	BOOST PUMP INVERTERS

The use of batteries to provide the primary source of electrical power for the Tug results in a simple, reliable, relatively inexpensive system. However, the Program 1 mission duration requires a total of 52,886 watt-hours of electrical energy. To supply this energy 944 pounds of batteries are required.

An equivalent fuel cell system for the source of electrical power weighs only 272 pounds resulting in a weight saving of 672 pounds. This weight saving of 672 pounds is significant for a vehicle with a payload capability of 3500 pounds.

For details on the power requirements for Program 1, see Volume 5, Book 1, Section 5.2.3.4.5(1).

BATTERIES VS. FUEL CELL

- POWER REQUIREMENTS DURING COAST (31 HOUR MINIMUM)

AVIONICS	1,097
HEATERS (ACPS & HYDRAULIC)	457
PROPULSION SUBSYSTEMS	157
	1,706 WATTS → 52.9 KW-HR.

- SYSTEM WEIGHTS

BATTERIES		FUEL CELL	
BATTERIES	944 LB.	FUEL CELL UNIT	128
		PLUMBING	60
		EMERG. BATTERY	36
		DRY WEIGHT	224 LB.
		REACTANTS	48 LB.

- SYSTEM DEVELOPMENT COST

BATTERIES	$0.4M	FUEL CELL	$4.3M

- PERFORMANCE IMPACT

△BURNOUT WEIGHT WITH BATTERIES +792 LB. (INCL. 10% CONTINGENCY)
△DEPLOY PERFORMANCE − 2,150 LB.
PAYLOAD WITH BATTERIES 3,200 LB. (LESS THAN 3,500 LB. MINIMUM)

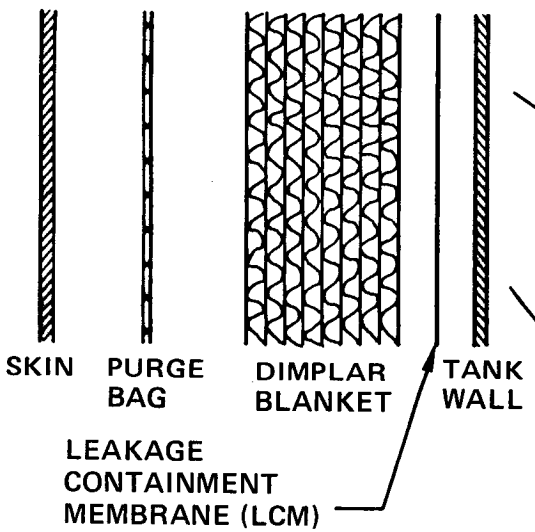
SELECT FUEL CELL

18093CVD4649

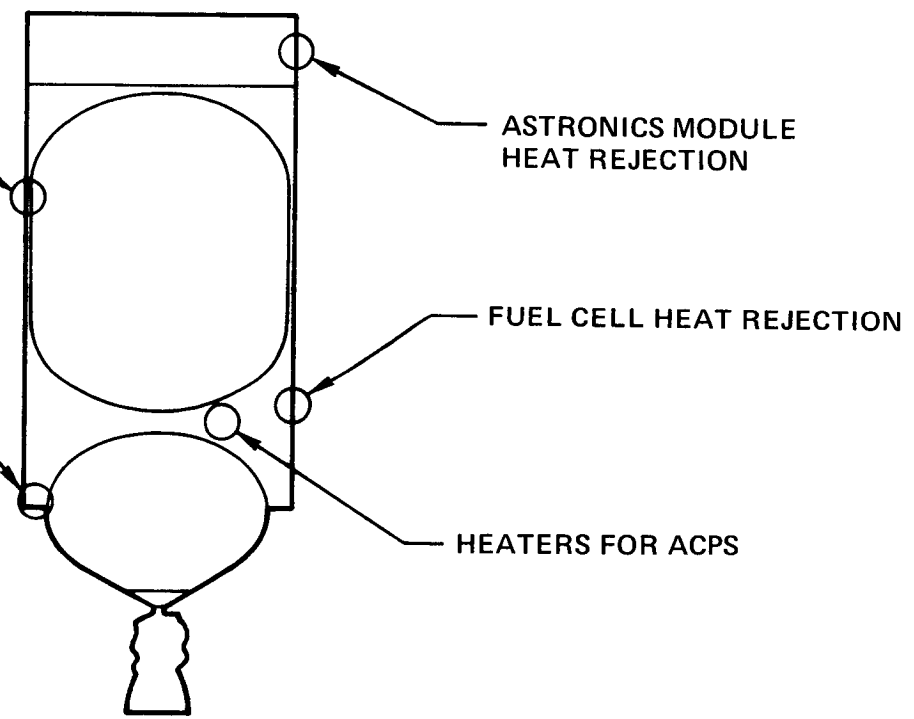
Insulation and thermal control systems are provided to minimize cryogenic propellant losses and to maintain components within prescribed operating temperature limits. The cryogenic insulation system will consist of a tank leakage containment membrane (LCM) located next to the tank surface, a Superfloc multilayer insulation (MLI) blanket, and a purge bag and purge distribution system. The Superfloc system has been subjected to considerable subscale thermal and structural testing and its characteristics are well known. This system was selected in that it provides excellent thermal performance over all stages of the mission. The combination of LCM and purge bag provides double containment and channeling of gases leaking from the propellant tanks. The primary function of the purge bag is to isolate the MLI from the external environment and to contain insulation preconditioning, purge, and repressurization gases. The thermal control systems remove excess heat from fuel cells and the astrionics module, and provide heat for the ACPS. About 75% of the astrionics module sidewall area will be utilized to radiate component generated heat to space. The remaining 25% of the sidewall area will be insulated to prevent excessively low module temperatures. The radiating area will incorporate a low solar absorbtance coating to minimize solar heating perturbations. A space radiator plate of about 50 ft^2 will also be required to reject fuel cell waste heat to space. This radiator will be located near the fuel cell in the intertank region and will also have a low solar absorbtance. The ACPS may require 250 watts of electrical power to prevent overchilling of the bottles, lines, and thrusters.

INSULATION & THERMAL CONTROL

CRYOGENIC INSULATION



VEHICLE THERMAL CONTROL



CHARACTERISTICS

- FLIGHT-PROVEN MLI (CENTAUR)
- ADEQUATE THERMAL PERFORMANCE AT MINIMUM COST
- DOUBLE TANK ISOLATION (LCM AND BAG)
- MLI PRECONDITIONING, PURGE AND REPRESSURIZATION
- MLI PROTECTION FROM ENVIRONMENT

CHARACTERISTICS

- SIMPLE, LIGHTWEIGHT PROVEN COMPONENTS
- MAINTAINS PRESCRIBED COMPONENT OPERATING TEMPERATURE LIMITS UNDER MOST SEVERE CONDITIONS

The facing chart illustrates the structural, fluid and electrical interfaces required for the Tug/payload mission.

Interface requirements include:

a) Structure support of Tug/payload in the Orbiter payload bay.

b) Tug rotation actuation, remote manipulator, Tug docking and latching mechanisms and payload release mechanism.

c) Fluid propellants feed, fill, drain, abort dump and boiloff venting.

d) Inert gas pressurants for purging and abort dump pressurization.

e) Electrical services for monitoring and control of the Tug and payload.

The Tug is supported in the Shuttle at four points. Three points are located on the support adapter, one on each side reacts Z and X loads and one on the lower centerline reacts Y loads. The remaining support is located on the forward left side of the Tug and reacts Z loads only.

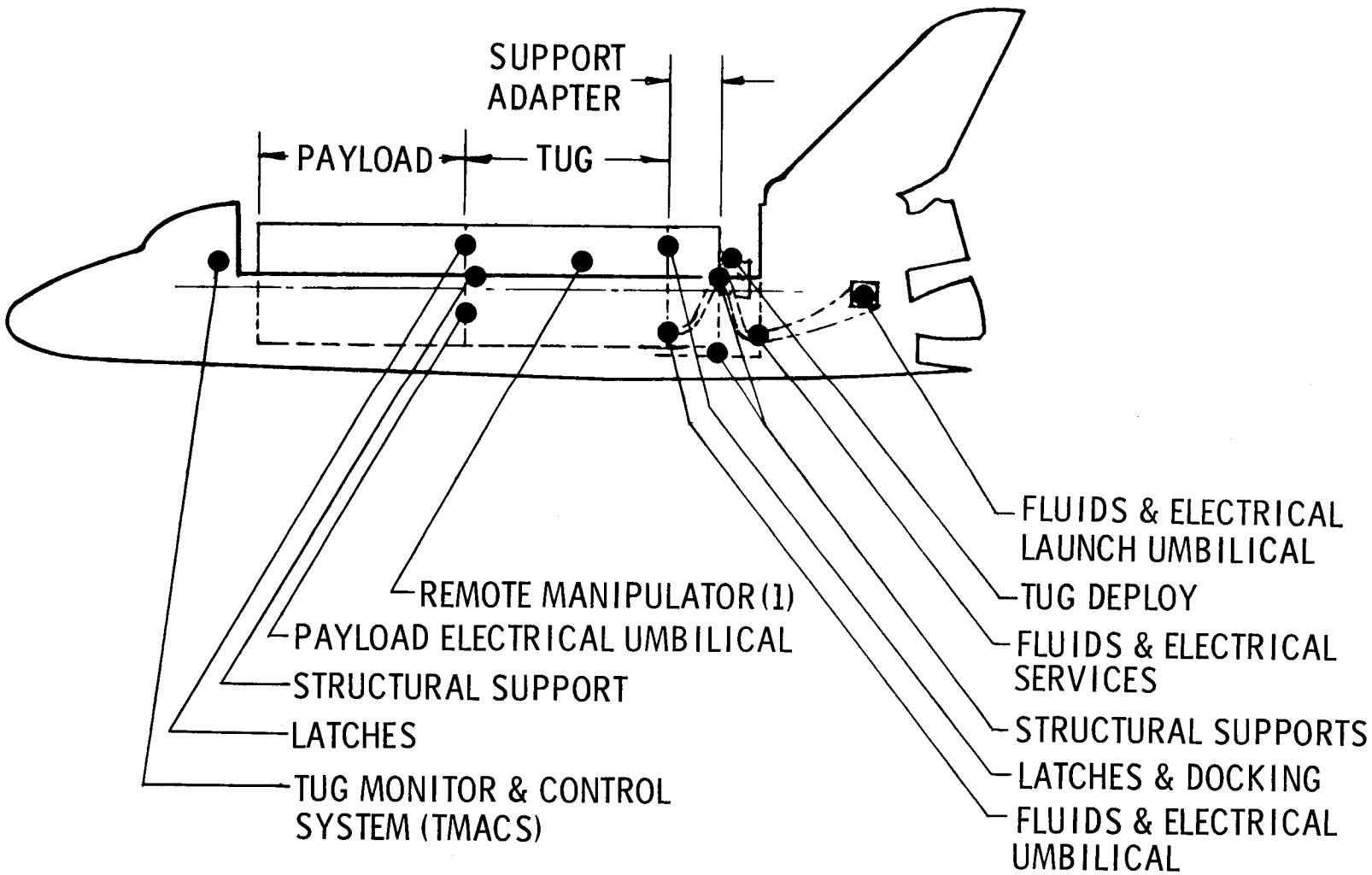
Overcenter type latches and a docking mechanism comprise the mechanical interface between the Tug and support adapter. Three probe/drogue docking units provide guidance and alignment for Tug to support adapter docking. The payload is separated from the Tug for launch by actuation of pyro pin puller type latches.

Fluid gases and electrical services are supplied to the Tug/payload from the launch umbilical panels on each side of the Shuttle. Lines and harnesses route thru the Shuttle to service panels located on the payload bay aft bulkhead then to umbilical panels located at the Tug/support adapter separation plane.

An electrical umbilical panel is located at the separation plane between the Tug and payload. This panel makes connections with the payload for payload condition signal and control. Tug monitoring and Control system (TMACS) also makes electrical interface connections at the services panel at the payload bay aft bulkhead.

For further details of the Shuttle/payload interface see Volume 5.0 systems report.

INTERFACES


SUPPORT ADAPTER
PAYLOAD
TUG
REMOTE MANIPULATOR (1)
PAYLOAD ELECTRICAL UMBILICAL
STRUCTURAL SUPPORT
LATCHES
TUG MONITOR & CONTROL SYSTEM (TMACS)
FLUIDS & ELECTRICAL LAUNCH UMBILICAL
TUG DEPLOY
FLUIDS & ELECTRICAL SERVICES
STRUCTURAL SUPPORTS
LATCHES & DOCKING
FLUIDS & ELECTRICAL UMBILICAL

The weights of the low DDT&E Program 1 baseline Tug are summarized in this chart. The weights represent a vehicle outfitted for the geosynchronous equatorial payload delivery mission. The overall weight installed in the Shuttle is 65000 pounds. Mass fraction of this vehicle is 0.865. This Tug has a substantial payload capability. Maximum payload is 5352 pounds, which is 1852 pounds in excess of the 3500 pound minimum set by NASA. Adequate margins have been included in the vehicle weights. There is a 10% contingency in the stage dry weight, a 1.73% of main impulse ΔV propellant set aside for flight performance reserve, and a 10% margin in attitude control propellant.

In developing the dry weight of this vehicle, appropriate allowances were included in each subsystem to meet producibility and safety requirements and to provide a vehicle reliability approaching 0.97. For example, the main propellant tank weights were calculated observing a 0.025-inch minimum gage requirement and making an allowance for tolerance penalties. Subsystems include redundant components. A large percentage of the vehicle weight is based on Centaur hardware and performance data. Examples of these are the RL-10 main engine installation, dimplar insulation blankets, and Centaur avionics. For non-Centaur items, the weighs were established by subsystems design analyses and by using weights data supplied by vendors. Current state-of-the-art designs were assumed in the Tug structure, such as the use of aluminum sheet-stringer for the outer shell. Because a large part of this vehicle weight is predictable, and because adequate margins exist, we have high confidence that the payload weight shown in this chart can be achieved.

The total Tug-chargeable weight of 65000 pounds include the weight of the Tug Monitoring and Control System (TMACS) located in the crew compartment, the weight of the Tug deployment adapter and adapter-mounted equipment, and the interface umbilicals and panels mounted inside the Shuttle payload bay.

A Breakdown of the weights summarized in this chart appears in Volume 5 - Systems, under Section 5.3.

WEIGHT SUMMARY
Synchronous Equatorial Deployment Missions

	WEIGHT (LB.)	
STRUCTURE	2,339	
PROPULSION	1,332	
THERMAL CONTROL	427	
AVIONICS	1,198	
STAGE DRY WEIGHT		5,296
CONTINGENCY	530	
TOTAL DRY WEIGHT		5,826
NON-USABLE FLUIDS (INCL. FPR)	753	
BURNOUT WEIGHT		6,579
NON-IMPULSIVE EXPENDABLES	477	
ACPS PROPELLANTS	727	
MAIN PROPELLANTS	49,715	
FIRST IGNITION WEIGHT		57,498
SHUTTLE INTERFACE ACCOMMODATIONS	2,150	
TUG WEIGHT AT SHUTTLE LIFTOFF		59,648
PAYLOAD WEIGHT (MAX. CAPABILITY)	5,352	
TOTAL TUG-CHARGEABLE WEIGHT		65,000
MASS FRACTION =	0.865	

The baseline Tug configuration for Program 1 has an RL10 Category 1 engine and is sized for maximum deployment capability to a synchronous equatorial orbit. The deployment capability is 5,352 lbs, which exceeds the Program 1 requirement by 1,852 lbs. It can also deploy 15,540 lbs in the expendable mode, or carry a sortie payload of 1,920 lbs to synchronous equatorial orbit.

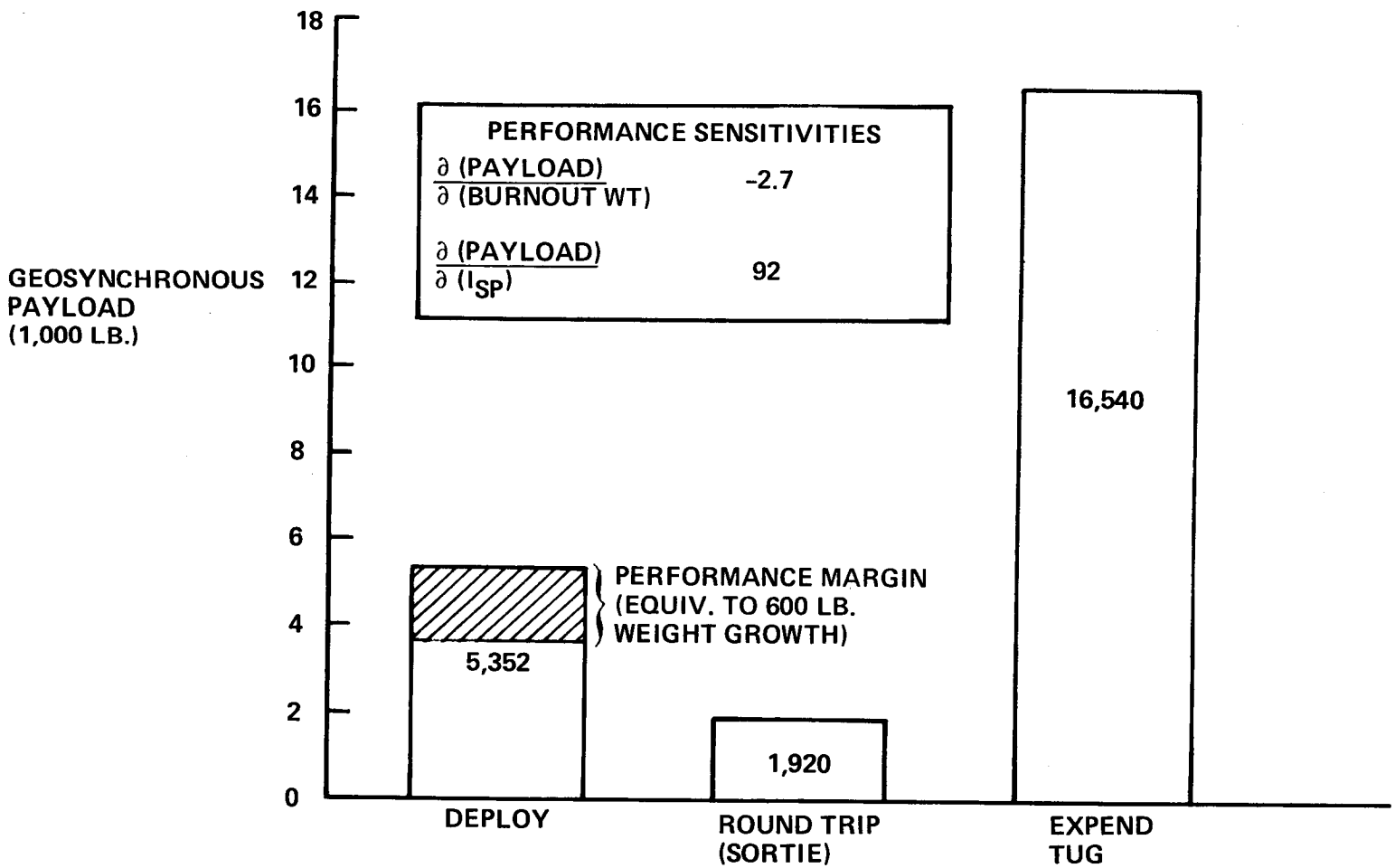
The sensitivity of payload capability to burnout weight and specific impulse variations is also shown. These derivatives are based on a fixed-size Tug.

References: Sections 4.1(1), 5.5(1), 6.3(1) and 6.12.1

TUG PERFORMANCE

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1



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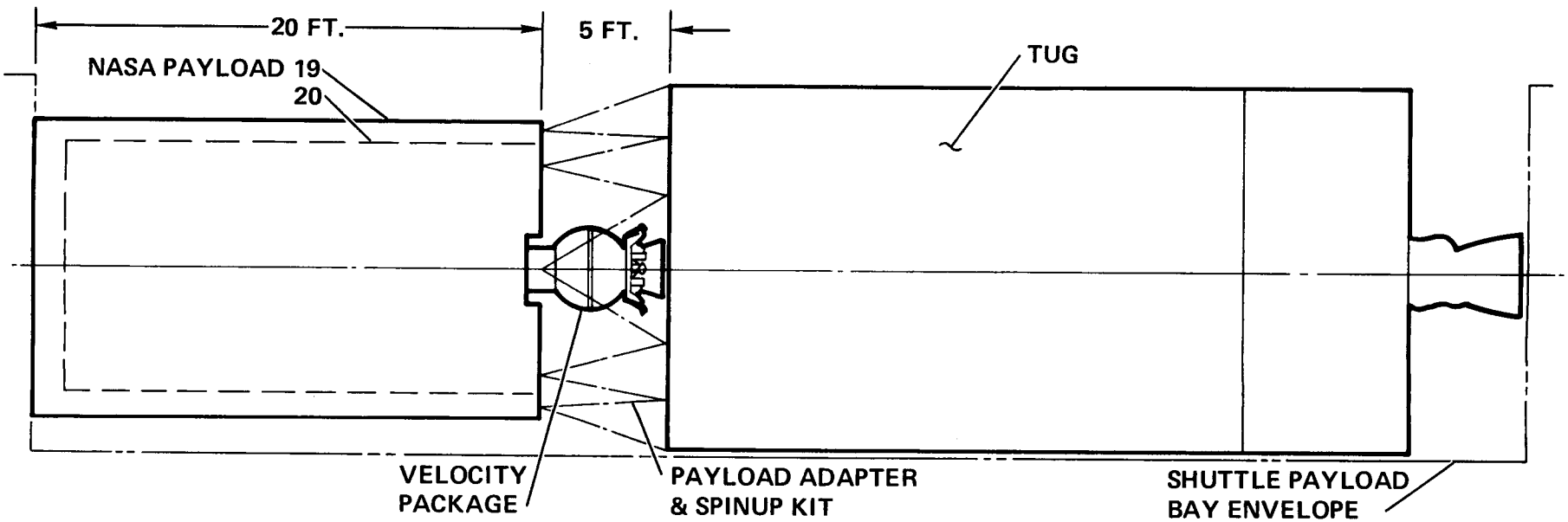
For Program 1 Tug the configuration of a velocity package is shown. Delivery of a 2560 lb. gross weight package is required and a Thiokel TE-M-364-11 motor is used. A payload adapter and separation system is mounted between payload and Tug. Despin rockets and the necessary batteries and sequencing equipment for ignition, despin and separation are mounted on the motor or the small adapter between motor case and payload. No guidance is provided, preburn aiming and spin up are accomplished by the Tug.

Further details are given in Volume 5.2.7.

KICK STAGE



CHARACTERISTICS

MASS PROPERTIES	
TOTAL WEIGHT	2,560 LB.
PROPELLANT WT.	2,300 LB.
MASS FRACTION	0.9
SIZE	
LENGTH	75 IN.
DIAMETER	38 IN.
PROPULSION	SLOW-BURNING SOLID
ATTITUDE CONTROL	SPIN STABILIZED
AVIONICS	
POWER	BATTERY
SEQUENCER	EVENT TIMER
TELEMETRY	NONE
GUIDANCE	NONE
DESPIN	DESPIN ROCKETS

18093CVD4668

The curves show the Program 1 Tug payload weight capability, for each applicable mission mode. The curves are all based on a due-east Shuttle launch, except for the deployment curve labelled polar. The Shuttle is assumed to have a payload weight capability of 65,000 lbs. due east and 36,000 lbs polar, to the nominal 160 n.mi. Tug staging orbit. The curves are based on a six-burn flight profile such as the synchronous equatorial deployment or sortie mission, except for the expendable Tug curve which is based on three burns.

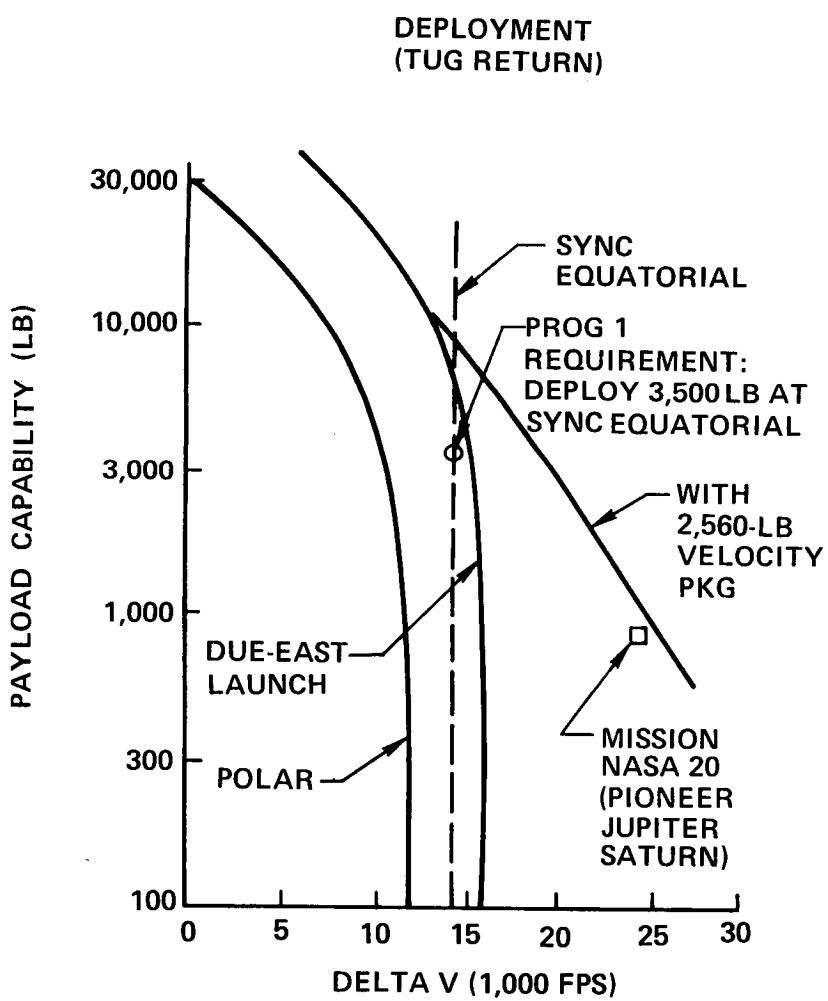
For illustration, planetary missions which require a velocity package and an expended Tug, respectively, appear on the graphs. All of the missions in the mission model can be done by this Tug, in one of the flight modes shown on the chart.

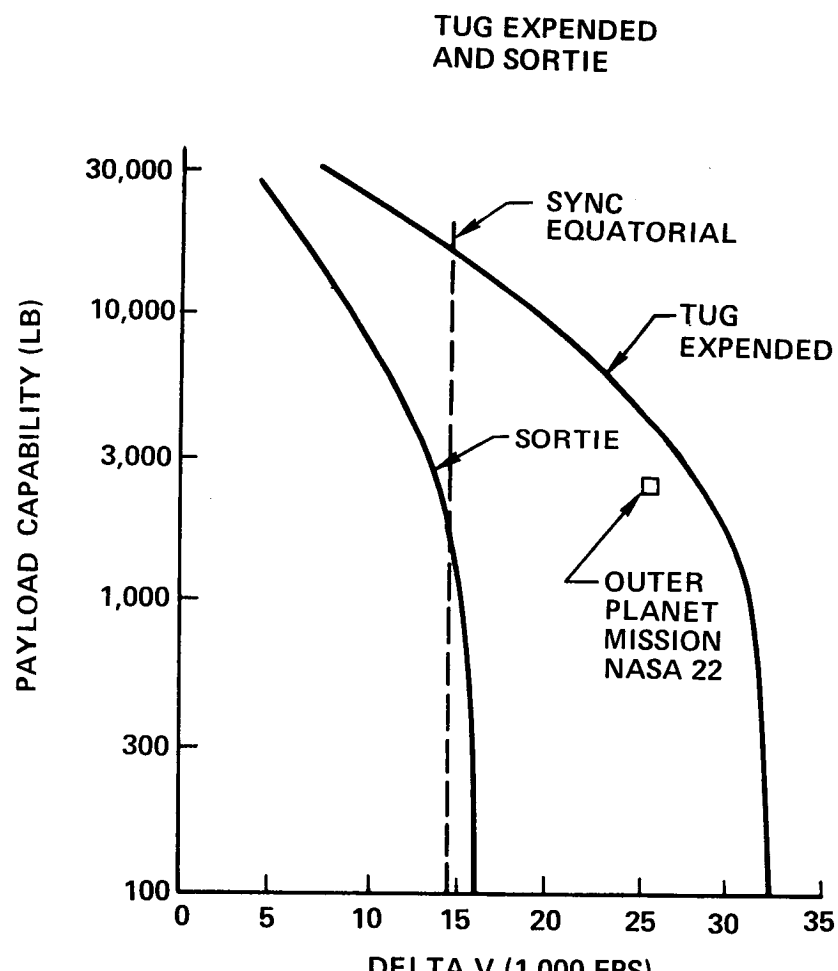
References: Sections 4.1(1), 5.5(1), 6.3(1) and 6.12.1

TUG PERFORMANCE
Payload Capability vs. Delta Velocity

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1





18093CVD4556

The safety related guidelines/requirements contained in the MSFC Tug requirements document have served as the basis for Tug design. Fault Tree Analyses and Mission Hazard Analyses have been used to systematically identify hazards and to identify and implement design approaches that eliminate/control each of the hazards. The main thrust in the Phase A STSS design has been this "building-in" of safety (as opposed to reliance on operational constraints, dependence on single-string reliability, etc.).

Safety criteria developed by the NASA/USAF were implemented to assure that all applicable safety criterion have in fact been accounted for in Tug designs.

The results of the safety analyses are presented in Volume 7.

SAFETY

CRITERIA SOURCE – DATA PACKAGE, AD HOC SAFETY GROUP

OVERALL GUIDELINES/REQUIREMENTS

- NO SINGLE TUG FAILURE SHALL RESULT IN A HAZARD THAT JEOPARDIZES FLIGHT OR GROUND CREWS
- TUG SHALL BE DESIGNED TO MEET MANNED ORBITER SAFETY REQUIREMENTS
- TUG SHALL NOT PRECLUDE ORBITER FROM INTACT ABORT

APPROACH

- "FAULT TREE" AND MISSION HAZARD ANALYSIS USED TO SYSTEMATICALLY IDENTIFY POTENTIAL HAZARDS

  ALL MISSION PHASES: PRELAUNCH THROUGH POSTLANDING

  EMPHASIS ON OPERATIONS WHEN TUG IS IN OR NEAR ORBITER
- DESIGNS EVALUATED WITH RESPECT TO SAFETY CRITERIA
- DESIGN FEATURES IMPLEMENTED WHICH ELIMINATED/MINIMIZED HAZARDS

STSS Tug designs have been checked against each of the safety criterion contained in the JSC Payload Safety Criteria, the MSFC Tug Requirements document and the NASA/AF Ad Hoc Safety Committee report. For purposes of the presentation charts, only the Ad Hoc Safety Committee criteria, and their resolutions, are presented.

As can be seen on the chart, all of the criteria have been complied with in STSS designs. With minor deviations, the same can be said for every JSC and MSFC criterion. Each of these criterion and their resolutions are discussed in detail in Volume 7.

AD HOC SAFETY GROUP CRITERIA

CRITERION	RESOLUTION
• CRASH LANDING LOADS ON ALL SYSTEMS	• SYSTEMS THAT COULD GENERATE A HAZARD DESIGNED FOR CRASH LANDING
• PROPELLANT DRAIN	
<30 MINUTES ON PAD	• DRAIN LINES/VALVES HAVE CAPABILITY
REDUNDANT PROPELLANT DUMP VALVES FOR INFLIGHT DUMP	• DUAL REDUNDANT
HORIZONTAL DRAIN	• NOT REQUIRED BECAUSE OF INFLIGHT DUMP
• NO HAZARD IF PRESSURE STABILIZED TANKS LOSE PRESSURE	• NO PRESSURE STABILIZED TANKS
• LIFE ASSURANCE VERIFICATION	• PRESSURE TEST AFTER EACH FLIGHT • ACOUSTIC EMISSION MONITORS • SELECTIVE X-RAYS
• ORBITAL DEBRIS	• EXPENDED TUGS & KICKSTAGES REACH ESCAPE VELOCITY. NO EARTH ORBIT DEBRIS

18093CVD4646

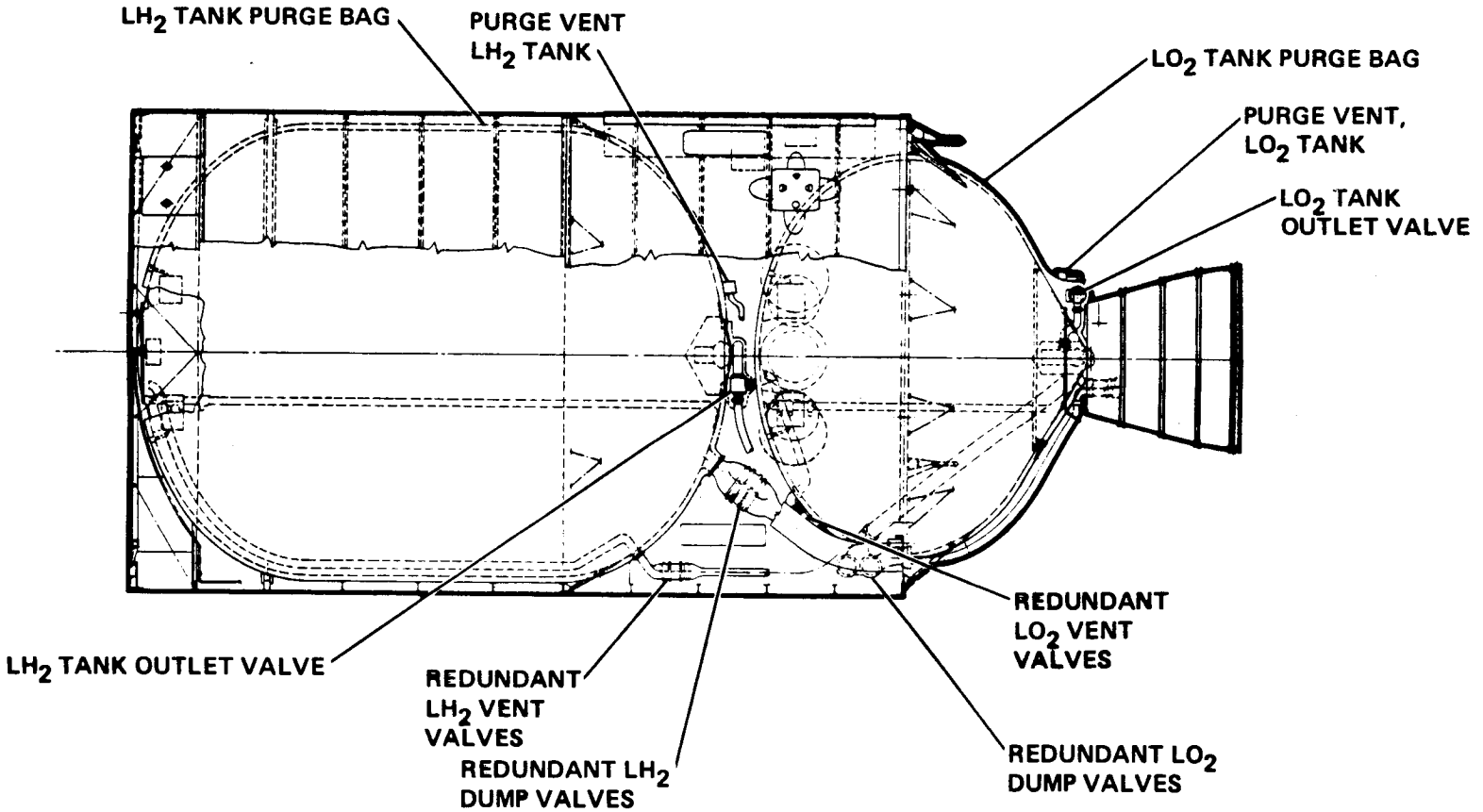
The Tug candidates in Programs 1, 2 and 3 are designed to meet manned safety factors up to and including crash landing loads. Additionally, each of the main propellant tanks, and its outlet valve, is individually enclosed in a purge bag. The purge bags are purged with helium and are individually vented external to the Orbiter. If a leak should develop in a propellant tank, the leaking propellant will be safely carried overboard. The tank outlet valves are used to maintain the propellant lines in an empty condition during the entire time that the Tug is in the Orbiter payload bay, thus eliminating the chance of a propellant leak from lines/fittings during Orbiter flight. Dual redundant dump valves are installed on each of the propellant tanks to assure propellant dump capability in event of an aborted flight.

Safety features that have been designed into the Tug, as well as ground turnaround operations required to verify structural integrity prior to each reflight are discussed throughout Volume 7.

PROPELLANT SAFETY FEATURES

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1



H_2 & O_2 TANK PURGE BAGS PROVIDE COMPLETE ISOLATION OF PROPELLANT TANKS

TANK OUTLET VALVES RESULT IN EMPTY PROPELLANT LINES DURING ENTIRE TIME TUG IS IN ORBITER PAYLOAD BAY

EACH TANK OUTLET VALVE IS ENCLOSED WITHIN ITS RESPECTIVE PURGE BAG

MULTIPLE FAILURES NECESSARY BEFORE CREW SAFETY IS COMPROMISED

18093CVD4580

The main thrust of the GD/CA safety effort has been the implementation of safety features into the design. The facing chart summarizes the principal design features that have been incorporated into Tug Programs 1, 2 and 3. The basis for each of the safety features is the systematic evaluation of potential hazards through Fault Tree analyses, mission hazard analysis, and the evaluation of designs against NASA safety criteria.

As indicated in this safety chart, each of the identified flight hazards has been countered by a specific design feature. The additional weight required to incorporate these safety features is also listed. The resulting weight penalty for safety implementation is $\approx$ 250 pounds.

While the safety features described on this chart are the ones that tend to have the greatest impact on Tug weight penalties, they are only representative of many safety considerations that have been incorporated into GD/CA Tug designs. These additional built-in safety features are described throughout Volume 7.

DESIGNED-IN SAFETY
Weight Penalty = 250 lb.

FLIGHT HAZARDS (FROM FAULT TREE ANALYSIS)	DESIGN FEATURES (ALL TUG CANDIDATES)	ΔWEIGHT (LB.)
• PROPELLANT LEAKS	• INDEPENDENT CONTAINMENT OF PROPELLANT	27
PROPELLANT TANK LEAKS	• PURGE BAGS INDEPENDENTLY VENTED	20
LEAKS IN LINES/FITTINGS	• BACKUP CONTAINMENT FITTINGS ON ALL TUG/ORBITER INTERFACES	20
• VENT SYSTEM FAILURE	• QUAD VENT VALVES USED FOR EACH PROPELLANT TANK (NO VENT VALVE FAILURE IN-OPEN OR CLOSED MODE WILL COMPROMISE ORBITER SAFETY)	86 (HALF TUG HALF ADAPTER)
• PREMATURE MAIN ENGINE OPERATION TUG/ORBITER COLLISION	• TANK OUTLET VALVES (INDEPENDENT ENGINE ISOLATION & SHUTDOWN CAPABILITY; NO PROPELLANTS IN LINES DURING ORBITER FLIGHT)	18
• PREMATURE ACPS OPERATION TUG/ORBITER COLLISION	• ACPS ISOLATION VALVES (INDEPENDENT ACPS ENGINE ISOLATION & SHUTDOWN CAPABILITY)	5
INADVERTENT DECOMPOSITION OF RCS PROPELLANT	• OVERBOARD VENT VALVES AT HYDRAZINE TANK OUTLET	4
• LOSS OF TUG STABILITY IN PAYLOAD BAY • INABILITY TO CLOSE PAYLOAD BAY DOORS	• 11 OF 12 LATCHES WILL SECURE TUG CRASH LANDING LOADS • EMERGENCY MANUAL RELEASE (EVA) AVAILABLE IF TUG HANGS UP IN PARTLY DEPLOYED POSITION	20
• PROPELLANT ABORT DUMP FAILURE	• PARALLEL DUMP VALVES FOR BOTH HYDROGEN & OXYGEN TANKS	30 22

The baseline abort technique chosen for all three programs is to dump both propellants in flight, always landing empty. This abort mode provides inflight propellant dump, with the dumping always occurring above 165,000 feet, thereby precluding any possible hydrogen ignition and resulting hazards. Authors agree on the lower concentration limit of LH_2 combustion in the atmosphere as requiring pressures of more than 0.1 psia for a hot surface ignition source. The pressure decay to 0.1 psia ambient is achieved on a nominal trajectory at 104 seconds flight time at an altitude of 110,000 feet. The hydrogen dump for the selected abort modes never take place at altitudes below 165,000 feet, which provides a significant margin of safety.

Helium pressurant supply is provided in the Tug support adapter which, in conjunction with the large dump lines (6 in. for LH_2, 5 in. for LO_2) allows for LO_2 dump within 260 seconds and LH_2 dump within 330 seconds while under Orbiter-powered flight.

For the Shuttle abort to orbit mode, propellant orientation in orbit must be provided by either the dumped propellant, OMS settling or Tug propellant acquisition devices.

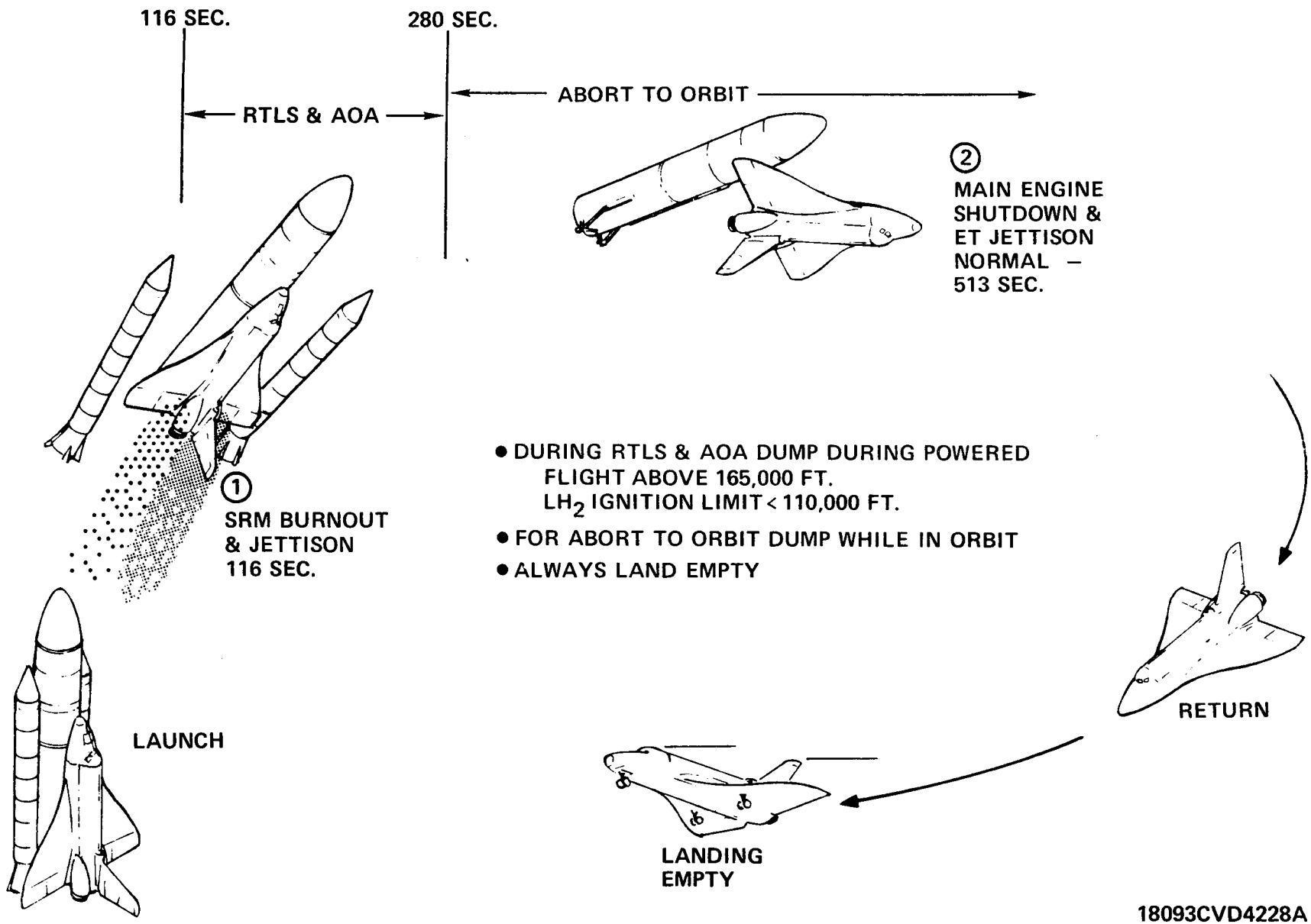
In no case is there a requirement or a condition where the Tug will return with fully loaded propellant tanks. The use of redundant dump valves and the techniques shown are designed to always provide the in-flight dump capability under all abort modes.

An investigation was also conducted of landing with fully loaded propellant tanks. Based on the results of that evaluation, the inflight dump mode was selected as the optimum abort technique based on both performance and operational considerations.

The abort system operation of the Tug is very dependent upon many Shuttle variables, and the final selected operational mode must be compatible with the final selected operating mode of the Shuttle. The details of the Tug abort must be finalized as the Shuttle operating modes become finalized. There are still some options open, particularly in achieving on-orbit propellant dump. However, each of the considered options are safe and feasible and the final selection depends only on the Shuttle requirements.

Ref. Volume VI, Section 6.6, Section 6.2.6

ABORT



- DURING RTLS & AOA DUMP DURING POWERED FLIGHT ABOVE 165,000 FT. LH_2 IGNITION LIMIT < 110,000 FT.
- FOR ABORT TO ORBIT DUMP WHILE IN ORBIT
- ALWAYS LAND EMPTY

18093CVD4228A

In accordance with redundancy/cost optimization analyses, redundancy was designed into the Program 1 Tug to allow attainment of a mission reliability of .97 for a baseline mission of 47 hours. The redundancy levels for each of the major subsystems, and the resulting reliability are summarized on the facing chart. As indicated on this chart, all subsystems are essentially dual redundant. The exceptions being the Data Management subsystem, which is triply redundant, and the APS subsystem, which is fail-operational/fail operational in several modes. The resulting reliability for the Program 1 Tug is .976 (without kick stage). For kick stage missions, the Tug only operates for 24 hours. The Tug reliability for this short mission is approximately .99. When the reliability of the kick stage is coupled with the Tug reliability, the overall kick stage mission reliability is approximately .97. (The kick stage package is a non-complex system similar to that used on the Pioneer G mission.)

Ref: Volume 5, paragraph 5.2.7
Volume 5, paragraph 5.7.1

REDUNDANCY IMPLEMENTATION

REDUNDANCY ADDED FOR MINIMUM COST & WEIGHT PENALTIES

SUBSYSTEM/COMPONENT	REDUNDANCY LEVEL (COST & WEIGHT OPTIMIZED)	Δ WEIGHT
DATA MANAGEMENT		
COMPUTER	TRIPLE	116
GUIDANCE & NAVIGATION		
INERTIAL MEASUREMENT UNIT (STRAPDOWN)	DUAL	32
FLIGHT CONTROL		
SERVO-INVERTER	DUAL	50
GUIDANCE UPDATE		
HORIZON SENSOR	TWO OUT OF FOUR	14
COMMUNICATIONS		
COMMAND DECODER	DUAL	4
ANTENNAS	DUAL	2
RECEIVER/TRANSMITTER	DUAL	8
MAIN ENGINE SUPPORT		
VENT VALVES	DUAL	86
FILL & DRAIN VALVES	DUAL	53
ATTITUDE CONTROL PROPULSION SYSTEM		
ENGINE MODULES	THREE OUT OF FOUR	19
ACPS SUPPORT	DUAL/QUAD	70
PREDICTED RELIABILITY (47 HR. BASELINE MISSION) = 0.9759		454 LB.

Tug flights for deployment, retrieval and round trip missions are identified for each year and for the total model in this chart. Tug flights are subdivided into deployment flight modes: deployment of 1, 2 or 3 payloads during a single flight of a reusable Tug, deployment of a single (planetary) payload with an expended velocity package and a reusable Tug flight, and deployment of a single, planetary payload by an expended Tug. Only a single retrieval flight mode is possible, no payloads up/one payload down — it is not used with program 1. The only type of round trip mission used with program 1 is a sortie type, where a single payload is carried to orbit by the Tug, remains attached to the Tug during its on-orbit operational period and returns with the Tug to the Shuttle Orbiter. Groundrules covering permissible flight modes are defined in NASA/MSFC PD-TUG-M (316-73).

Over the total mission model, 216 Tug flights are used to deploy payloads; 111 of these are single payload flights by a reusable Tug, 58 Tug flights deploy two payloads; and there are 30 flights where three payloads are deployed on a single reusable Tug flight. Seven flights are accomplished with velocity packages, and 10 expended Tug flights are required. There are no retrieval missions and four sortie missions are accomplished.

The entire mission model (338 deployment payloads, 4 sortie payloads) is accomplished using 220 Tug and Shuttle flights. Since no Tug-to-Tug or velocity package-to-Tug on-orbit assemblies are required,the number of Tug and Shuttle flights is identical. Flight mode assignments for NASA, DOD, ETR and WTR missions are in Section 4.2.1 (1) and payload combinations for individual Tug flights are in Section 4.2.3(1).

MISSION MODEL FLIGHT SUMMARY

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1

TUG FLIGHT MODE	NUMBER OF TUG FLIGHTS DURING YEAR											TOTAL
	80	81	82	83	84	85	86	87	88	89	90	
DEPLOYMENT												
1 PAYLOAD WITH TUG RETURN	3	9	9	12	12	11	9	11	10	13	12	111
2 PAYLOADS WITH TUG RETURN	0	1	5	10	6	5	5	7	6	7	6	58
3 PAYLOADS WITH TUG RETURN	0	4	1	4	2	4	3	4	3	3	2	30
TUG RETURN + VEL. PACKAGE*	0	0	2	0	2	0	1	2	0	0	0	7
EXPENDED TUG	0	0	0	0	2	0	3	1	0	3	1	10
TOTAL	3	14	17	26	24	20	21	25	19	26	21	216
RETRIEVAL (0 PAYLOAD UP – 1 PAYLOAD DN)	0	0	0	0	0	0	0	0	0	0	0	0
ROUND TRIP												
1 PAYLOAD UP/1 PAYLOAD DN	0	0	0	1	0	1	0	1	0	1	0	4
2 PAYLOADS UP/1 PAYLOAD DN	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	0	0	1	0	1	0	1	0	1	0	4
TOTAL TUG/SHUTTLE FLIGHTS	3	14	17	27	24	21	21	26	19	27	21	220

*2,560-LB. VELOCITY PACKAGE (EXPENDED)

18093CVD4520

The buildup in number of payloads deployed and retrieved, and the required number of Tug flights over the mission model years from 1980 through 90 are shown in this chart. The mission model was defined in NASA/MSFC memo PD-TUG-M (316-73) and the Tug flight buildup in NASA/MSFC memo PD-TUG-M/P. The mission model is limited to deployment missions of NASA current-design payloads and DOD payloads, and the retrieval of sortie type payloads.

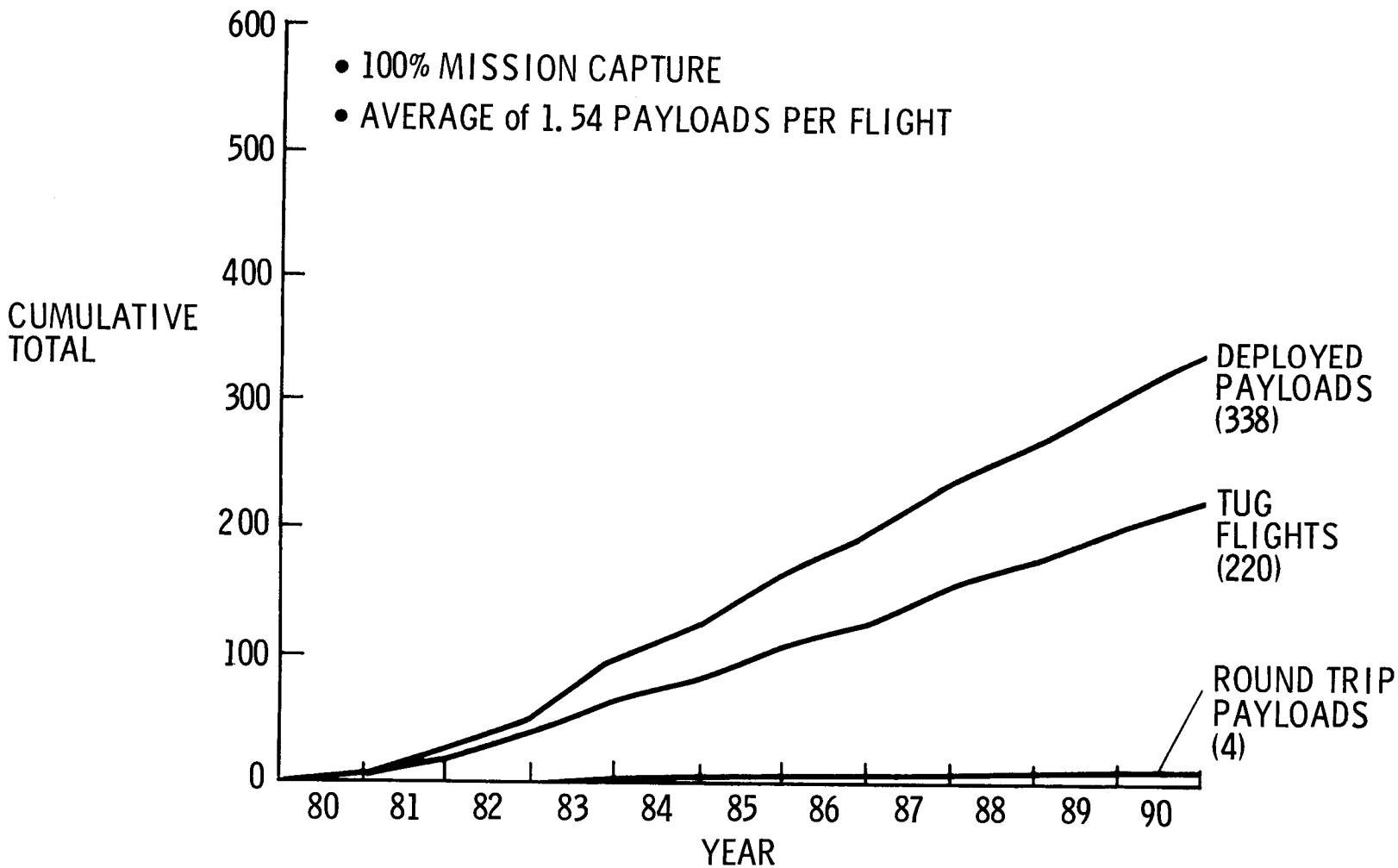
During the first year, Tug missions are limited to three, single-payload flights. After 1980, multiple payloads are deployed during a single Tug flight. A total of 342 payloads are deployed and retrieved (330 deployed, 4 sortie-payloads retrieved) over the mission model years 1980-90. Since up to three payload may be deployed on a single Tug flight, only 220 Tug flights are required to accomplish the entire mission model.

The average number of payloads deployed/retrieved per Tug flight is 1.54. Mission capture is 100%. Details of the mission capture analysis are in Section 4.2.1(1) (Tug flight details) and 4.2.3(1) (payload combinations on individual flights).

MISSION MODEL & TUG FLIGHTS

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1



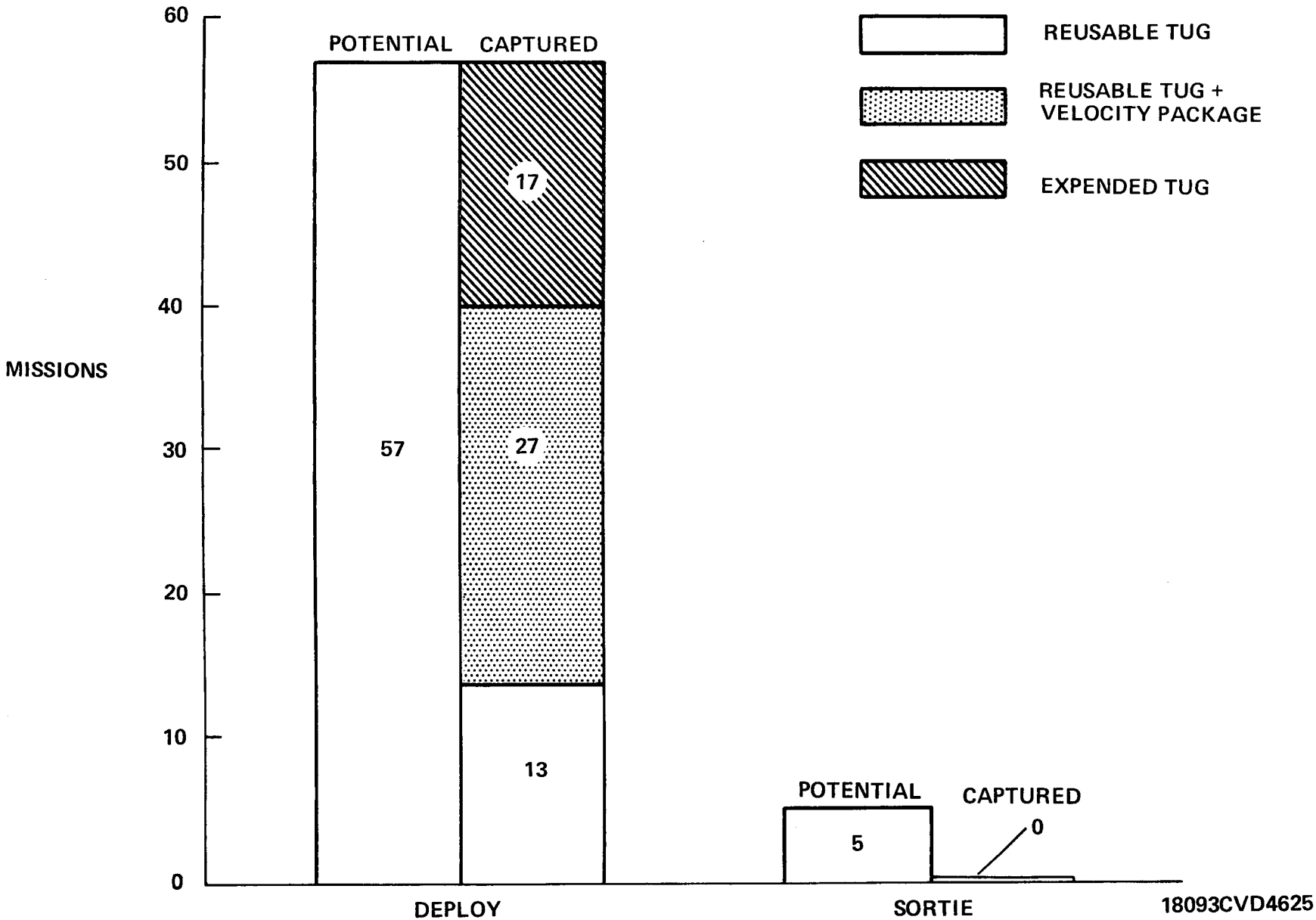
18093CVD4523

A total of 62 additional potential missions over the 1980-90 mission model period have been identified in NASA/MSFC memo PD-TUG-M (318-74) for program 1. Fifty-seven of these missions are deployment, none are retrieval; and 5 are sortie missions. All of the potential deployment missions can be captured; 13 with a reusable Tug 27 with an expended velocity package and a reusable Tug, and 15 planetary missions with an expended Tug. None of the potential sortie missions can be capture. A total of 57 of the 62 potential missions can be capture. Details of the additional payload capture analysis are in Section 4.2.2(1).

ADDITIONAL PAYLOAD CAPTURE

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1



The Air Force will be the operating agency for the DOD and will be the launch agency at VAFB. NASA will be the operating agency for all users other than DOD and will be the launch agency at KSC. NASA and DOD will each use both operational launch sites. Vehicle operations control will be assumed by the operating agency at start of flight, regardless of the launch site. The NASA flight operations controller is located at the Operations Management Center (OMC) in JSC Houston and utilizes the SDTN while the DOD flight operations controller is located at the OMC in the STC Sunnyvale and utilizes the SCF network.

From liftoff until the Tug is enabled outside the Orbiter the mission specialist in the Shuttle is in control with the flight operations controller at OMC available for support if communications permit. The Tug flight to the mission orbit and back to the Shuttle rendezvous orbit is monitored by the flight controller at OMC with the launch control facility available for support. The control of the Tug is then transferred back to the mission specialist in the Orbiter for docking activity, system safing and statusing, and return of the Tug to the launch site.

This assignment of responsibility is based on Orbiter safety requirements and the Level I autonomy of the Tug. The mission specialists primary function is to assure the safety of the Orbiter and crew during Shuttle ascent and descent. In addition the mission specialist performs a final subsystem status check prior to Tug enable/activation. At this point the Tug becomes autonomous and performs the mission. Level I autonomy results in the Tug flight controller at OMC being a monitor of Tug/mission status information with the communications link primarily for information transfer down. There is Tug onboard contingency planning for reasonable payload alternative action so the ground uplink use would be limited to initiation of a pre-programmed alternate mission or mission termination. Maintenance data is recorded onboard by a mass storage unit for playback following landing in support of ground turnaround activity.

Flight operations nonrecurring costs are for development of the software onboard the Tug, on the Shuttle to support the Tug and for the flight control console at OMC. Recurring flight operations cost include updating this software, mission analysis supporting this update, post flight evaluation, and the mission specialists and flight controllers.

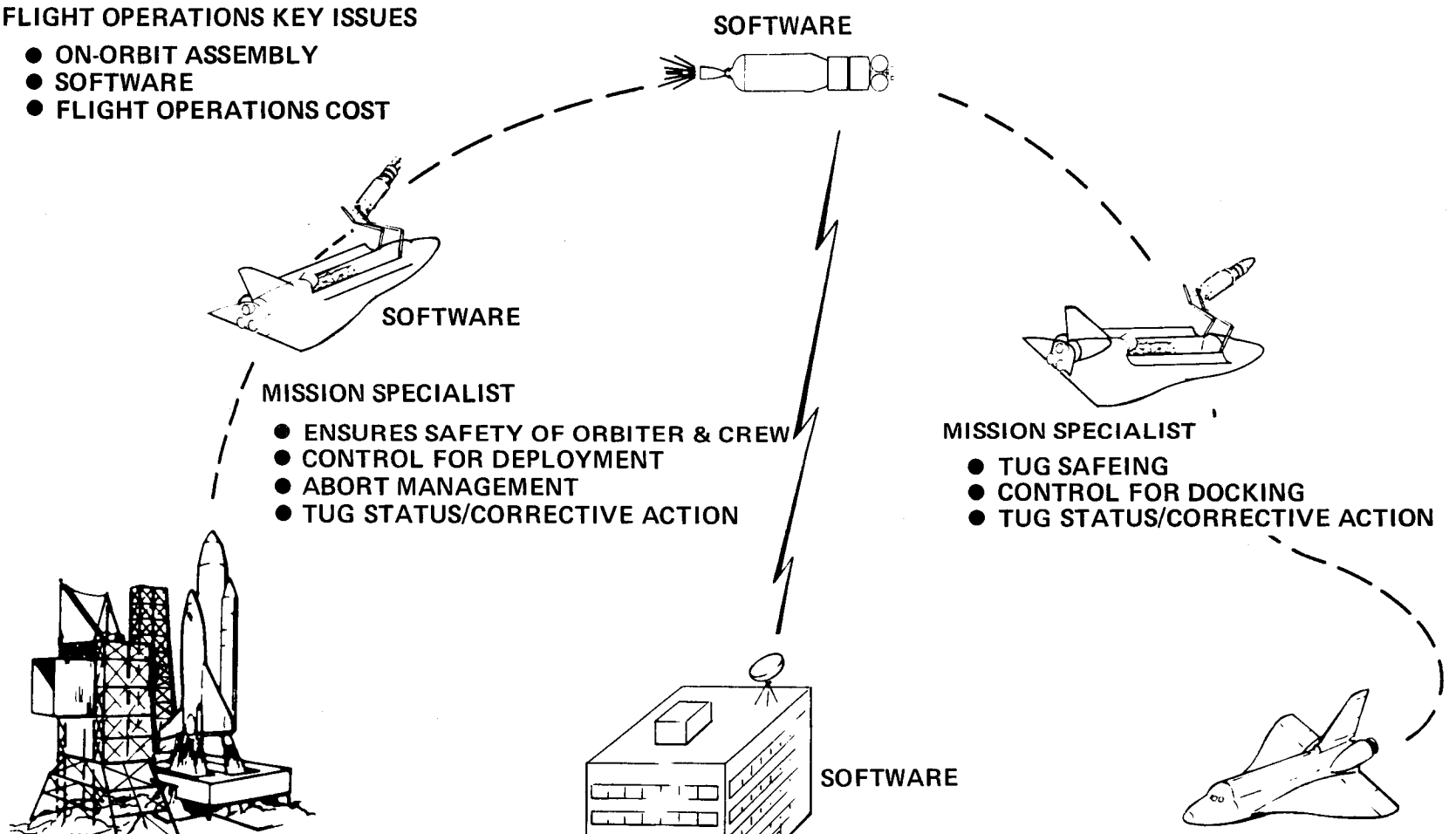
Key flight operations issues are software requirements, flight operations costs and Tug-to-Tug on-orbit assembly versus expending Tugs.

For details see Volume 6, Operations.

FLIGHT OPERATIONS

FLIGHT OPERATIONS KEY ISSUES

- ON-ORBIT ASSEMBLY
- SOFTWARE
- FLIGHT OPERATIONS COST



18093CVD4611

The Tug Monitor and Control System (TMACS) provides the Orbiter crew the ability to ensure the safety of the Shuttle and crew, verify Tug status for mission readiness, and control and monitor operations, including Tug mission preparation, deployment, separation, docking, safeing and abort.

The baseline TMACS design includes all hardware functions necessary to perform these functions. The actual mechanization of these requirements may involve integrating the capabilities of the Orbiter, Mission Specialist station, Payload Specialist station, and special-purpose Tug supplied hardware and software.

To ensure the safety of the crew and Shuttle, the TMACS continuously monitors and displays Tug critical safety functions and provides automatic corrective action sequences and abort sequences when necessary. The TMACS continuously monitors and displays the status of all Tug subsystems to ensure deployment of an operational Tug. The TMACS also provides for issuing commands from the Shuttle to Tug.

There are any number of ways to implement the TMACS requirements between the following philosophies:

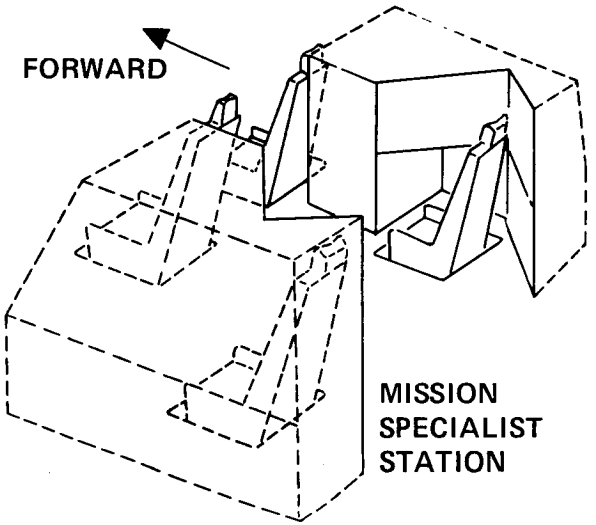
1. TMACS requirement completely satisfied by use of Orbiter payload interface capabilities.
2. TMACS requirements completely satisfied by special-purpose equipment located in the space for payload-supplied equipment in the Payload Specialist Station.

To maximize the use of Orbiter payload support capability and to lower TMACS costs, the support capabilities, and integration of the TMACS function into the Mission Specialist station and Payload Specialist station were investigated. These results are presented in Volume 6.

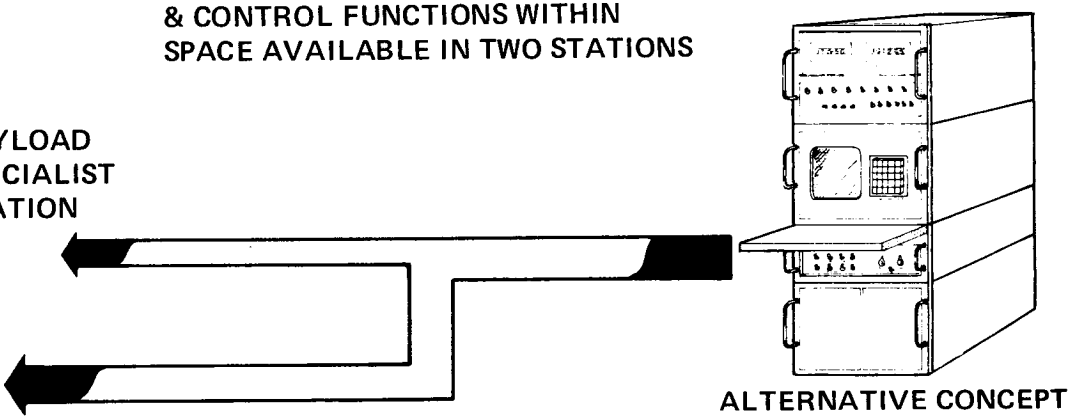
For details see Volume 6, Operations.

TUG MONITOR & CONTROL SYSTEM

USED WHILE TUG IS IN OR NEAR ORBITER

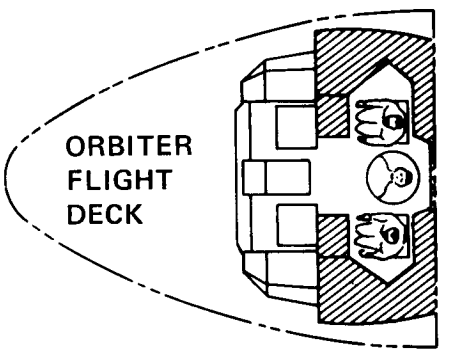


INTEGRATE TUG MONITOR & CONTROL FUNCTIONS WITHIN SPACE AVAILABLE IN TWO STATIONS



ALTERNATIVE CONCEPT STAND-ALONE TMACS

- ENSURES SAFETY OF CREW & SHUTTLE
- VERIFIES TUG MISSION READINESS
- PROVIDES CONTROL FOR:
  - MISSION PREPARATION
  - DEPLOYMENT
  - SEPARATION
  - ABORT
  - DOCKING
  - SAFING
- MAJOR EQUIPMENT
  - PROCESSOR (REAL TIME)
  - MASS STORAGE (SOFTWARE & DATA)
  - CRT DISPLAY & KEYBOARD
  - TMACS/SUPPORT ADAPTER COMMUNICATION
  - CAUTION & WARNING DISPLAYS



18093CVD4319A

One of the key elements associated with flight operations in previous space programs has been the ground support of flight operation. Ground support of flight operations involves the tracking network and the flight control personnel. The functions that could be performed by the ground for the Tug are tracking, status evaluation, command, maintenance data storage and payload checkout. These require communication with the Tug and have an active tracking network and a relatively large flight control center crew.

The proposed Tug configuration has level 1 autonomy which means that it does not have to rely on man made inputs after separation from the Orbiter. This means that the Tug does not require the use of the tracking, telemetry and control network to accomplish a mission. Status will be obtained on a low priority network use basis. Command uplink override capability is available if needed.

Maintenance information for use in ground turnaround will be stored onboard for use when the Tug returns to the ground.

Reference: Section 6.4

GROUND SUPPORT DURING TUG FLIGHT

POTENTIAL GROUND SUPPORT FUNCTIONS

- TRACKING
- COMMUNICATIONS
  - COMMANDS
  - STATUS INFO.
  - MAINTENANCE INFO.
  - PAYLOAD DATA
- DECISIONS

TUG CHARACTERISTICS

- TUG HAS LEVEL I AUTONOMY
  OPERATES INDEPENDENTLY OF
  MANMADE INPUTS
- MAINTENANCE DATA STORED ONBOARD
- PAYLOAD CHECKOUT NOT REQUIRED IN MODEL

CONCLUSIONS

- NETWORK NOT REQUIRED TO ACCOMPLISH MISSION
- NETWORK WILL BE USED ON LOW-PRIORITY BASIS FOR STATUS
- COMMAND UPLINK OVERRIDE CAPABILITY EXISTS

18093CVD4619

The high operational complexity of Tug-to-Tug on-orbit assembly suggested the need to evaluate expending the Tug to get required performance with low operational complexity. Program costs associated with high energy missions using Tug on-orbit assembly and expended Tug flight modes were developed. An interim Tug and a full capability Tug were chosen to represent options covering the range of Tug capabilities. Costs were evaluated for the Concept Selection Meeting mission capture data. Twenty-one on-orbit assemblies or expended Tugs were required with the interim Tug and 15 for the full capability Tug. Cost elements included in the analysis are:

Shuttle Flights - The number of Shuttle flights are identified and costed at the rate of $10.5M per flight. This is the most significant cost penalty for the on-orbit assembly flight mode.

Tug Flights - Costs are divided into ground and flight operations and support, and refurbishment. Tug life is amortized over an expected life of 40 flights. Expended Tugs are charged as though they were expended midway through their expected life. In the case of the full capability Tug, the rendezvous & docking electronics are removed from the full capability expended Tug reducing the cost by $1.6M. Reductions in production costs resulting from learning effects are included. The cost for expending Tugs is the most significant cost penalty for the Tug expended flight mode.

Tug-Tug Adapter - On-orbit assembly has DDT&E and investment costs for Tug-Tug adapter.

Velocity Packages - Are required by the Interim Tug for the on-orbit assembly flight mode; both investment and operations costs are included.

Tug Failures - Shuttle and Tug costs for flying missions aborted by Tug failures (at the rate of 3 failures per 100 flights) are charged to both flight techniques. Tug losses of 1 per 100 flights are charged as lost with 50% of their life remaining.

Program costs are $173.7M less for the Tug expended flight mode with the Interim Tug and the saving per mission is $8.3M. The full capability program costs are $123M for the Tug expended flight mode and the saving per mission is $8.2M.

Since both program cost and flight operations complexity favor Tug expended missions over on-orbit assembly missions, it is recommended that high energy missions be accomplished with the Tug expended flight mode.

For details see Volume 6, Operations.

FLIGHT OPERATIONS TRADE STUDY
Expend Tug Versus Tug to Tug on Orbit Assembly

OPERATION COMPLEXITY

FLIGHT MODE	CRITICAL MISSION EVENTS	
TUG TO TUG ON ORBIT ASSEMBLY	10	DEPLOYMENT/SEPARATION
TUG WITH VELOCITY PACKAGE	6	RENDEZVOUS
TUG	5	DOCKING
EXPEND TUG	3	PLACEMENT

COST ANALYSIS

COST ELEMENTS	ON ORBIT ASSEMBLY	EXPEND TUG
TUG FLIGHTS	X	X
TUG-TUG ADAPTER	X	
VELOCITY PACKAGE	X	
TUG FAILURES	X	X
AMORTIZATION	X	X
SHUTTLE FLIGHT	X	X

PROGRAM CAPABILITY	PAYLOAD TO SYNC. EQ. (LB.)	NUMBER OF FLIGHTS	COSTS ($M) ON-ORBIT ASSEMBLY	COSTS ($M) EXPEND TUG
INTERIM	4,915	21	537.4	363.7
FULL	9,759	15	378.3	255.3

(TRADE STUDY CONDUCTED WITH SYSTEMS FROM CONCEPT SELECTION MEETING)

CONCLUSIONS:

EXPEND TUGS
- ELIMINATES MOST COMPLEX MISSION MODE
- LOWERS PROGRAM COST: $125 M TO $175 M

18093CVD4508

Flight operations complexity consists of two major elements. These are the ground support during flight and the number of critical flight events required to accomplish a mission.

Since Level 1 autonomy is being used there is no required dependency on the ground and the ground support during flight consists primarily of status monitoring if desired.

Each mission mode has a certain number of critical events as indicated. The expendable mission mode is the least complex since it does not have to return and rendezvous with the Shuttle. Considering a reusable Tug mission, the number of critical events can be kept down by being able to accomplish the mission without velocity packages or drop tanks which increase the number of critical events and hence flight operations complexity. The high performance capability of cryogenic Tugs permits this to be done for most of the mission.

Reference: Section 6.7

FLIGHT OPERATIONS COMPLEXITY

FLIGHT OPERATIONS COMPLEXITY

- GROUND SUPPORT DURING FLIGHT

LEVEL 1 AUTONOMY ELIMINATES DEPENDENCY ON GROUND

- CRITICAL FLIGHT EVENTS

	CRITICAL EVENTS PER MISSION
• REUSABLE TUG MISSIONS	5
• EXPENDABLE TUG MISSIONS	3
• VELOCITY PACKAGES	1
• ADDITIONAL P/L DELIVERED OR RETRIEVED	2

HIGH PERFORMANCE CAPABILITY OF CRYOGENIC TUGS PERMITS ACCOMPLISHING MOST OF MISSION MODEL IN RELATIVELY SIMPLE SINGLE REUSABLE TUG MODE

The Tug onboard software developed during DDT&E consists of 9 modules to satisfy required mission functions. These modules provide the Tug with the capability to perform synchronous equatorial missions for DOD and NASA. This basic software package contains 43,900 words.

In order to provide the Tug with the capability to handle missions other than synchronous equatorial, new mission packages must be developed during the operations phase. Each mission package consists of 6200 words of guidance and sequencing module changes. The number of missions other than synchronous equatorial is obtained from the Program 1 mission model. This means that DOD must develop 7 new mission packages and NASA must develop 15 new mission packages. Although NASA and DOD have some similar mission orbits other than synchronous equatorial it was assumed that separate mission packages will be developed for each user.

Each mission has one or more flights. For example Mission 14 has seven flights from 1984 to 1990. Each of these flights will require the development of a flight operations package of 450 words. These flight packages reflect payload peculiar changes and flight to flight variations. This is based on the assumption that payloads will undergo some changes in characteristics over the life of the program rather than stay constant as shown by the mission model data. The flight packages contain changes in the following modules; altitude control, guidance, navigation, sequencing, and thrust vector control. The number of flight packages required is based on the Program 1 mission model and mission capture data. NASA will require 116 flight packages. DOD will require 104 flight packages.

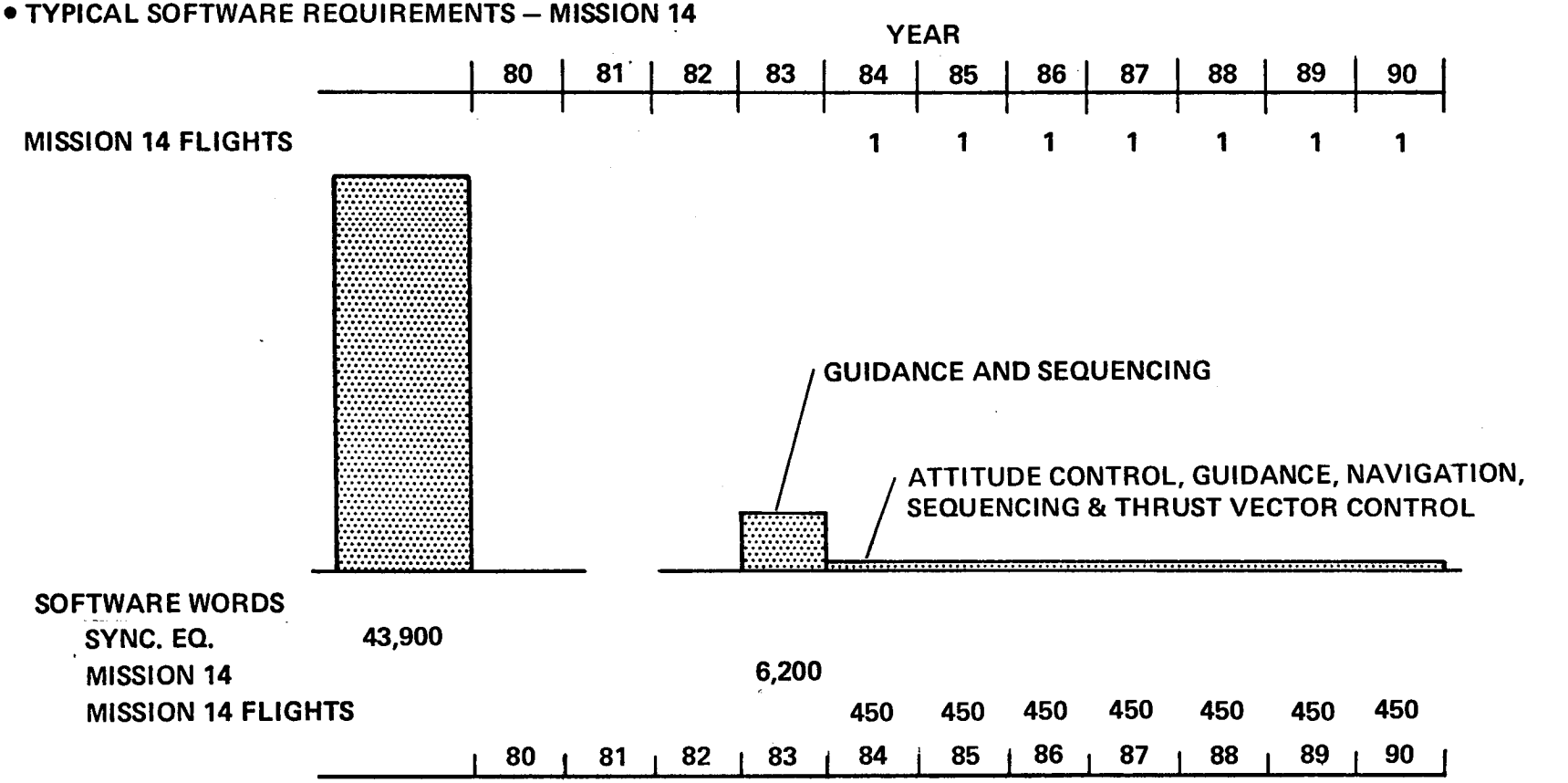
This mission package and flight package approach provides the required mission flexibility without penalty to DDT&E. The individual payload user with repeated flights will have a reduction in cost per flight. DOD in total will have lower software cost per flight than NASA due to a higher number of flights per mission package.

For details see Volume 6, Operations.

TUG SOFTWARE REQUIREMENTS

- SOFTWARE DEVELOPMENT
  - SOFTWARE DEVELOPED IN DDT&E FOR ALL NASA & DOD SYNC. EQ. MISSIONS
  - MAJOR SOFTWARE CHANGES MADE FOR EACH MISSION OTHER THAN SYNC. EQ.
  - MINOR SOFTWARE CHANGES MADE FOR ALL FLIGHTS
- TYPICAL SOFTWARE REQUIREMENTS – MISSION 14

	NASA	DOD
MISSIONS OTHER THAN SYNC. EQ.	15	7
TOTAL FLIGHTS	116	104



18093CVD4497

The total nonrecurring cost for flight operations is contained in Flight Support Software. Three major tasks are performed; the onboard Tug software is developed, the onboard Shuttle software to support Tug is developed and the OMC flight controller console software is developed. Software development includes analysis of requirements, coding, verification and documentation. This software is for synchronous equatorial mission use by both NASA and DOD. It is placed under the WBS element of the agency developing the Tug.

Recurring flight operations consist of mission planning, flight control, flight evaluation, and flight support software for NASA and DOD. These costs reflect the number of operational years, launch rates at each site and number of missions for each user. From this data manpower and software update requirements are defined and costed.

NASA is shown as the Tug developer and hence is assigned the $18.5Million development cost. The equivalent manyears shown are based on $40,000 per manyear. The operations costs are shown for NASA and DOD. DOD cost per flight is lower due to a higher number of flights for each mission which requires reduced software updating. The equivalent men per year is provided to give an indication of the approximate support level required for flight operations. NASA is higher because of the previously mentioned higher software update requirements coupled with a higher launch rate.

For details see Volume 6, Operations.

FLIGHT OPERATIONS COST SUMMARY

PROGRAM 1

	DDT&E		OPERATIONS		
	COST ($M)	EQUIVALENT MAN-YR.	COST ($M)	EQUIVALENT MAN-YR.	
NASA					
MISSION PLANNING			4.8	120	$382,000/FLT OR ~100 MEN/YR.
FLIGHT CONTROL			17.7	441	
FLIGHT EVALUATION			0.9	23	
FLIGHT SUPPORT SOFTWARE	18.5	463	20.9	523	
TOTAL	18.5	463	44.3	1,105	
DOD					
MISSION PLANNING			4.4	111	$294,000/FLT. OR ~70 MEN/YR.
FLIGHT CONTROL			12.4	309	
FLIGHT EVALUATION			0.8	21	
FLIGHT SUPPORT SOFTWARE			13.0	325	
TOTAL			30.6	766	

18093CVD4500

Only the maintenance and post-maintenance checkout tasks (Blocks 1.1 and 1.2) are sensitive to Tug configuration. Spacecraft-Tug mating and demating operations are primarily handling tasks which are not sensitive to the hardware configuration differences. Tug systems integrated checkout, from a time and manpower viewpoint do not change appreciably between configurations. The primary difference here is in ground and airborne software requirements needed to accomplish the largely automated tasks. Four major function blocks cover joint Tug-Orbiter tasks and these are more constrained by Orbiter timelines than by Tug configuration changes.

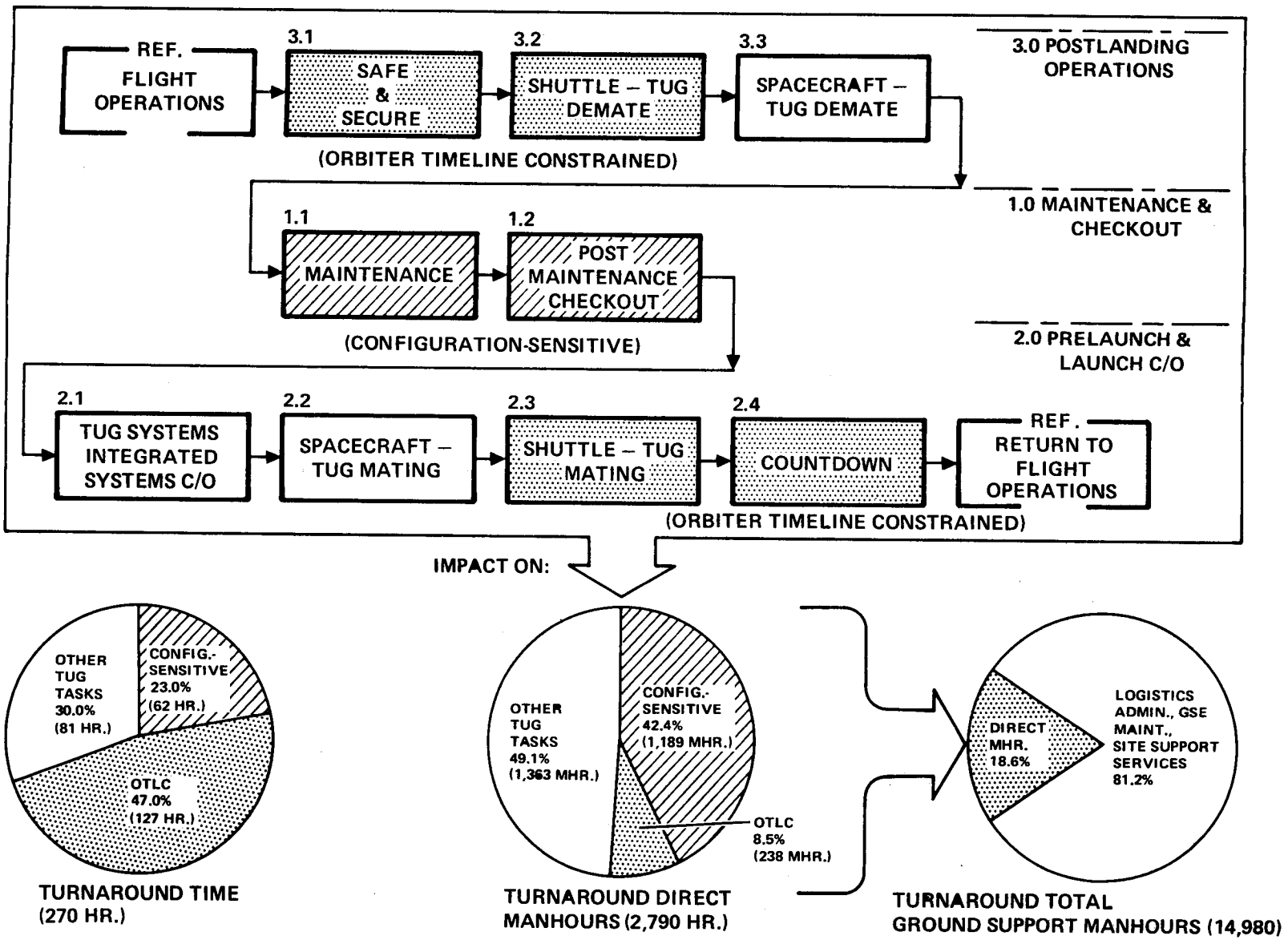
Looking at the pie charts we see that the configuration sensitive tasks account for only 23% of the total basic turnaround time, but do account for 42% of the total direct turnaround manhours expended on a turnaround cycle. However, the other Tug tasks which are not configuration sensitive combined with those that are Orbiter timeline constrained comprise 77% of the turnaround time and 58% of the manhours. Even more important, when you look at the total number of manhours (14,980) available during an average turnaround cycle considering all logistics, administrative, GSE maintenance and site support services, the total direct manhours expended on Tug turnaround come to only 19% of that total. Thus, there is an adequate manpower pool available for such things as unscheduled contingency maintenance tasks and, during the vehicle changeover in phased development options, vehicle modification and update tasks. Within limits, this available manpower can also accommodate uneven launch centers when required by the traffic model and launch windows.

(Reference: Vol. VI, 6.11.3)

GROUND TURNAROUND OPERATIONS

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1



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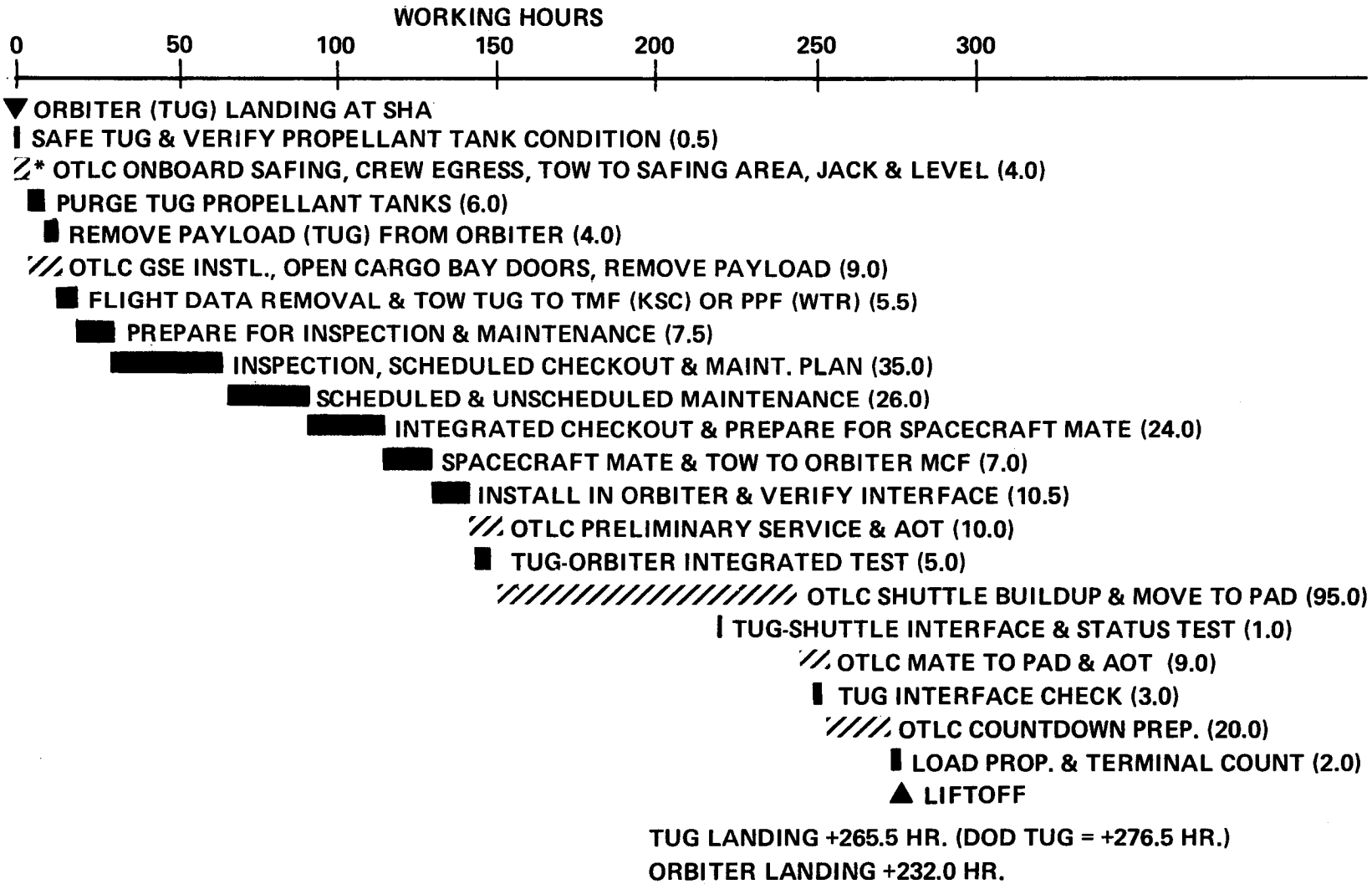
The summary timeline shown here is for a NASA Tug at either KSC or WTR. The time scale is in working hours and assumes a two-shift, five-day work week. Where Tug tasks are constrained by the Orbiter timeline, there is a broken time bar. This can be seen immediately following landing where Orbiter safing, crew egress and tow to safe area tasks are indicated. The Tug is removed from the Orbiter at the Safing Area and is clear at Landing + 14 hours. It is then towed to the Tug Maintenance Facility (TMF) (PPF at WTR) for postflight inspections followed by scheduled and unscheduled maintenance. After scheduled maintenance and a post-maintenance checkout, the Tug may be placed in short term storage or proceed directly to mission peculiar modifications and integrated systems tests as required by the traffic model. Following integrated systems test, a spacecraft will be brought to the TMF for mating. Then the payload (mated Tug and spacecraft) will be moved to the Orbiter Maintenance and Checkout Facility (MCF) for loading into the Orbiter. For the remainder of the turnaround cycle, 140 working hours, the payload is constrained by Orbiter timelines as shown by broken time bars.

Liftoff will be at Tug landing + 265.5 working hours for a NASA Tug. A DOD Tug will take 276.5 working hours, the additional 11.0 hours being required for Commsec LRU removal, installation and checkout. The corresponding Orbiter turnaround time is landing + 232.0 working hours.

(Reference: Volume VI, 6.11.3.5(1))

GROUND TURNAROUND TIMELINE SUMMARY
NASA Payloads – WTR & KSC

PROGRAM 1



TUG LANDING +265.5 HR. (DOD TUG = +276.5 HR.)
ORBITER LANDING +232.0 HR.

* OTLC = ORBITER TIMELINE CONSTRAINT

18093CVD4478

Basic ground turnaround crew sizes for both KSC and WTR are summarized here. This crew size represents the manpower skills and quantities by shift at each launch site to accomplish turnaround on a single Tug. At KSC launch rates require a standard two-shift operation to sustain operations. The very low annual launch rates expected at WTR permit going to a slightly modified single shift operation. At WTR, avionics, propulsion and structures technicians are augmented to support joint Orbiter-Tug two-shift operations during postlanding and prelaunch (payload/Orbiter mating to liftoff) operations. Engineering and administrative support personnel are somewhat reduced in recognition of the smaller number of direct support personnel and active Tugs being serviced. Level II shop support personnel are eliminated at WTR to indicate manning levels attainable when Orbiter and spacecraft Level II shops are shared.

(Reference: Volume VI, 6.11.3.6(1))

GROUND TURNAROUND
Basic Crew Sizes

PROGRAM 1

MANPOWER SKILLS	KSC		WTR 1 SHIFT
	SHIFT 1	SHIFT 2	
DIRECT SUPPORT			
AVIONICS	8	6	10
PROPULSION – FLUIDS	8	6	10
STRUCTURES – HANDLING	6	4	8
QUALITY CONTROL	2	2	2
SAFETY	1	1	1
ENGINEER	3	2	3
OTHER	4	2	4
SUBTOTAL	32	23	38
ENGINEERING & ADMIN. SUPPORT			
LOGISTICS & ADMINISTRATION	13	5	10
DESIGN – SYSTEM ENGINEERING	6	2	5
SCHEDULING	2	1	2
PROCEDURES – TEST REQT.	4	–	3
DATA ANALYSIS	4	–	3
PROGRAMMING	2	–	2
SUBTOTAL	31	8	25
LEVEL II SHOPS			
METAL	2	–	
PAINT	2	–	
PLASTICS – MLI	2	1	
PNEUMATICS	1	1	
AVIONICS	1	1	
STANDARDS – INSPECTIONS	1	1	
SUBTOTAL	9	4	
TOTAL	72	35 (107)	63

Both crew size and minimum active fleet size vary as a function of annual launch rates as shown here. A basic crew size was developed to accomplish turnaround operations on a single vehicle. As launch rates increase, particularly at KSC, two, and sometimes three Tugs at a time will be undergoing different phases of the ground turnaround cycle concurrently. To accommodate these concurrent operations, the ground turnaround crew is augmented with additional direct support, engineering and administrative personnel as shown in this chart. Launch rates at WTR never increase to the point where augmentation is required.

Minimum active fleet size is also a direct function of the launch rates. In an ongoing mature operating system, a single Tug can make a complete launch-flight-ground turnaround-launch cycle in approximately 24 calendar days, or slightly over 12 launches per year maximum. Thus, the minimum active fleet size for each launch site is established as shown. At KSC, there are also a total of 10 expendable missions as shown which make a total requirement of 13 vehicles. In addition, attrition losses at one percent of the total missions must be accounted for. This adds three additional vehicles resulting in a total fleet buy of 16 Tugs for this program.

(Reference: Volume VI, 6.11.8(1))

CREW SIZE & MINIMUM ACTIVE FLEET SIZE Vs. ANNUAL LAUNCH RATE

		CALENDAR YEAR											TOTAL
		80	81	82	83	84	85	86	87	88	89	90	
TUG FLIGHTS	KSC*	3	14	17	20	22	16	18	22	17	20	19	188
	WTR				7	2	5	3	4	2	7	2	32
	TOTAL	3	14	17	27	24	21	21	26	19	27	21	220
	*EXPENDABLE FLIGHTS					(2)		(3)	(1)		(3)	(1)	(10)
GROUND TURN-AROUND CREW	KSC	107	107	107	113	113	107	113	113	107	107	113	
	WTR				63	63	63	63	63	63	63	63	
	TOTAL	107	107	107	176	176	170	176	176	170	176	176	
ACTIVE FLEET REQMT.	MINIMUM ACTIVE FLEET												
	KSC	1	1	2	2	2	2	2	2	2	2	2	2
	KSC EXP.					2		3	1		3	1	10
	WTR				1	1	1	1	1	1	1	1	1
	SUBTOTAL	1	1	2	3	5	3	6	4	3	6	4	13
	ATTRITION												3
	TOTAL BUY												16

Once total fleet buy requirements have been established at 16 Tugs as discussed in the previous chart, fleet delivery requirements, disposition and utilization can be examined as shown here. Tugs are delivered to KSC unless noted with WTR in the Tug Number column. Need dates are initially based on site activation and/or test flight requirements for the first two vehicles at KSC and the first vehicle at WTR. After that, need dates are derived from delivery capability on a reasonable production schedule with Tug completions set at six month centers.

As vehicles are delivered to the launch sites they are phased into the active fleet to obtain relatively even usage on all vehicles as indicated by the total flights per Tug shown in the last column. Expendable Tugs thus accumulate a number of flights before being expended in the years indicated. A comparison of the actual active fleet values shown in the bottom row for each year with minimum active fleet requirements on the previous chart shows that there are adequate vehicles available to accommodate cumulative attrition losses in whichever year they randomly occur. For the utilization plan shown here for Program 1, Tug 6 is delivered to WTR, flies nine missions there and is then transferred to KSC for an expendable mission in 1987. Tug 7 is available as a backup Tug at WTR in 1990, but both scheduled missions will be flown by Tug 16. Tugs 6 and 7 are delivered to WTR in 1982, but do not make any flights until the following year.

(Reference: Volume VI, 6.11.8(1))

FLEET REQUIREMENT & UTILIZATION

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1

VEHICLE SCHEDULING				CALENDAR YEAR											TOTAL FLIGHTS
TUG NO.	NEED DATE	DELIVERY DATE	DISPOSITION	80	81	82	83	84	85	86	87	88	89	90	
1 (F-1)	SEP. 78	SEP. 78	EXPENDED	1	3	4	3	2*							13
2 (F-2)	APR. 79	DEC. 78	EXPENDED	1	3	4	3	2*							13
3	JUN. 80	JUN. 80	EXPENDED	1	3	3	3	3	2	1*					16
4	DEC. 80	DEC. 80	EXPENDED		3	3	3	3	2	1*					15
5	JUN. 81	JUN. 81	EXPENDED		2	3	3	3	2	1*					14
6 WTR	JAN. 82	DEC. 81	EXPENDED				4	1	2	2	1*KSC				10
7 WTR	JUN. 82	JUN. 82	INVENTORY				3	1	3	1	2	1	3		14
8	JAN. 83	DEC. 82	EXPENDED				3	3	2	2	3	2	1*		16
9	JUN. 83	JUN. 83	EXPENDED				2	3	2	2	3	2	1*		15
10	JAN. 84	DEC. 83	EXPENDED					2	2	2	3	2	3*		14
11	JUN. 84	JUN. 84	EXPENDED					1	2	2	3	2	3	1*	14
12	JAN. 85	DEC. 84	INVENTORY						1	2	3	2	3	4	15
13	JUL. 85	JUN. 85	INVENTORY						1	2	3	2	3	4	15
14	JAN. 86	DEC. 85	INVENTORY							2	3	2	3	4	14
15	JUL. 86	JUN. 86	INVENTORY							1	1	3	3	6	14
16 WTR	JAN. 87	DEC. 86	INVENTORY								1	1	4	2	8
TOTAL FLIGHTS				3	14	17	27	24	21	21	26	19	27	21	220
ACTIVE, FLEET				3	5	5(2W)	9	11(2E)	11	13(3E)	11(1E)	10	10(2E)	7(IE)	

* YEAR EXPENDED
→ TRANSFER LAUNCH SITE
S STORAGE

10893CVD4475

The objective of the Refurbishment & Maintenance (R&M) concept is shown. This R&M operation is highly cost effective when considering the cost risk of each flight involves the cost of the Tug, the cost of the P/L, and Shuttle and Tug operations costs. By restoring each returning Tug to the required levels of reliability and safety, these costs risks are minimized. The cost to refurbish the Tug is small compared to the cost risks of flight.

The approach to achieving high confidence of refly mission reliability and safety is in the use of CMM_{PF} (Condition Monitored Maintenance with pre-flight test). The CMM_{PF} philosophy is a direct outgrowth of the CMM concept developed and used by commercial airlines. It requires considerable on-board performance monitoring capability. This capability results in reliable, fast and low cost turnaround.

Condition assessment has been identified as the ciritcal refurbishment operation. Once the condition of a returning Tug has been accurately determined and deficiencies identified, the tasks required to restore the vehicle are known, and work can proceed with confidence.

A major contributor to high confidence and reduced manhours for the condition assessment operation is the operational flight instrumentation (OFI). This is based on the fact that the "best test" of any system, subsystem, or component is the last flight, provided that sufficient data is returned for maintenance analysis.

Computerized data processing and manual analysis of operational flight instrumentation (OFI) will be used as the primary method to assess the condition of a Tug returning from a mission. External and internal visual inspections, leak checks, and tests as shown will be made as part of the CA process. This condition assessment process will lead to either, verification that subsystems are operationally intact or a requirements exists to remove and replace a component or perform some servicing. Components with known life requirements will be replaced on a scheduled basis. Unscheduled maintenance will be performed on components determined to be in need of replacement by the CA process.

The unscheduled maintenance process consists of fault confirmation and isolation, corrective maintenance which consists of calibration and adjustment or remove and replacement of a component which then receives repair and overhaul and is placed in stock as a spare.

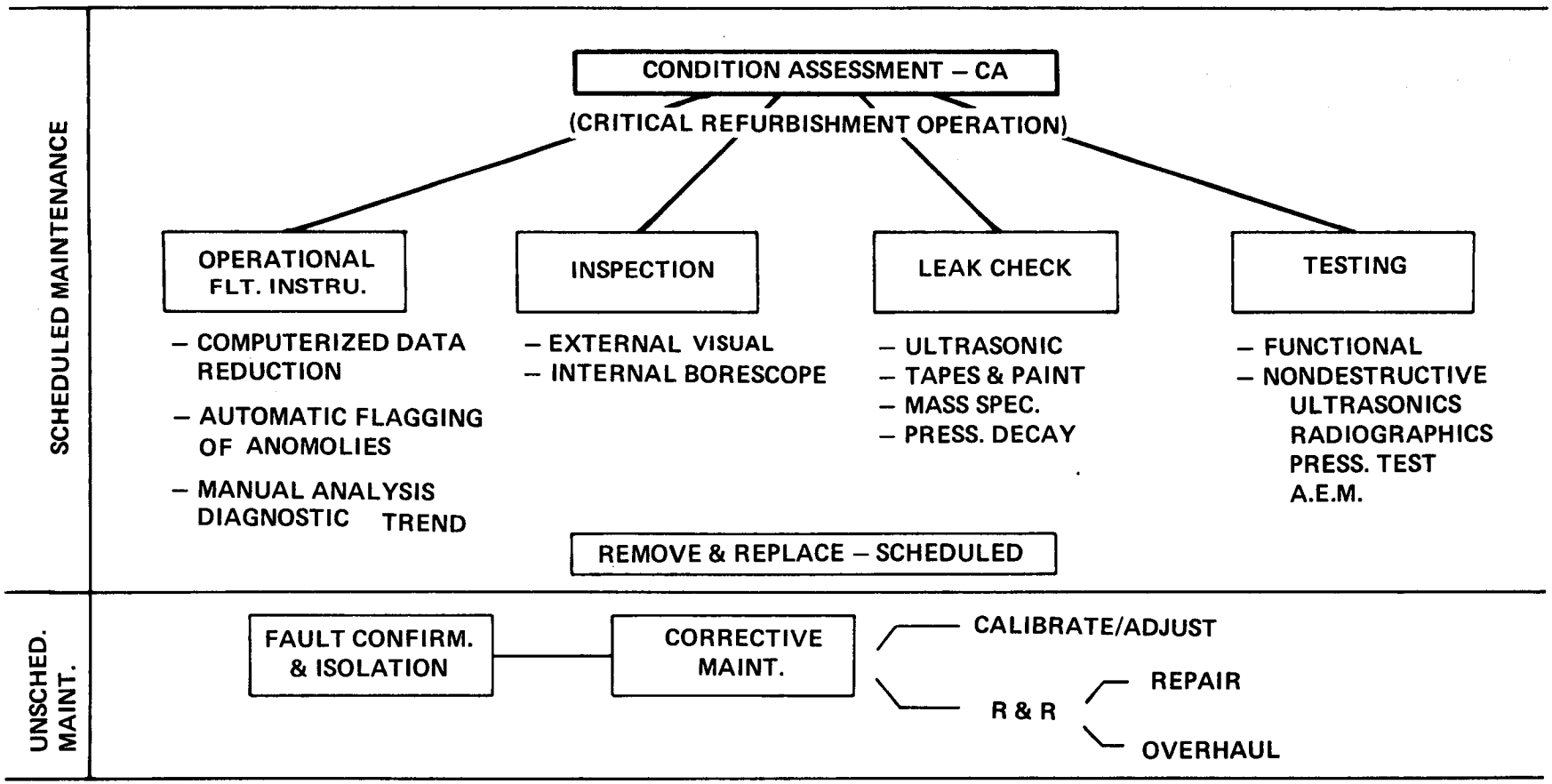
After the scheduled and unscheduled tasks have been performed, the Tug will receive a post maintenance end to end integrated checkout to determine the status of various subsystems; namely, valve position, power system voltage, current, and frequency, etc. Note that functional tests and analysisof OFI has been performed during the maintenance phase such that functional operation of all subsystems has been verified. (Ref. Vol. 6.0, Para 6.11.7 Maintenance/ Refurbishment/Checkout.)

REFURBISHMENT & MAINTENANCE CONCEPT

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1

- OBJECTIVE:
  RESTORE RETURNING TUG TO REQUIRED SAFETY & RELIABILITY FOR PRACTICAL COST
- APPROACH:
  CONDITION MONITORED MAINTENANCE WITH PREFLIGHT TEST



PREFLIGHT TEST – POSTMAINTENANCE END-TO-END INTEGRATED CHECKOUT (STATUS)

18093CVD4631

Shown is a summary of specific refurbishment and maintenance (R&M) plans; for each major subsystem. Design features which contribute to the maintenance plans, the primary concern for maintenance and the maintenance plans are shown in the columns.

STRUCTURAL SHELLS: Concern here is handling or meteoroid damage, maintenance of the thermal coating, and possible out of tolerance loads. CA each mission will be as shown. No scheduled replacements are planned.

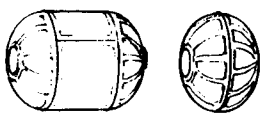
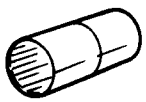
PROPELLANT TANKS: Tanks are designed for leak before break based on fracture mechanics with a safety factor of 1.4 applied. Tank life is expected to be>100 flights and with a usage of 20 flights there is a further margin. The concern for maintenance is the detection of actual and incipient cracks in the tank wall. OFI analysis and ground tests as shown will be used to assess tank condition. Acoustical emission monitoring (AEM), an advanced technology which listens for crack growth as tank pressure is brought up to operating pressure is one recommended method of detecting incipient failures in the tank (cracks). This method is now in development.

MAIN ENGINE: The 25 OFI parameters will be analyzed each flight to determine the health of the main engine. Visual inspection, leak checks, etc. will be conducted also. Main engine will be scheduled for overhaul each 10 missions. Each 20 missions on the average, an unscheduled overhaul will be performed.

ACPS ENGINES: OFI will be analyzed to determine ACPS performance. The concern is catalyst bed degration which can be detected by analyses of average chamber pressure, chamber pressure roughness, chamber pressure spiking, ignition delay, and tail off time. Visual inspection and leak checks of control valves will be made also.

PROPULSION SUPPORT: Analysis of OFI, visual inspection, leak checks, and some functional checks of valves and regulators which cannot be instrumented readily will be made.

REFURBISHMENT/MAINTENANCE PLANS

SUBSYSTEM	CONCERN	PLAN
PROPELLANT TANKS (Al WELDMENTS)  SF = 1.4 LIFE >100 USAGE < 20 FLT.	DETECTION OF ACTUAL & INCIPIENT CRACKS OR FLAWS IN TANK WALL	ANALYSIS OF FLIGHT INSTRUMENTATION (PRESSURE TEMPERATURE TRACES, GO_2 & GH_2 SNIFFERS UNDER INSULATION BLANKETS) GROUND TESTS (LEAK TEST ANALYSIS, ACOUSTIC EMISSION MONITOR) (ADVANCED TECHNOLOGY)
STRUCTURAL SHELL (Al SKIN-STGR) 	DAMAGE, COATING OUT OF TOLERANCE LOADS	VISUAL INSPECTION + RADIOGRAPHICS RECOAT THERMAL COATING AS REQ.
MAIN ENGINE LIFE/OH 10 FLT (TIME) 20 FLT (START) OFI ADEQUATE FOR CA	RELIABILITY SAFETY PERFORMANCE INCIPIENT FAILURES LEAKAGE	ANALYSIS OF FLIGHT INSTRUMENTATION (25 PARAMETERS) INSPECTION – VISUAL EXTERNAL & BORESCOPE LEAK TEST FUNCTIONAL CHECK TVC ACTUATION TURBOPUMP TORQUE CHECK REMOVE & REPLACE AFTER 10 FLIGHTS (SCHEDULED OH) UNSCHEDULED MAINTENANCE – OH 20th FLT INSTRUMENTATION CHECK & CALIBRATE
ACPS ENGINES OFI – ADEQUATE LIFE LIMITED BY CATALYST ≈ 10 FLT/OH	RELIABILITY, SAFETY & PERFOMANCE LEAKAGE	ANALYSIS OF FLIGHT INSTRUMENTATION (5 PARAMETERS) VISUAL INSPECTION LEAK TEST REMOVE & REPLACE THRUSTER QUADS AFTER 10 FLIGHTS FOR OH UNSCHED. MAINT R&R THRUSTER QUADS
PROPULSION SUPPORT (FEED, FILL, DRAIN, VENT, ETC.) LIFE >40 FLT OFI – ADEQUATE	RELIABILITY, SAFETY & PERFORMANCE LEAKAGE	ANALYSIS OF FLIGHT INSTRUMENTATION VISUAL INSPECTION LEAK TESTS FUNCTIONAL CHECK OF VALUES

18093CVD4593

AVIONICS: Avionics is comprised of data management, guidance and navigation, flight control,communications, instrumentation, and power distribution subsystems. These systems, which are continuously monitored by OFI, are characterized by high component MTBF and on-line or standby redundancy. The failure mode is random rather than wearout and the high MTBFs result in few failures during a 20-mission life. Avionics condition assessment is achieved through an inherent capability for simple status and self tests. Fault isolation will be to the line replaceable unit (LRU) level with all LRUs readily accessible for removal and replacement.

FUEL CELL: The fuel cell has a high-duty cycle (50 hours per mission). Coupled with a service life between overhaul of 2,000 hours leads to no schedule removals. Four parameters of OFI will enable functional assessment and evaluation of performance each flight. It is assumed that the fuel cell is shut off when Tug enters the Shuttle payload bay with reactants locked in. Reactivation of the electrical power output of the cell is then a simple procedure. Removal requires shtudown and purge. Four units are in spares inventory, giving a 99% probability of a unit being available at any time. A freshly charged battery will be installed every flight.

TANK INSULATION: OFI will be analyzed by comparing actual versus predicted boiloff, to determine the condition of the MLI. Visual inspections and leak tests will be conducted each flight. The insulation will provide $\approx$20 mission life such that no scheduled replacements are planned. Unscheduled replacements will be one panel each 20 missions due to damage.

THERMAL CONTROL: Analysis of OFI, leak and flow tests will be conducted. Radiation surface will be recoated to meet thermal requirements.

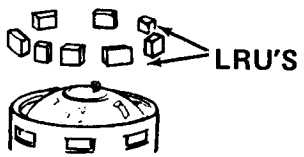
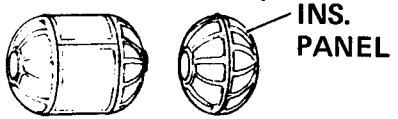
ORBITER INTERFACE: Maintenance plans are as indicated.

REFERENCE: P. 6.11.10, Appendices B Maintenance Plan).

REFURBISHMENT/MAINTENANCE PLANS (Continued)

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1

SUBSYSTEM	CONCERN	PLAN
DATA MGMT. SYSTEM GUIDANCE & NAV. FLIGHT CONTROL COMMUNICATIONS INSTRUMENATION POWER DISTRIBUTION  HIGH MBTF COMPONENT REDUNDANCY	FAULT DETECTION & ISOLATION	ANALYSIS OF FLIGHT INSTRUMENTATION VISUAL INSPECTION CHECK OUT INSTRUMENTATION POST-MAINTENANCE INTEGRATED TESTS UNSCHEDULED MAINTENANCE – FAULT CONFIRMATION & ISOLATION MAINT. CHANGEOUT OF LRUs (ACCESSIBLE) MAJOR REPAIR/OH AT DEPOT
FUEL CELL HIGH MTBF OFI ADEQUATE FOR CA ACCESSIBLE LRU'S	RELIABILITY, SAFETY & PERFORMANCE	ANALYSIS OF FLIGHT INSTRUMENTATION STACK VOLTAGE, CURRENT & CONDENSER TEMP. VISUAL INSPECTION UNSCHEDULED MAINTENANCE – CHANGEOUT UNITS
THERMAL CONTROL 	RELIABILITY, SAFETY & PERFORMANCE	ANALYSIS OF OFI – TEMP, PRESS., FLOW RATE LEAK TESTS RECOAT RADIATOR (LIFE CYCLE OF SYSTEM >20 FLT)
TANK INSULATION (20-MISSION LIFE)  	INSULATION PANELS INTACT	ANALYSIS OF FLIGHT INSTRUMENTATION ACTUAL VS. PREDICTED BOILOFF VISUAL INSPECTION LEAK TEST INSULATION LEAK & FUNCTIONAL TEST OF PURGE SYSTEM
ORBITER & PAYLOAD INTERFACES	RELIABILITY, SAFETY & PERFORMANCE LEAKAGE DAMAGE TO DISCONNECTS	ANALYSIS OF FLIGHT INSTRUMENTATION VISUAL INSPECTION LEAK CHECK FUNCTIONAL TESTTUG/ORBITER DOCKING, LATCHING, ADAPTER DEPLOYMENT & UMBILICAL ACTUATION SYSTEMS

18093CVD4601

The objective of the Spares requirements analysis is to provide a high probability of spare parts available at low investment cost. USAGE, (expected usage per mission times number of missions and T.F.U.) and INVENTORY (initial spares, for pipeline + reserve + shelf spares) are determined as shown in summary, for major elements of the WBS.

STRUCTURE: Basically, structural elements are expected to last the life of the vehicle. Handling and meteoroid damage are the basis for the spares requirement as shown.

PROPULSION: Scheduled removals of the main engine are determined by considering expected life/mission usage in terms of burn time and number of starts. The first overhaul O/H at 10 MDC involves basically gearing refurbishment, the second at 10 MDC involves basically gearing refurbishment + change out of the thrust chamber. These overhauls will average = .56 of a new engine cost, and will be refurbished at the Depot level. Unscheduled removals are estimated 1/20 MDC and require Depot level refurbishment. Other engine components will be refurbished at the launch site. ACPS engine require O/H at ≈ 10 MDC at .15 times new engine cost, for replacement of the catalyst beds. Spares requirements are summed for main engine support and ACPS support systems.

AVIONICS: There are no planned scheduled replacements of avionics equipment because of the hi MTBF values demonstrated.

THERMAL CONTROL: Main propellant tank insulation is expected to have a reuse of ≈ 20 MDC. Based on an average reuse of 20 for the vehicle, no scheduled replacements are planned. Handling and meteoroid damage and surface emissivity degradation requires unscheduled replacement.

ORBITER INTERFACE: Orbiter interface equipment spares requirements are shown.

DEPOT REFURB: Depot refurbishment factors are determined for main engines, ACPS components and avionics. Depot refurb. costs totals are shown.

SPARES + DEPOT REFURB: Costs are shown as totals and in percent of total operations costs.

SPARES REQUIREMENTS

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1

- OBJECTIVES – HIGH PROBABILITY OF PARTS AVAILABILITY, LOW INVESTMENT COST

	USAGE	INVENTORY		CRITERION FOR SPARES REQUIREMENT & REMARKS
	$M 220 MISSN.	EQUIV. SHIP SETS	$M	
STRUCTURE				BASICALLY STRUCT. ELEMENT LIFE > REUSE REQT.
MAIN TANKS	0.1	1.0	0.4	HANDLING & METEOROID DAMAGE
BODY	1.1	0.0	0.0	REPAIR IN PLACE
PROPULSION				
MAIN ENGINE	3.1	5.7	4.0	SCHED. = 10 MDC*/OH, UNSCHED. = 20 MDC/OH
ACPS ENGINES	1.6	2.2	0.7	SCHED. = 10 MDC/OH, CATALYST BED CHANGE
SUPPORT	2.4	5.8	7.3	FEED, FILL, DRAIN, VENT, PRESS, ETC. PURGE SYSTEMS
AVIONICS				NO SCHEDULED REMOVALS, HIGH MTBF
DMS	2.2	1.4	4.4	
G&N – F/C	0.4	5.9	2.3	
COMM.	0.1	3.2	1.5	
FUEL CELL & BATT.	0.5	4.2	1.4	NO SCHEDULED REMOVALS; UNSCHEDULED: 20 MDC/REMVL
THERMAL CONT.				
INSULATION	1.0	0.0	0.0	INSUL. LIFE $\geq$ 20 MDC, UNSCHEDULED 1 PANEL RMVL./20 MDC
CONT. SYS.	1.1	1.2	0.2	
ORBITER INTERFACE	2.4	2.2	0.9	
TOTAL =	$ 16.0		$ 20.2	

- DEPOT REFURBISHMENT = $9.7M
- SPARES + DEPOT REFURB. = $36.2 + 9.7 = $45.9M

≈ 25% TOTAL OPERATIONS COST

*MISSION DUTY CYCLES PER OVERHAUL

18093CVD4587

Ground support equipment costs were derived from the operations analysis task. For each function block in the turn-around sequence a set of requirements data sheets was prepared which identified personnel, facilities, and GSE required to accomplish the tasks. The GSE requirements were collected and index list prepared. For each item of GSE a description sheet was developed which indicated functional requirements, quantities and use location. Based on the functional descriptions, unit and DDT&E costs were estimated and fed into the cost runs for each program.

A complete set of GSE Data Sheets may be found in Volume VI, Appendix 6E. GSE discussion is in 6.11.5 and resulting GSE costs are summarized in 6.11.9 of this Volume.

(Reference: Volume VI, 6.11.5(1))

GROUND SUPPORT EQUIPMENT

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1

GROUND OPERATIONS ANALYSIS

FUNCTION FLOWS REQUIREMENTS DATA SHEET

GSE REQUIREMENT

ITEM NO.	ITEM
1001	HANDLING PALLET
1002	FLIGHT PALLET
1003	TRANS
1023	WORKSTAND, INSPECTION
1024	MAINTENANCE, ASSEMBLY & TEST WORKSTAND
1025	

TUG GSE ITEM DESCRIPTION

ITEM NO. 1024

UNIT COST $502,286

NAME Maintenance, Assembly & Test Workstand (MAT Workstand)

REQUIREMENT SUMMARY Provide horizontal support for Tug during engine and adapter removal/installation; component removal/installation; system test and checkout.

FUNCTIONAL/PHYSICAL DESCRIPTION 60 ft x 90 ft elevated platform (7-1/3 ft above MAT area floor level); two cutouts and supporting structure for two Tugs; hinged platform sections permitting engine and adapter removal; access ladder and platforms; [illegible] elevator for component, tool, and GSE lift to platform level; interface connections between Tug electrical, electronic and fluid systems, and TMF facility [illegible]; 90 psig shop service air; 120 V, 60 Hz, single phase outlets; space for checkout GSE and work benches.

ELECT PWR 120 V 60 Hz 1 Ø ___ KW WEIGHT ___ LB DIM [illegible]

FLUID MEDIA GN_2, GHe PRESSURE 5000 psi QTY DETAILS [illegible] to pneumatic test panel.

EXIST. EQUIP SIMILARITY None

EXIST. EQUIP AVAILABILITY None

ARTICLE OR ASSEMBLY SUPPORTED Tug

CRITICALITY Safety and reliability

VEHICLE INTERFACE Exterior and interior, all systems. Structural interface [illegible] points at LH_2 shell and LO_2 shell; fluid and avionics service disconnects.

FACILITY INTERFACE TMF: overhead crane; fluid and avionics service lines.

OTHER INTERFACING GSE H. L. Bar (#1017); internal platforms (#1025); adapter dolly (#1028); engine dolly (#1043); checkout GSE (#1029-1040); adapter docking simulator (#1044); S/C docking simulator (#1045).

MOBILITY EQUIPMENT No

OPERATIONAL MODE LOCAL ___ REMOTE ___ BOTH X DETAILS ___
Checkout using ground automatic r/o facility in TMF

AUTOMATION & SOFTWARE REQUIREMENTS Checkout instructions and procedures.

ALLOCATION:

BLOCK FUNCTION	LOCATION	NO. REQD.
1.1.3-1.1.11	TMF	1 - KSC
2.1.4-2.1.12	FPV	1 - WTR
1.2.1-.3		

TOTAL REQ. 2

6E-27

$ UNIT COST X QTY + DDT&E

COST RUN – PROGRAM ONE

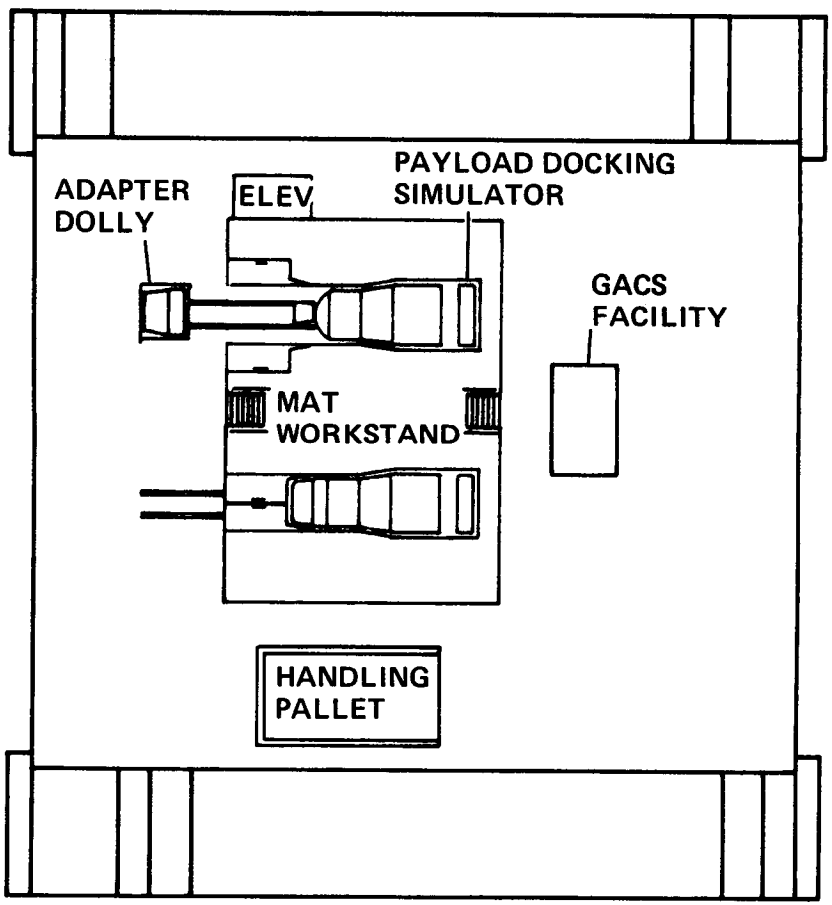
	GSE	
07-02	ETR GSE	$
07-03	WTR GSE	$

18093CVD4598

Hangar J at KSC has sufficient floor area to accommodate a two-bay Tug maintenance stand. The mezzanine area is adequate for administration and engineering offices. First floor area may also be used for adapter and main engine service areas. Level II shops are assumed to be common with Orbiter and/or existing base facilities.

TUG MAINTENANCE FACILITY

- MEZZANINE AREA AVAILABLE FOR ADMINISTRATION & ENGINEERING OFFICES
- FIRST FLOOR SHOP AREA AVAILABLE FOR ADAPTER & MAIN ENGINE SERVICE AREAS



HANGAR J
41,212 SQ.FT. (INCLUDING MEZZANINE)

18093CVD4596

This chart summarizes the basic differences between the NASA and the DOD approaches to the Tug program development and production phases. In general, the NASA approach emphasizes a nominal risk program structured for low DDT&E costs and with a view toward minimizing funding requirements during the Space Shuttle peak development funding years. Further, development and production phase concurrency are implied by the scheduling of full-production vehicles to satisfy and meet all Tug flights within the vehicle's performance capability.

On the other hand, the DOD approach emphasizes adequate demonstration of vehicle performance, refurbishment and reusability prior to proceeding with the production phase. The Full-Scale Development Program reflects this approach and is expected to take longer and cost more than the NASA development approach. Confidence in operational capability should be higher and probability of post-production retrofits should be somewhat lower with this approach.

DEVELOPMENT PROGRAM DIFFERENCES

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1

NASA	DOD
• PROGRAM STRUCTURED FOR LOW DDT&E DOLLARS	• PROGRAM STRUCTURED TO DOD REQUIREMENTS
• MINIMIZE FUNDING DURING FY '75 TO '80	FUNDING NOT CONSTRAINED BY SHUTTLE PEAK FUNDING YEARS
• REASONABLY "LOW RISK" PROGRAM AT LOW DDT&E COSTS	• ADEQUATE DEMONSTRATION OF PERFORMANCE CAPABILITY (INCLUDING REUSABILITY) & INITIAL OPERATIONAL TEST & EVALUATION.
• MINIMIZE OVERALL PROGRAM COSTS	• MINIMIZE PRODUCTION & OPERATING COSTS
• EARLY IOC ('79) EMPHASIZED	• DEMONSTRATION OF CAPABILITY & OPERATION EMPHASIZED
• PRODUCTION GEARED TO SATISFY MISSION MODEL FOLLOWING '79 IOC	• "FLY-BEFORE-BUY" (DOD DIR. 5000.3): DEMO. PERFORMANCE, REUSE & INITIAL OT&E BEFORE PRODUCTION DECISION
• DEVELOPMENT & PRODUCTION CONCURRENCY IMPLIED	• EMPHASIS ON MINIMIZING DEVELOPMENT & PRODUCTION CONCURRENCY (RE: AFSCP 800-3)
• IOC AS SIGNIFICANT MILESTONE MARKING END OF DDT&E & START OF OPERATION	• "FULL-SCALE DEVELOPMENT COMPLETE" & "1ST PROD. VEH. FLIGHT" AS COMPARABLE MILESTONES

1809CVD4628

This chart is the summary development schedule for an existing state-of-the-art Tug as considered in Program 1. It reflects an early, low-cost development approach (without a payload retrieval capability) in support of a 12/31/79 IOC.

The schedule is predicated on a one-shift operational basis and reflects the subsystem development and vehicle integration activities necessary to confidently support the initial flight as the IOC.

Individual subsystem development, including design, testing, procurement and/or fabrication are included in the subsystem line schedules. Fabrication and primary assembly of the individual propellant tanks and shells are considered as subsystem level activities and are delivered to vehicle assembly as completed units, ready for plumbing and lines and insulation installation. There are two major ground test articles in the DDT&E program; these are for structural loads testing and fatigue & life cycle evaluations. Other major tests include the deployment adapter and the astrionics module tests.

There are a total of 16 tugs produced for the vehicle inventory, the first two of which are built early in order to support pre-IOD mission simulation & environmental testing and vehicle/site integration and validation. The initial flight is the IOC flight as it will satisfy the initial payload placement requirement. This vehicle will carry development flight instrumentation (DFI) and, following deployment of the payload, will be exercised in various modes to attain verification of flight data not available from the payload placement flight profile.

The payload mission model has been converted to tug flights, by-year, as shown in the lower right-half of the schedule. Tug production is scheduled to satisfy these flight requirements.

The primary pacing activity in this schedule is software development and its interaction with the vehicle assembly and pre-flight activities. The propellant tank development, fabrication & assembly is a secondary pacing element.

Refer to Volume 8.0, Programmatics/Cost, for a further discussion of this program development approach.

$$psia = \frac{NPSH\ \rho}{144}$$

$$= \frac{14 \times 4.4}{144} = .428$$

RL10A-3-3A

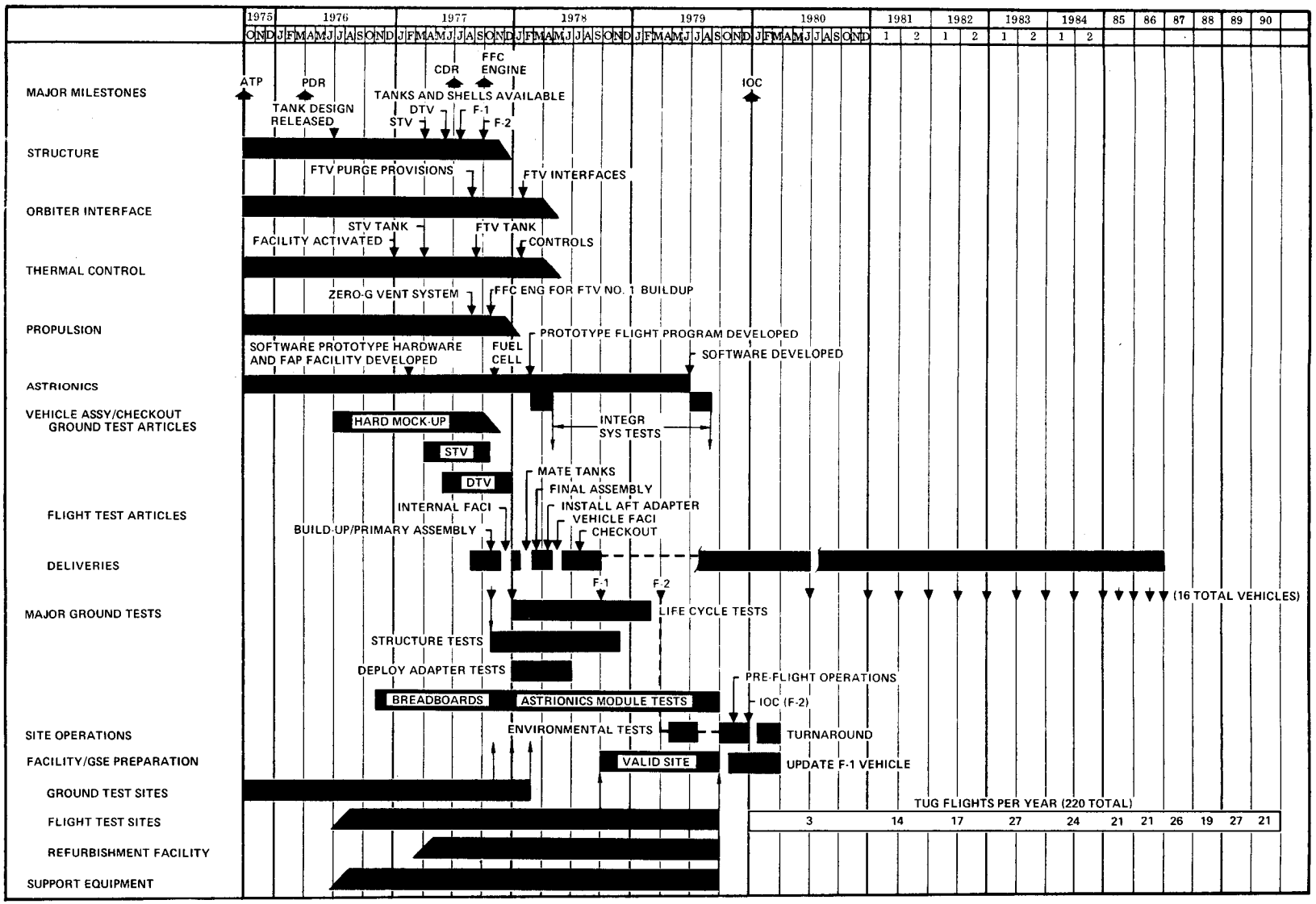
NPSP	at engine inlet		Cat I. *	
LOX	~~8.0~~	4.0	11.5'	60.5 psia
LH_2	~~4.0~~	2.0	56'	30.0

* REF. Application of RL10 Engine for Space Tug Propulsion
P&W FR 5523 Jan 31, 1973

Cat II*	LOX	0'
	LH_2	16'

ASE 0/0

PROGRAM SUMMARY
NASA Format



18093CVD4461

This chart is the summary development schedule for an existing state-of-the-art Tug under consideration in Program 1, but developed under the DOD method of doing business (DOD Dir 5000.3 and AFSCP 800-3).

The principal differences between the NASA and the DOD approach to development and production are as follows, with the DOD approach being shown in this schedule.

The basic subsystem development is similar for both NASA and DOD. However, the vehicle integration ground testing is expanded to include extended mission simulations and attain initial hardware and system reuse data under operational environments. Two Tugs are initially designated as development flight articles and will perform a minimum of three test flights to evaluate performance and demonstrate refurbishment, reusability and initial OT&E testing. These flight tests complete the Full-Scale Development Phase and are followed by a DSARC Review which will constrain a "Production Release" decision (fly-before-buy concept). This production release is assumed to constrain start of fabrication of any vehicle hardware. Material and other long-lead procurements are started during the DT&E phase on the strength of favorable test program results. OT&E flight operations are continued for a period beyond the full-scale development phase and are considered to satisfy the requirements of the Tug flight model as shown. The IOC milestone, as shown in the NASA schedule, is replaced by two other milestones in this schedule; "Full-Scale Development Complete" and "First Production Flight".

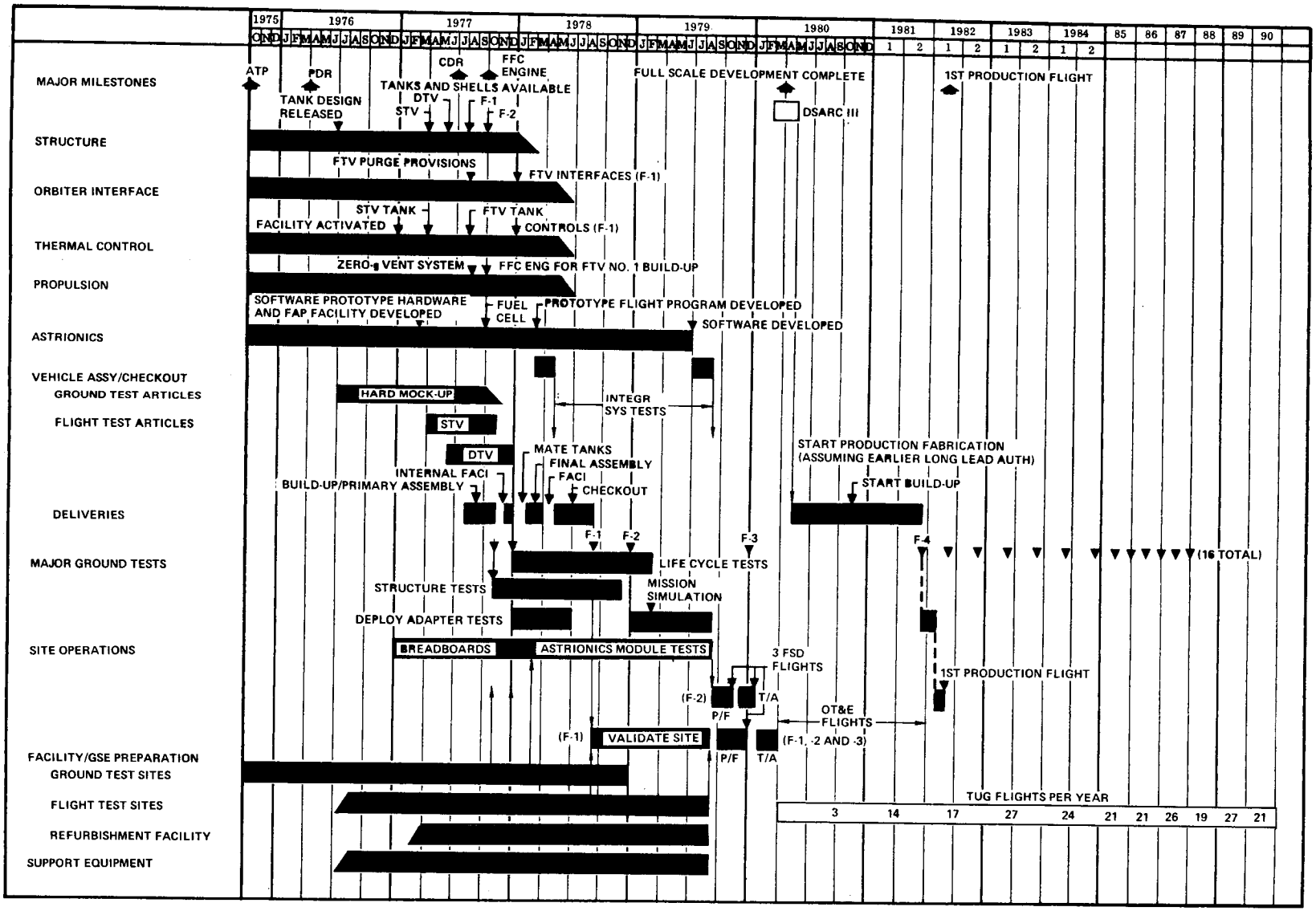
Sixteen Tugs are required in the vehicle inventory, the same as under the NASA approach since all Tug flights are met. Thirteen of these are production vehicles, two are initially flight test vehicles and one is a pre-production vehicle being built during the FSD phase to help meet the flight requirements prior to the initial production availability. The three pre-production vehicles would be consumed on expended Tug flights. The pacing elements of this program include software development and the vehicle assembly, site integration and flight test program.

Refer to Volume 8.0, Programmatics/Cost for further data on this development approach.

PROGRAM SUMMARY
DOD Format

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1



18093CVD4562

Evaluation and qualification testing will be required by the Tug contractor (and/or his suppliers) on all newly designed components and assemblies. Requalification of any "off the shelf" items will also be necessary wherever prior operating environments are to be exceeded. A sample size of two will be required for qualification.

Propulsion testing will consist of basic engine development tests, engine qualification for Space Tug use and integration testing of the Tug engine support subsystems with the main engine as an "add-on" activity to the engine manufacturer's basic test program. No dedicated propulsion test vehicle (PTV) or altitude simulation is required for the RL10 CAT I engine.

Structural qualification of the basic Tug structures will be accomplished by a series of static load tests simulating critical service loading conditions under cryogenic temperatures. Testing will be performed on a structural test vehicle (STV), first in a totally assembled configuration, then separately on the LO_2 and LH_2 tanks and associated structures. Structural vibration and life cycle tests will be performed on a fatigue test vehicle (FTV) dedicated for this purpose. Major testing will consist of low level modal surveys (for dynamic characteristics determination) and tank pressure cycle tests (for service life proofing).

Deployment adapter development tests to verify tug deployment and retrieval capabilities will be required using prototype hardware. Operational mission environments of weightlessness, temperature, approach angles and maneuvering loads will be simulated where critical.

Astrionic subsystems development and integration testing will be primarily accomplished using a prototype Tug astrionics module complete with functional electronic packages. The unit will also be used for integration testing with the shuttle astrionics and with launch site AGE. Thermal/vacuum testing will be performed on a flight vehicle prior to the first flight test to verify satisfactory thermal control and insulation characteristics. Launch site validation testing will consist of a complete run-through of all planned preflight activities for operational integration of the Tug with its launch facilities/AGE.

Flight testing will be required to verify ground test results and to investigate the effects of true space environments, which can not be totally simulated by ground testing. The manner in which this testing is accomplished differs significantly between the NASA and the DOD procurement approaches. The chart on flight testing elaborates on this point.

TEST PROGRAM KEY ELEMENTS

TEST SERIES	TEST ARTICLE	KEY OBJECTIVES
COMPONENT SUBSYSTEMS	PREPRODUCTION COMPONENTS	DESIGN EVALUATION & ENVIRONMENTAL QUAL. & LIFE DEMONSTRATION
PROPULSION	CAT. I ENGINE WITH FEED SYSTEM HARDWARE	ENGINE QUAL., ENGINE/PROPELLANT SYSTEMS INTEGRATION & REUSE DEMONSTRATION
STRUCTURAL QUALIFICATION	STRUCTURAL TEST VEHICLE (STV)	STRUCTURAL QUALIFICATION OF BASIC STRUCTURES UNDER CRYO CONDITIONS
STRUCTURAL LIFE CYCLE	FATIGUE TEST VEHICLE (FTV)	DYNAMIC CHARACTERISTICS & SERVICE LIFE DEMONSTRATION
TUG DEPLOYMENT ADAPTER	DEPLOYMENT ADAPTER WITH SIMUL. TUG MASS, LATCHING MECH., UMBILICAL PANELS	DEPLOYMENT & RETRIEVAL SYSTEMS
ASTRIONICS SYSTEMS	ASTRONICS MODULE WITH ASTRIONICS ASSEMBLIES	ASTRIONICS HARDWARE/SOFTWARE/AGE PROOFING & INTEGRATION, REUSE DEMO.
THERMAL-VACUUM	FLIGHT VEHICLE	INSULATION EFFECTIVENESS, THERMAL CONTROL VERIFICATION & REUSE DEMONSTRATION
LAUNCH SITE VALIDATION	FLIGHT VEHICLE & ORBITER BAY SIMUL.	TUG/LAUNCH SITE FACILITIES/AGE INTEGRATION & REFURBISHMENT DEMONSTRATION
FLIGHT TESTS	1. OP. FLT. VEHICLE (NASA) 2. FLT. TEST. VEH. (DOD)	FLIGHT MISSION PROOFING & REUSE DEMO.

18093CVD4564

This chart provides a composite summary of all major ground tests as proposed for the Space Tug under both the NASA and DOD procurement guidelines. Total estimated costs (in millions of dollars) are identified for each test activity under each of the two development approaches, together with the total summary program cost for each concept. Where appropriate, the test location and the test article assumed in the cost estimate are also listed.

Component and subsystem level testing was not studied in depth during this study since these were not considered to be significant program drivers. It should be emphasized, however, that this level of testing will have to be given very thorough attention during subsequent Space Tug studies. Previous space systems development programs have demonstrated the importance of a thorough, well planned and managed component and subsystem test program.

The major ground tests formulated for this program support both engineering development and operational refurbishment/reuse objectives. During these tests, the planned operational inspection, turn-around, and refurbishment procedures will be utilized to the maximum extent possible in order to verify Tug reusability.

For the most part, ground test costs for both the NASA and DOD approaches are the same. The same number and type of test articles are used in both programs. The only significant difference in ground testing appears to center on a slightly more extensive DOD requirement for formally demonstrating Space Tug reuse capabilities. This affects two areas. First, an additional 3 months of test time has been allowed for propulsion testing, to demonstrate a refurbishment cycle on the engine system. Secondly, a refurbishment/reusability demonstration of the total Space Tug is proposed in conjunction with thermal/vacuum testing. This test (planned for the DOD case only) is conceived as a rather extensive activity involving one or more complete refurbishment/flight mission profile simulations.

GROUND TEST PROGRAM

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1

TEST ACTIVITY	TEST SITE	TEST ARTICLE	TOTAL COST ($M) (INCLUDING TEST ARTICLE)		REMARKS
			NASA	DOD	
COMPONENT TESTS	CONVAIR & VENDOR LABS	PREPRODUCTION COMPONENTS	13.8	13.8	SAMPLE SIZE OF 2 REQ. FOR QUALIFICATION
PROPULSION TESTS	P&W (E6)	ENGINE & FEED SYS. HARDWARE	3.5	4.0	ENGINE RETURNED TO INVENTORY
STRUCTURAL TESTS	MSFC (4550)	STV	4.4	4.4	INCL. FUNCT. TESTS OF INSULATION, PROP. LOADING, DRAIN & VENT SYSTEMS
LIFE CYCLE TESTS	MSFC (4557)	FTV	5.8	5.8	
DEPLOYMENT ADAPTER	CONVAIR	ORBITER INTERFACE HARDWARE	1.7	1.7	DEMONSTRATES FUNCT. CAPABILITY
ASTRIONICS SYSTEMS	CONVAIR JSC KSC	ASTRIONICS MODULE	6.4	6.4	HARDWARE, SOFTWARE & AGE INTEGRATION
THERMAL VACUUM	LeRC (B2)	F-2 FLT. ART.	1.0	1.0	CRYO CONDITIONS REQ. MENTS
REUSABILITY EVALUATION	LeRC (B2)	F-2 FLT. ART.	—	1.5	EXT. OF THERMAL-VACUUM TEST
LAUNCH SITE VALIDATION	ETR WTR	F-1 FLT. ART. F-X FLT. ART.	2.6 2.6	2.6 2.6	
TOTAL GROUND TEST COST ($M)			41.8	43.8	

18093CVD4567

Flight testing will be necessary to supplement ground testing for purposes of demonstrating the validity of ground test environments, loads, and test results as well as imposing the effects of zero G and other effects not satisfactorily duplicated in ground testing.

The Space Tug's inherent capability of relatively long orbital stay time and operating flexibility will allow an extensive amount of testing during a single flight test mission. Each flight test mission will be divided into numerous phases, during which various Space Tug operating modes are tested. These phases will be constructed so that operation involving progressively more stringent conditions are separated by periods of data evaluation and continued testing of lower risk subsystems.

The greatest impact due to differences in NASA and DOD procurement approaches, occurs in the area of flight testing. For this reason, separate flight test plans for each approach were necessarily formulated to satisfy the individual requirements as established by (1) the NASA Space Tug Study guidelines, and (2) DOD Directive 5000. 3, respectively. The highlights of each of these resulting flight test plans are summarized in the accompanying chart.

Significant in the NASA approach, is the concept of not dedicating a flight vehicle for flight test purposes. Instead, it appears to be cost effective, technically feasible, and relatively low risk to place operational payloads into low performance orbits on the initial Tug flights. The remaining vehicle performance could then be utilized for developmental flight testing into progressively higher risk operating regimes. This approach reduces overall DDT&E costs and enables early operational usage at a reasonable risk.

Under the DOD "fly before buy" concept, Space Tug performance and reusability must be demonstrated prior to a production decision (DSARC III milestone). In addition, Initial Operational Test and Evaluation (IOT&E) should also be performed by the planned user agency prior to DSARC III. As shown on the chart, two prototype flight test vehicles are required to satisfy these requirements — one with R&D instrumentation to support Development Test and Evaluation (DT&E), and one in operational configuration to support IOT&E. Following DSARC III, both would be used for an approximate 9-month formal OT&E program planned for completion prior to first operational vehicle delivery. The two flight test vehicles would then be refurbished and/or updated as required and released into the operational fleet inventory.

FLIGHT TEST PROGRAM

NASA PROCUREMENT APPROACH	DOD PROCUREMENT APPROACH
• NO "DEDICATED" FLIGHT TEST VEHICLE • R&D INSTRUMENTATION OF FIRST FLIGHT VEHICLE • OPERATIONAL MISSION ACCOMPLISHED WITH FIRST FLIGHT / CONSERVATIVE FLIGHT ENVELOPE TO PAYLOAD DEPLOYMENT / TUG SYSTEM SIMILAR TO EXISTING CENTAUR SYSTEMS / ADEQUATE GROUND TEST SUPPORT AVAILABLE • ENGINEERING DATA "PIGGYBACKED" / "TESTING" PERFORMED AFTER PAYLOAD DEPLOYMENT / REFINES OPERATING & PERFORMANCE PREDICTIONS IN "HIGHER RISK" REGIMES • ADDITIONAL FLIGHTS WITH R&D INSTRUMENTATION / FURTHER DATA OBTAINED USING SAME VEHICLE ON AT LEAST 6 ADDITIONAL FLIGHTS / OBTAINS DATA WITH DIFFERING PAYLOADS & MISSION REQUIREMENTS	• TWO PROTOTYPE FLIGHT TEST VEHICLES REQUIRED / DDT&E VEHICLE WITH R&D INSTRUMENTATION (F-2) / OT&E VEHICLE WITHOUT R&D INSTRUMENTATION (F-1) • FLIGHT TEST 1 (DDT&E FLIGHT USING (F-1) / DEMONSTRATES DEPLOYMENT MODE CAPABILITY / POSTFLIGHT REFURB. CYCLE DEMONSTRATED AFTER FLIGHT • FLIGHT TEST 2 (IOT&E FLIGHT USING F-1) / INITIAL OPERATIONAL TEST & EVALUATION / DIRECTED BY OPERATING AGENCY • FLIGHT TEST 3 (DT&E FLIGHT USING F-2) / DEMONSTRATES REUSABILITY ⇩ DSARC III (CONSTRAINED BY FLIGHTS 1 THROUGH 3) ⇩ • OT&E PROGRAM (OT&E FLIGHTS USING F-1 & F-2) / CONTINUED OPERATIONAL TEST & EVALUATION / APPROX. 9-MONTH PROGRAM (16 FLIGHTS)

The overall program of manufacturing, tooling and planning for the development of the initial Space Tug test articles and first flight vehicle is depicted in this chart.

Major program elements that significantly effect the successful adherence to the production schedule include procurement of raw materials for both vehicle components and detail and assembly tooling. Current material problems indicate that early authorization for the ordering of certain long lead raw materials will be mandatory.

Engineering data, loft lines and basic tank dimensions would be available in time to proceed with the full size hard mock structure. Tool design activity, based on major tool concepts developed during the phase B study would commence following initial engineering design availability. Major tooling fixture base structures, not sensitive to minor design changes would be initiated as tool design and materials became available.

Operations planning documents, deliniating the individual fabrication steps and process requirements, are prepared for first indenture test hardware using preliminary released engineering. Following the Preliminary Design Review milestone, the official release of the engineering permits the final release of planning, shop orders and tool designs.

Based on proven tooling and manufacturing schedules, indenture set-back tables, shop loading and material flow data, production tooling would be available for test article detail fabrication 12 months after program start.

The fuel and oxidizer tank bulkheads for the structural test article are shown to be welded, tested and ready for mating with their respective body structure module 18 months after go-ahead. Major component assembly includes the mating of the tanks, modules and conducting hardware installations and inspections. Mating and final assembly operations for the structural test article starts 22 months and completes with the article available for the Structural test program 25 months after go-ahead.

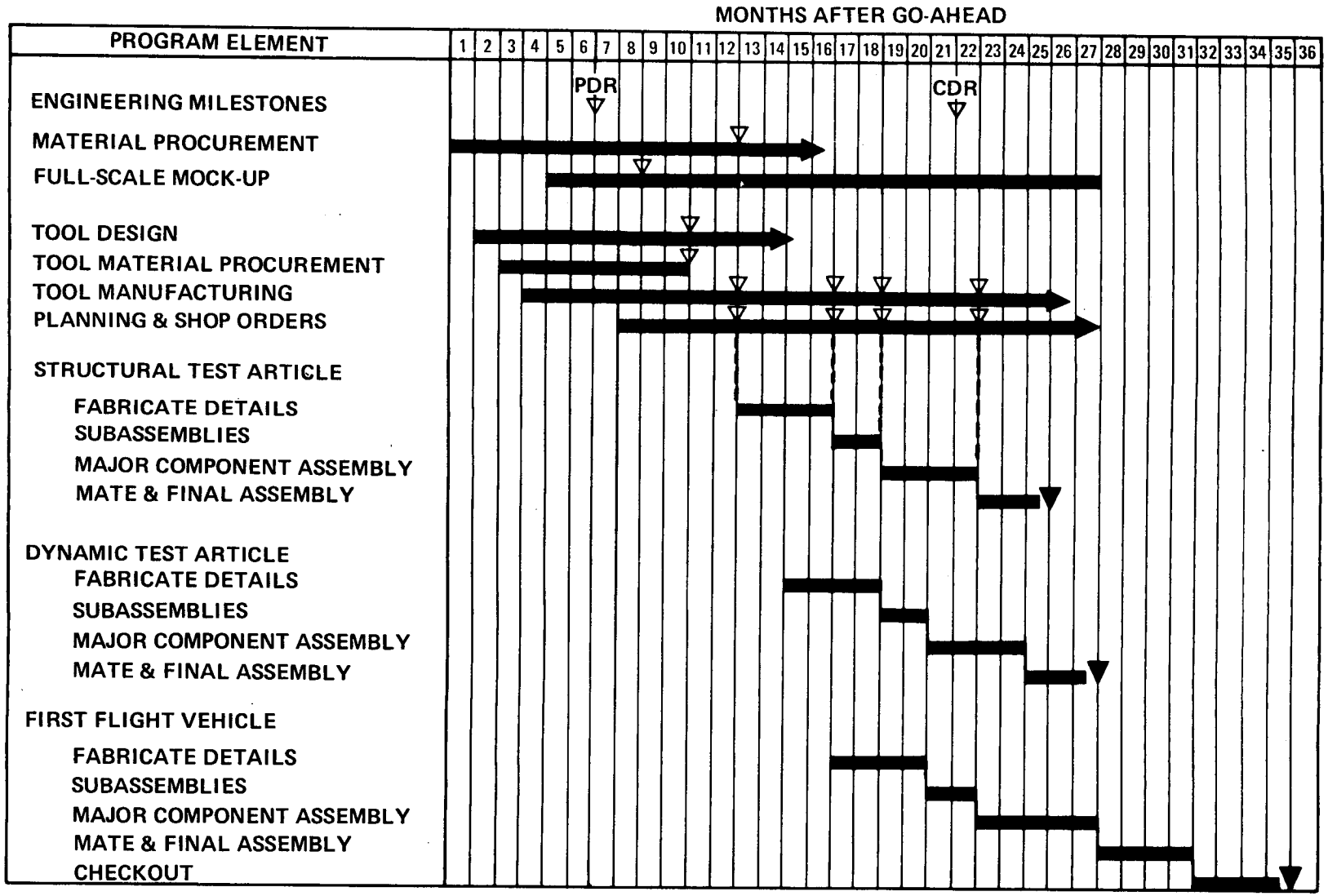
The Dynamic test article follows a similar pattern of manufacturing and assembly and is available 2 months later.

First flight vehicle major component schedule is increased by 1 month due to additional systems installations and subsequent first article configuration inspection requirements. Checkout of the flight vehicle is scheduled for 4 months and includes a final first article configuration inspection prior to acceptance.

MANUFACTURING PROGRAM SCHEDULE

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1



▽ NEEDED FOR STRUCTURAL TEST ARTICLE
▼ DELIVERY

18093CVD4591

This chart portrays in a broad sense, the overall plan for the orderly manufacturing, assembly and checkout of the Space Tug. Manufacturing breakpoints within each major component are established to facilitate material sizes, machine tool capacities, processing and material handling and other pertinent criteria.

Fuel and oxidizer tank bulkhead gores following stretch forming are chemically milled to precise thickness requirements, fitted and buttwelded together using the newly developed and proven "high frequency pulsation TIG welding equipment". After welding, the bulkhead domes are helium leak tested and prepared for mating to form the individual tank components.

The fuel tank bulkheads and cylinder section are fitted together, buttwelded and the completed tank radiographic inspected, pressure tested and cleaned. The oxidizer tank bulkheads are buttwelded, inspected, hydrostatically tested and cleaned. Internal, external plumbing and electrical systems are installed on each tank and the insulation blankets fitted, inspected and leak tested prior to the mating with the fwd and aft module body structures.

The manufacturing sequence for the body structure follows conventional aircraft techniques. Internal frames members are formed, trimmed, spliced and assembled in the fixture for mating with the 4 skin panel assemblies. Subsequent to the installation and testing of module attached plumbing and electrical systems, the insulation covered fuel and oxidizer tanks are lowered into the modules and secured with the tank support struts.

Mating of the fuel tank assembly and oxidizer tank assembly is planned to be accomplished in the vertical position following the installation of major subassemblies and components in the intertank area of the aft module. These include ACS systems and monopropellant bottles, fuel cells and associated plumbing and fuel and oxidizer plumbing.

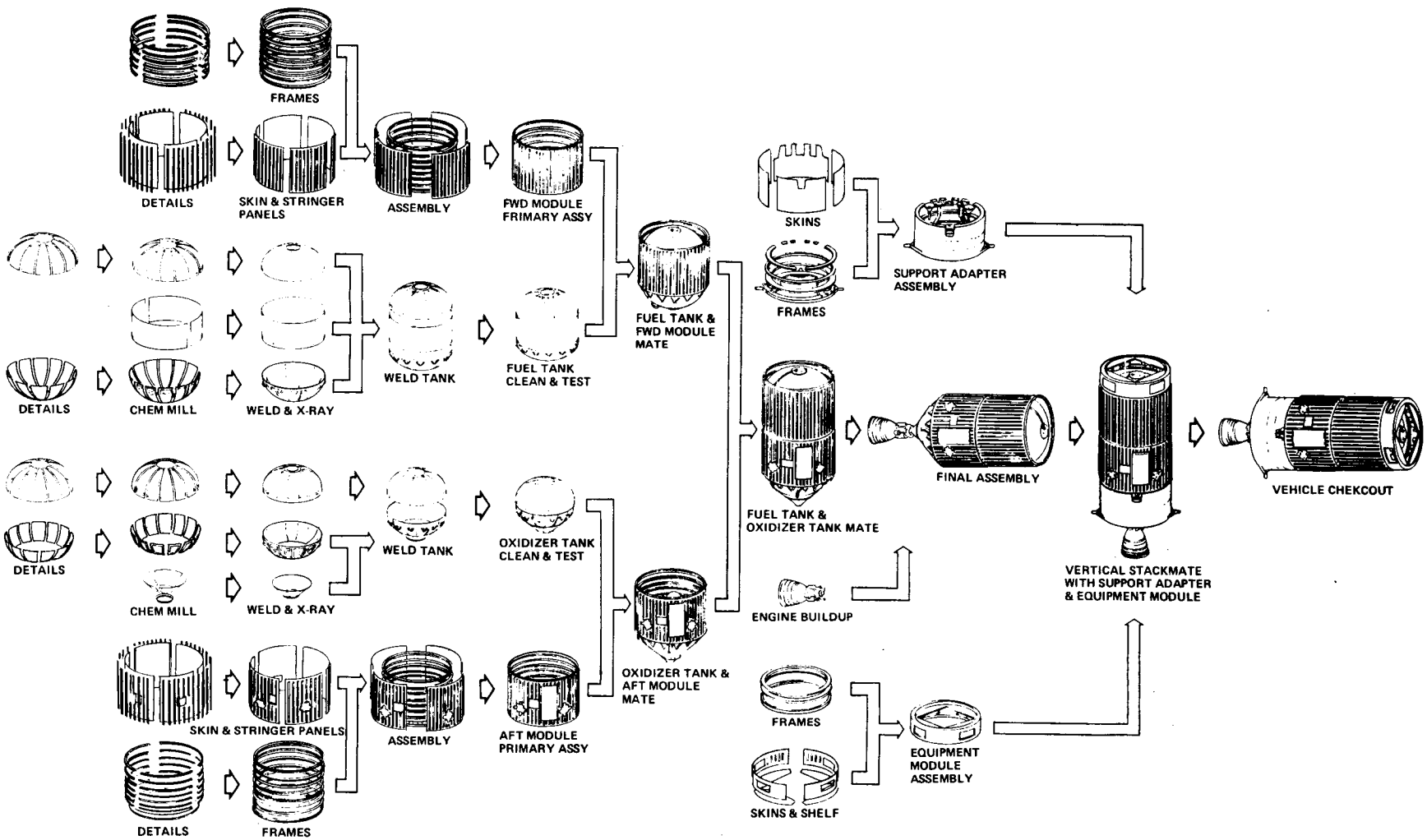
Skins for the support adapter structural build-up are chemically milled to provide stiffness and load transfer, routed to size, fitted and mechanically fastened to the frame members. The fwd and mid frames, a combination of machined and formed details are assembled in conventional aerospace tooling. The aft frame is a build-up of numerically machined components and milled webs. Propellant transfer systems, electrical interface panels, harnesses and mechanical installations are assembled and checked out prior to the mating of the adapter to the assembled Tug vehicle.

Build-up of the astrionics equipment module follows the general pattern of the support adapter. Electrical harnesses and mechanical systems are installed, the astrionics packages positioned and a preliminary checkout accomplished prior to assembly with the vehicle.

Mating of the support adapter and astrionics module to the Tug vehicle is accomplished in the vertical position to facilitate mating and latch tests. The vehicle is then returned to the horizontal for complete systems checkout.

MANUFACTURING SEQUENCE & ASSEMBLY FLOW

PROGRAM 1



18093CVD4671

In concert with the "low development cost" approach to the Space Tug program, General Dynamics proposes the consideration of existing and operating facilities for the manufacturing of the Space Tug vehicles.

Design concepts generated and selected during the study program indicate that no extraordinary size, weight or material limitations exist that preclude the use of existing private or government owned industrial facilities. Overall size of the Tug vehicle lends itself to several methods of transportation which erase specific geographical disadvantages in the selection of the manufacturing site.

In this light, the report will portray the requirements for the manufacturing operations of the Space Tug superimposed on the General Dynamics' Convair Aerospace Division, Kearny Mesa plant, home of Atlas/Centaur Space Vehicles.

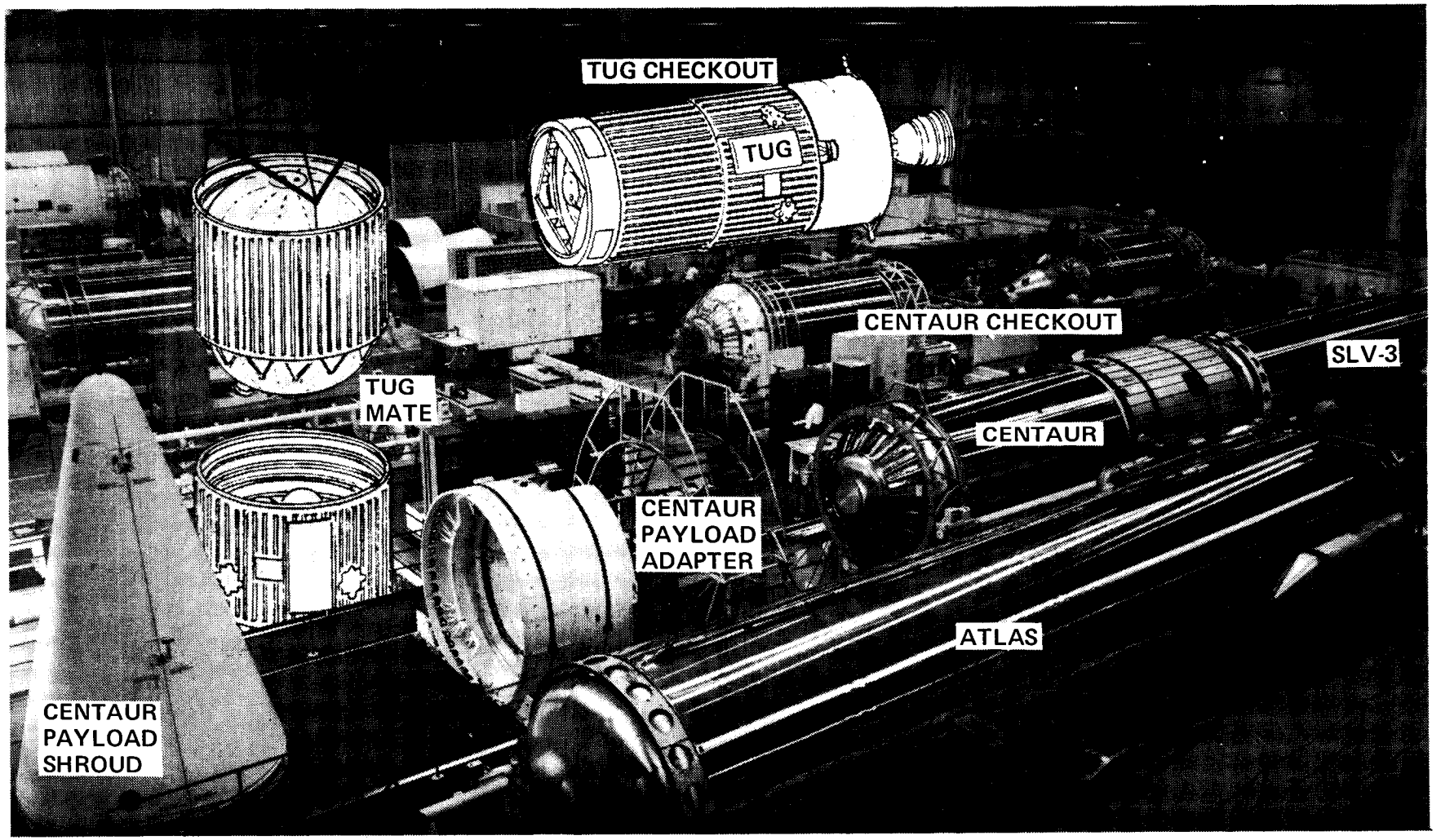
Convair's inventory of machine tools provide sufficient capacity and versatility to support both the manufacturing of production tooling and fabrication of Space Tug detail hardware.

The facility requirements were developed for the Program baseline configuration in accordance with the manufacturing plan, as shown in Section 8.4 (vehicle manufacturing).

Assembly of the Space Tug will require an 88,000 square foot building to accommodate the subassembly, assembly and testing of the Tug major components as well as the vehicle vertical mate, final assembly and checkout operations.

MANUFACTURING FACILITY

GENERAL DYNAMICS
Convair Aerospace Division



CANDIDATE FACILITY	NEW	MTF	KSC	MAF	MSFC	GD/CA
FACILITY COST ($M)	8.6	2.5	2.3	1.6	0.68	0.10

18093CVD4684

This chart presents the breakdown of the Tug vehicle portion of Tug program development cost. The Tug vehicle portion is slightly over $100M. This low cost is obtained through extensive use of existing components and techniques particularly those from the Centaur program. The chart illustrates the major subsystem areas where existing components are used. The structure is the only subsystem category that does not use at least some existing components.

Reference Section 8.6.1(1)

TUG VEHICLE DEVELOPMENT COST BREAKDOWN

	DDT&E ($M)	COMMENT
STRUCTURES	28.9	LOW-COST APPROACH
MAIN ENGINE	13.0	EXISTING ENGINE
MAIN ENGINE SUPPORT	10.5	CENTAUR-PROVEN TECHNIQUES/COMPONENTS
ACPS SYSTEM	7.3	EXISTING COMPONENTS USED
PROPULSION	30.8	
DATA MANAGEMENT	5.9	MODIFIED CENTAUR
GN&C	8.9	CENTAUR & OTHER EXISTING COMPONENTS
COMMUNICATIONS	3.9	MODIFIED EXISTING COMPONENTS
INSTRUMENTATION	1.6	MODIFIED CENTAUR
ELECTRICAL POWER	4.5	MODIFIED SHUTTLE FUEL CELL
POWER DISTR. & CONTROL	4.4	MODIFIED CENTAUR COMPONENTS
ASTRIONICS	29.2	
INSULATION	1.9	CENTAUR TYPE
CONTROL	1.3	
THERMAL CONTROL	3.2	
INST. ASSEMBLY & CHECKOUT	9.1	
TOTAL VEHICLE	101.2	

LOW COST OBTAINED THROUGH EXTENSIVE USE OF EXISTING COMPONENTS & DEVELOPED TECHNIQUES

This chart presents the development cost breakdown for both NASA and DOD procurement. The NASA procurement approach yields a total development cost of $193M. In addition to the Tug vehicle development the significant cost items are GSE, vehicle test and flight software. The DOD procurement development costs are higher due to the additional testing required in the DOD approach.

Reference: Section 8.6.1(1)

DEVELOPMENT COST

PROGRAM 1

	NASA PROCUREMENT ($M)	DOD PROCUREMENT ($M)
SPACE TUG VEHICLE	101.2	135.2
ORBITER INTERFACE EQUIPMENT	7.6	7.6
AUXILIARY STAGE	1.7	1.7
LOGISTICS	4.6	4.6
FACILITIES	0.6	0.6
GSE	24.9	24.9
VEHICLE TEST	16.7	28.2
FLIGHT SOFTWARE	18.6	18.6
PROJECT MANAGEMENT	5.7	7.4
SE&I	11.6	15.2
TOTAL	193.1	244.1

18093CVD4665

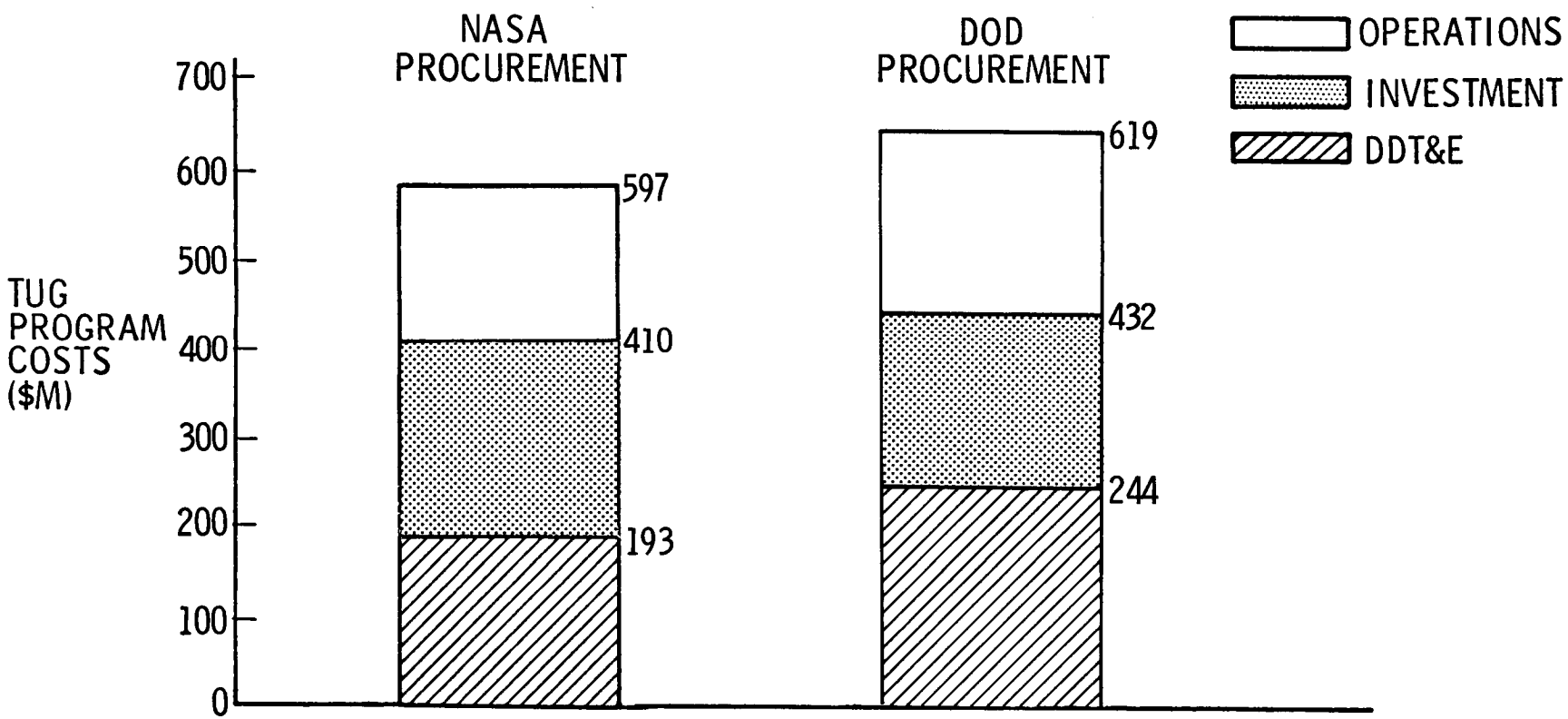
This chart shows the total Tug Program cost for both NASA and DOD procurement approaches. The breakdown of costs into DDT&E, investment and operations is indicated.

Reference: Section 8.6(1)

TUG PROGRAM COST SUMMARY

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1



18093CVD4662

This chart shows the breakdown of cost per flight for the three flight modes. The three modes differ only in the cost of any expended hardware. The primary reusable Tug mode has a cost per flight of $.88 million.

Reference: Section 8.6.9(1)

COST PER FLIGHT

	COST ($MILLION) MODE		
	1	2	3
LAUNCH OPERATIONS	0.23	0.23	0.23
MAINTENANCE & REFURBISHMENT	0.18	0.18	0.18
GROUND OPERATIONS TOTAL	0.41	0.41	0.41
FLIGHT OPERATIONS	0.38	0.38	0.38
OPERATIONS SUPPORT	0.09	0.09	0.09
EXPENDED HARDWARE	0	10.71	0.27
TOTAL AVERAGE COST/FLIGHT	0.88	11.59	1.15

MODE 1 REUSABLE TUG

MODE 2 EXPENDABLE TUG

MODE 3 REUSABLE TUG & VELOCITY PACKAGE

18093CVD4694

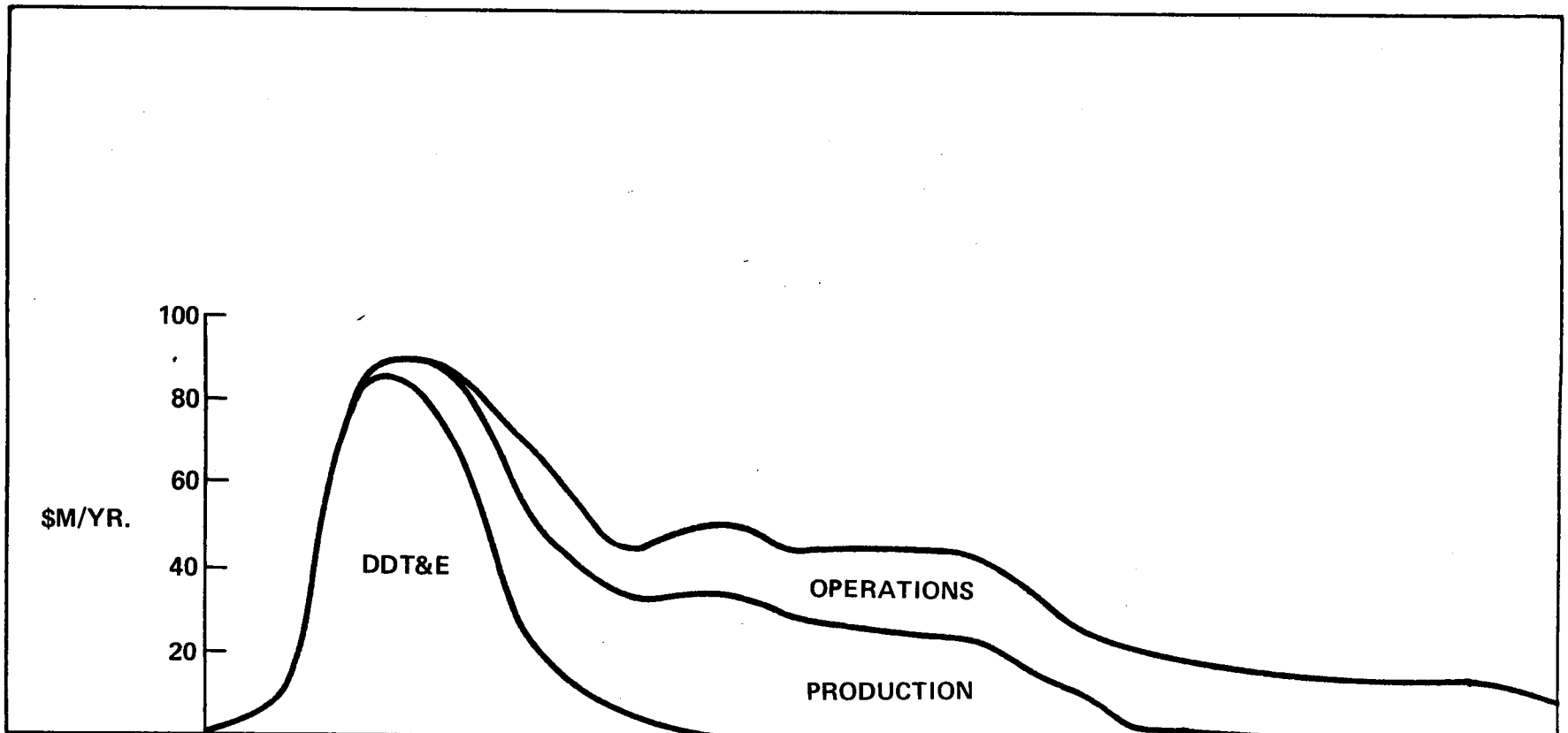
Peak year funding for the Program 1 Tug occurs in 1977, with 1978 nearly as high. This is due to the relatively compressed development time, which requires early heavy development activity. Vehicle production requirements to meet early heavy launch schedules keep funding requirements above $45 million through 1982.

Reference: Sections 8.6.4(1) to 8.6.7(1)

ANNUAL FUNDING

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1



FY	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
DDT&E	16.6	85.6	65.9	19.6	5.4											
PRODUCTION		3.0	18.0	27.2	30.9	37.2	30.3	27.0	24.1	15.3	3.4	0.3				
OPERATION					9.4	15.5	15.7	17.4	18.6	18.5	18.5	17.5	16.2	16.2	16.0	7.9
TOTAL	16.6	88.6	83.9	46.8	45.7	52.7	46.0	44.4	42.7	33.9	21.9	17.8	16.2	16.2	16.0	7.9

18093CVD4698

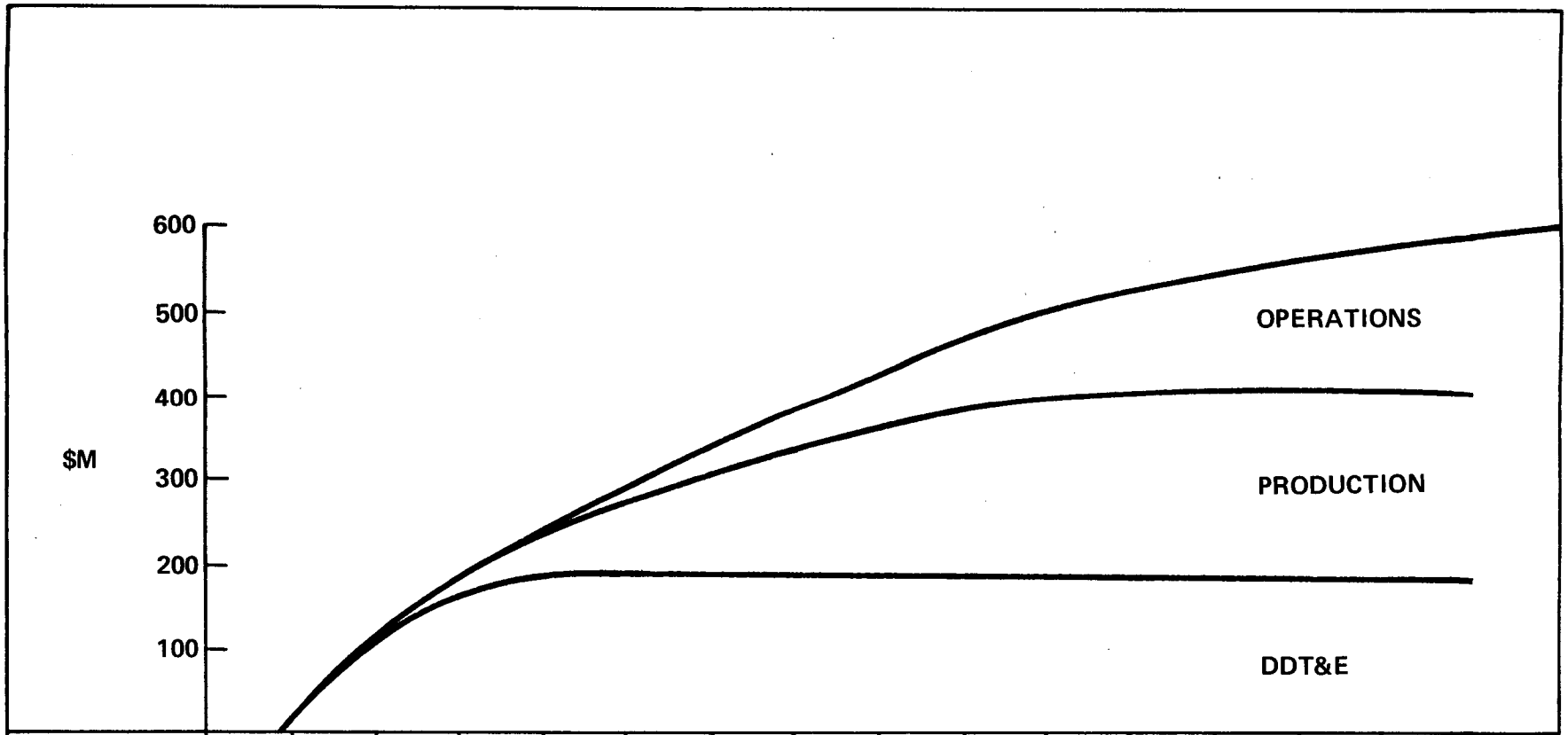
This chart shows the cumulative funding requirements and includes the breakdown into DDT&E, production and operations.

Reference: Section 8.6(1)

CUMULATIVE FUNDING

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1



FY	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
DDT&E	16.6	102.2	168.1	187.7	193.1											
PRODUCTION		3.0	21.0	48.2	79.1	116.3	146.6	173.6	197.7	213.0	216.4	216.7				
OPERATION					9.4	24.9	40.6	58.0	76.6	95.2	113.7	131.2	147.4	163.6	179.6	7.9
TOTAL	16.6	105.2	189.1	235.9	281.6	334.3	380.3	424.7	467.4	501.3	523.2	541.0	557.2	573.4	589.4	597.3

18093CVD4697

The purpose of the risk assessment is to identify those areas which could degrade Tug performance or programmatics/cost if predicted values are not attained. Risk assessment is concerned with the residual risks in the configuration and program as defined and as assessed at this point in time. Risk and program/configuration definition is an iterative process and many of the risk areas identified could be changed by suitable modifications to designs, test programs, etc.

Areas of concern are listed on the left hand side of the chart. These are arranged in decreasing order of concern as expressed by NASA/DOD personnel on the Tug program, i.e., safety is the issue of greatest concern followed by cost, schedule, etc.

An overall program risk assessment is practical if all elements of the program are included and if numerical ratings can be assigned. The horizontal bars show the relative risk on a scale of 0-10. These risk ratings are based on the MF-003M rating for cost confidence. The zero (low risk) value is used for off the shelf items, where familiar procedures are used, where detailed analyses have been made; in general when there is high confidence that the technical/programmatic/cost predictions will be attained easily. The 10 (high risk) value relates to advanced technology subsystems that have no hardware basis, where major development is required, where adequate analyses have not been made, where the program is overconstrained by cost, performance and schedule requirements.

The right hand column shows a brief explanation of why the risk for each area of concern is so rated on the 0-10 scale.

For Program 1, as defined in this report, schedule is considered to be most vulnerable item followed by ground operations, structure and cost. The items of least concern are subsystem weights and propulsion performance because of large margins and off-the-shelf propulsion systems (Section 8.9.2). Safety is also rated a low risk because potential hazards have been overcome by designing-in adequate solutions, absorbing the associated weight penalties and structuring the ground test program to verify these solutions. IOC could slip by up to 5 months (See Section 8.9).

In general, the risks associated with Program 1 are extremely small and much less than is usually associated with an advanced space program in its phase A development status.

RISK
Program Drivers = Schedule & Reusability

AREA OF CONCERN	MEASUREMENT OF RISK (LOW 0 – 2 – 4 – 6 – 8 – HIGH 10)	EXPLANATION
SAFETY		SAFETY DESIGNED IN (252 LB. WEIGHT PENALTY), VERIFICATION TEST PROGRAM, CREW MONITOR & OVERRIDE
COST		CONFIDENCE LEVEL = 3.25, CENTAUR COST STUDY
SCHEDULE		TANKS & SOFTWARE ARE PACING ITEMS
MISSION EFFECTIVENESS		100% MISSION CAPTURE, LARGE GROWTH POTENTIAL (1.54 PAYLOADS/FLIGHT)
FLIGHT OPS. COMPLEXITY		97% OF FLIGHTS = SINGLE TUG OPERATION
REUSABILITY		PROVEN COMPONENTS, MAX. RELIABILITY FOR MIN. COST, MTBF IS INSENSITIVE FOR REDUNDANT SYSTEMS
GROUND OPERATIONS		REUSE NOT DEMONSTRATED BUT TECHNIQUES UNDERSTOOD
WEIGHT		TOTAL CONTINGENCY = 23% FOR 3,500-LB. PAYLOAD
TECH. PERF: STRUCTURE		FRACTURE CONTROL & FLAW DETECTION IN TANKS, PROOFING OF DOCKING SYSTEMS
PROPULSION		AVAILABLE TECHNOLOGY SIMILAR TO CENTAUR
ASTRIONICS		CENTAUR TECHNOLOGY + ADDED REDUNDANCY GUIDANCE UPDATE ACCURACY & STRATEGY
THERMO		CENTAUR TYPE CONFIG., PURGE BAG DEVELOPMENT

The technology requirements shown represent the areas where significant technology development would be desirable in order to assure orderly development of the Tug with low risk. For the most part, they represent demonstration that current technology development items will operate as intended for the Tug mission and that these items will operate through the cyclic environment of multiple reuse.

A significant amount of technology development is needed to develop practical NDT methods for inspection and check-out of major Tug subsystems.

Refer to Volume 5, Book 1.

TECHNOLOGY REQUIREMENTS

- N_2H_4 ACPS CATALYST BED LIFE AS AFFECTED BY LAUNCH VIBRATION, COLD & HOT STARTS, ATMOSPHERIC CONTAMINATION (~$250,000)
- BULK EXCHANGER ZERO-g VENT OPERATIONS UNDER SIMULATED TUG CONDITIONS FOR BOTH O_2 & H_2 TANKS (~$200,000)
- DATA MANAGEMENT & SOFTWARE REDUNDANCY TECHNIQUES (~$500,000)
- AUTONOMOUS GUIDANCE UPDATE SYSTEM ACCURACY (~$500,000)
- RELIABLE INSTRUMENTATION TO SUPPORT MAINTENANCE WITH SELF-CHECKING (~$200,000)
- CHECKOUT TECHNIQUES APPLICABLE TO REDUNDANT COMPONENTS (~$200,000)
- HIGH CONFIDENCE CONDITION ASSESSMENT TECHNIQUES FOR TANKAGE (~$300,000)
- METEOROID IMPACT EFFECTS ON PRESSURIZED TANKAGE (CRATERING, SPALLATION); ESTABLISH DAMAGE CRITERIA CONSTRAINT (~$100,000)
- INSULATION PURGE GAS DISSIPATION, CONDUCTIVITY TESTING & DAMAGE ASSESSMENT TECHNIQUES (~$300,000)

18093CVD4608

This chart shows the schedule sensitivity of Program 1 to a two year extension of the IOC date (from 12/79 to 12/81) while maintaining the same ATP date. Such an extension greatly reduces the potential of any schedule risk with the 12/79 IOC program. Ample contingency time would be available for critical event evaluations before proceeding too far with activities that should be constrained by such events. For a tight program (like the 12/79 IOC) this is a situation not normally attainable. The included schedule activities are displayed by major program disciplines rather than by WBS elements for simplicity of presentation. All significant subsystem and vehicle development events are included with their appropriate activity line schedule.

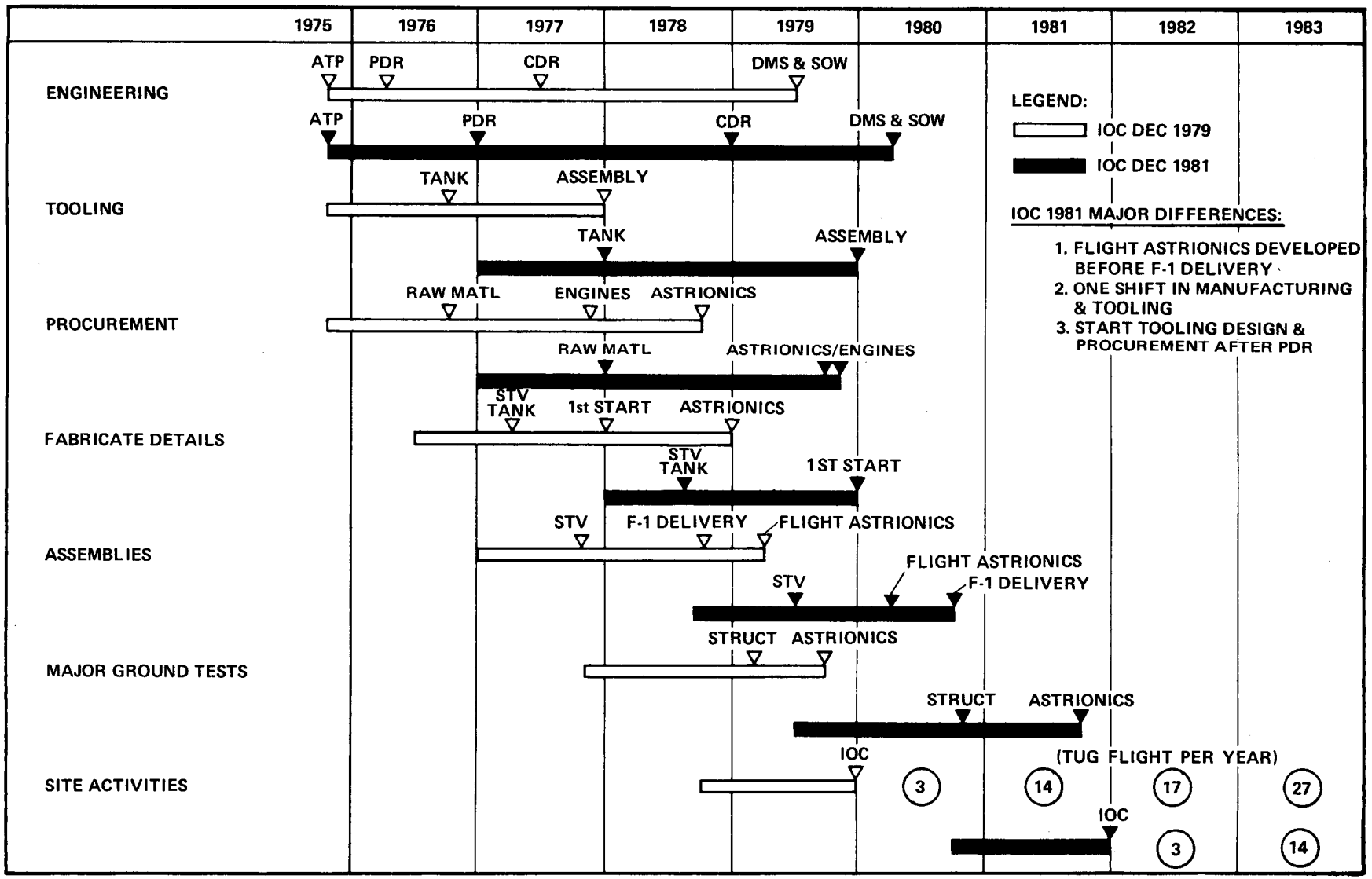
This program extension would also reduce the early years funding requirements as reflected by a later PDR and start of detail fab. Manufacturing and tooling activities would function on a one-shift basis. Start of tooling and material and hardware procurement would be initiated after PDR rather than before. Another feature not enjoyed on the shorter program is the availability of astrionics and software integration prior to the initial flight vehicle delivery. Such a schedule also permits better time correlation between vehicle qualification testing and flight article production.

A development program of this duration could logically support the necessary payload retrieval capability development if such capability were desired, but of course at increased costs and early year funding.

SPACE TUG DEVELOPMENT PROGRAM SUMMARY

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1
TWO YEAR
EXTENSION



18093CVD4685

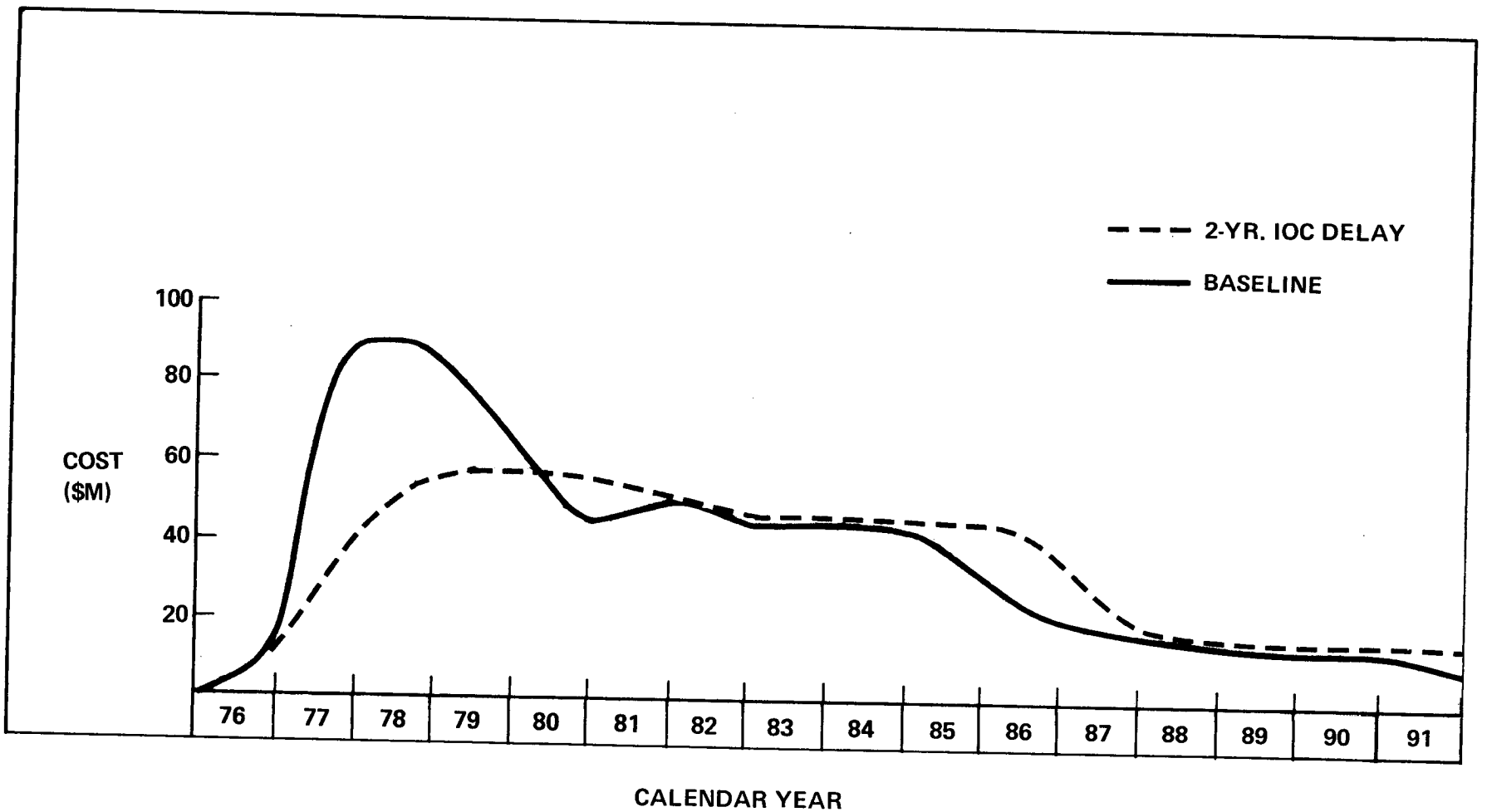
This chart shows the funding spread for a two year IOC delay with the same ATP. The baseline funding spread is shown for reference. The IOC delay reduces the peak funding from $89M in 1977 for the baseline to $57M in 1979 and 1980.

Reference: Section 8.8 (1)

IOC VARIATION
Impact on Annual Funding

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 1



18093CVD4715

COMPARATIVE SENSITIVITIES

The sensitivity of Tug reliability to mission duration is described on the facing chart. The mission reliabilities for Programs 1, 2 and 3 were first established for the baseline missions associated with each of these programs. The mission durations were then varied for each of the programs in accordance with the sensitivity analysis groundrules. As indicated in this chart, the rates of reliability change with respect to time are: 0.009 per day for Program 1, 0.005 per day for Program 2 and 0.004 per day for Program 3. Program 1 reliability, therefore, is significantly more sensitive to variations in mission duration than Programs 2 and 3. The principal reason being that Program 1 redundancy levels were based on achieving a reliability of .97 for a baseline mission of only 47 hours. When an attempt is made to extend the mission duration, the reliability falls off relatively sharply. On the other hand, Program 2 and 3 Tugs are designed to attain a 0.97 reliability for approximately 6 & 5-day missions. A greater degree of redundancy was consequently built into these designs and the sensitivity of their reliability to mission duration is comparatively small.

Since performance also varies with mission duration, the reliability vs. mission duration sensitivity analysis must be played against performance sensitivity. To permit this comparison to be made, an inset chart of performance sensitivity to mission duration has been provided.

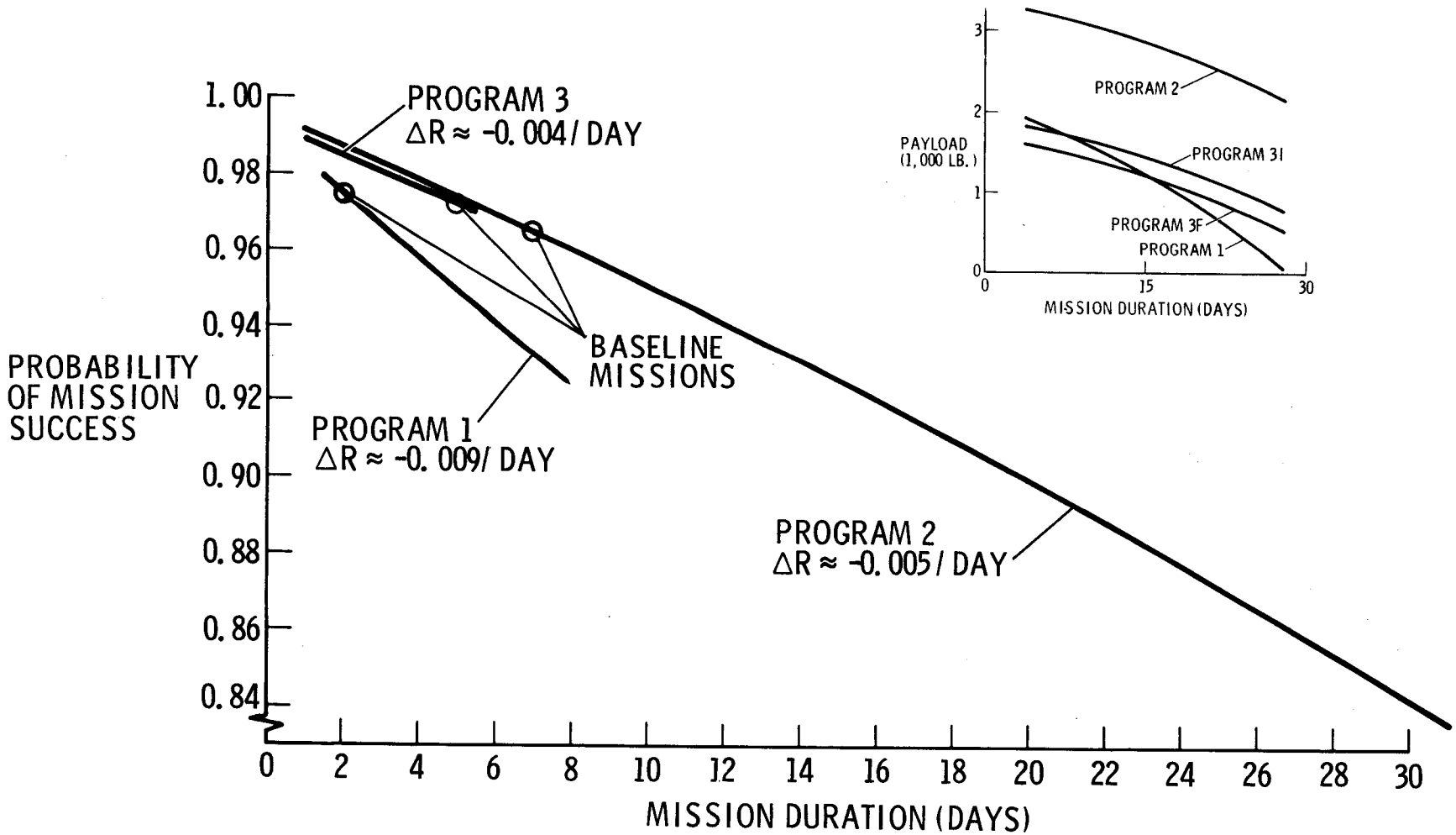
The inset chart shows the decrease in payload capability with extended mission durations for each of the Tug program configurations. A synchronous equatorial sortie mission is used for illustration. The Tug takes the payload to synchronous equatorial orbit, supports it without separation for a variable number of days, then returns the payload to the Orbiter. The decrease in payload is due to propellant venting, residuals, and the consumption of propellants for attitude control and fuel cell operation.

Similar trends apply for other mission modes, such as the round-trip mission, with adjustments to account for delta velocities and appropriate increases in ACS propellant tank capacity. In some cases (e.g., the multiple satellites service mission), delta velocities decrease as mission duration increases, resulting in a peak in the payload-vs.-duration curves. Such cases are mission-peculiar, depending on the amount of phasing required.

Ref. Volume 5, para. 5.9.2
Ref. Volume 5, para. 5.7.1

RELIABILITY VS. MISSION DURATION

GENERAL DYNAMICS
Convair Aerospace Division



18093CVD4689

The cost of autonomy was analyzed for Programs 1, 2 and 3. The analysis of cost and weight differences was referenced to Autonomy Level I because Programs 1, 2 and 3 have Autonomy Level I implementation in the Guidance Update and Rendezvous and Docking subsystems. In terms of equipment, this means a horizon sensor and a star sensor for guidance update and dual laser radars for automatic rendezvous and docking. The weight differences for Level II is the result of removing the star sensor and adding a sun sensor and navigation satellite user equipment; for Level III, removal of the star sensor and the addition of the sun sensor and, in the case of Program 2 and 3 final, the addition of television and its associated communications equipment. The same is true of Level IV.

Cost differences involve the costs of the above hardware changes plus considerations of software variations, ground support hardware, software and operations personnel and their training. The cost elements are shown in detail in Volume 6. (Refer to Section 6.12.4)

AUTONOMY SENSITIVITY
Δ's REFERENCED FROM AUTONOMY LEVEL I

	PROGRAM 1			PROGRAM 2			PROGRAM 3I			PROGRAM 3F		
	AUTONOMY LEVELS			AUTONOMY LEVELS			AUTONOMY LEVELS					
Δ COST ($M)	II	III	IV	II	III	IV	II	III	IV	II	III	IV
Δ WEIGHT	+23	-3	-3	+23	+35	+35	+23	-3	-3	–	+35	+35
DDT&E	+1.6	+2.1	+3.4	+1.6	+10.1	+11.9	+1.6	+2.1	+3.4	–	+8	+8
PRODUCTION & SPARES	+0.4	-1.5	-1.5	+0.4	+2.7	+2.7	+0.4	-1.5	-1.5	–	+4.2	+4.2
OPERATIONS	0	+5	+9.9	0	+5.5	+8.6	0	+1.8	+3.6	–	+3.5	+5.5
PROGRAM	+2.0	+5.6	+11.8	+2.0	+18.3	+23.2	+2.0	+2.4	+5.5	–	+15.7	+17.7

AUTONOMY LEVEL I HAS:

- LOW DDT&E COST
- LOW OPERATIONS COST
- LOW TOTAL PROGRAM COST

18093CVD4714

The Tug vehicle has been designed to be reusable but no attempt has been made to limit the number of reuses for which the vehicle would be designed. Conversely, very little additional DDT&E effort has been included to extend the life of components. The design was allowed to progress in a normal manner and component life checked after the design met the specified strength, accuracy, etc. The only components found to have a mean time between overhaul or design life less than 100 missions are: 1) the RL10 Cat. I engines, 2) the ACPS thrusters, 3) the MLI, and 4) the fuel cell.

The RL10 Cat I engine design life data and refurbishment cost was obtained from Pratt & Whitney Aircraft and can be summarized as 5 hours or 190 cycles between overhauls. This is equivalent to 10 missions (engine firing per mission is ~0.5 hours). Thus, the RL10 engine requires a minor overhaul of the gearing and inspection of the parts, plus a hot firing after each 10 missions. The cost of this operation is 41% of the engine cost. After 20 missions, the thrust chamber is assumed to need replacement which, when added to the gearing and inspection overhaul has a total cost of 71% of the engine cost.

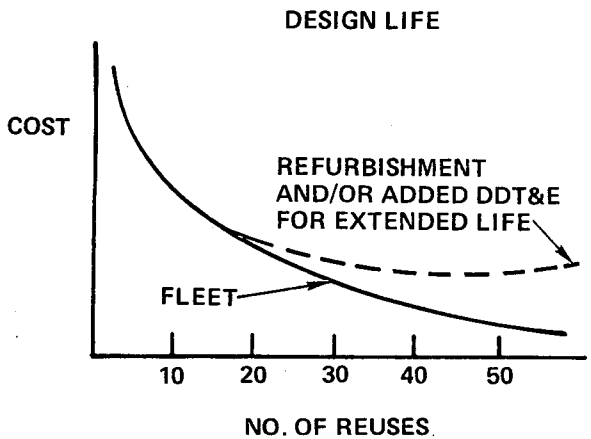
The ACPS engine is assumed to last 10 missions before overhaul which consists of replacing the catalyst bed. This assumes cutting the engine aprt, replacing the catalyst and rewelding which is done once per engine. The cost is assumed to be 15% of the cost of a new engine.

The MLI is assumed to have a life of 20 missions. Beyond that, the insulation is removed and replaced. Should the insulation upon removal show little damage the design life for succeeding sets may be increased beyond the 20-mission nominal.

The fuel cell is predicted to have a life in excess of 5000 hours, which is equivalent to approximately 50 missions. Beyond this, if the cell shows signs of deterioration, it will be replaced. The data to be accumulated on the Tug and Shuttle fuel cells will better define this life.

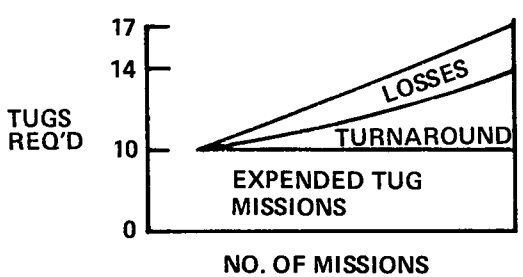
All other systems have a life far in excess of the 100 missions equivalent and will be subject to random failure replacement. The cyclic testing required would increase to show this increased life, but the major cost of the test is the test setup and the test specimen. The additional time required to test to a larger number of cycles is generally small.

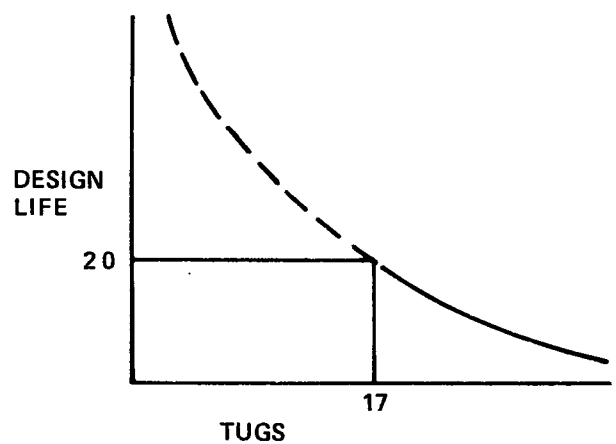
DESIGN LIFE



MINIMUM COST IS NEAR 40 TO 50 REUSES, BUT MISSIONS DRIVE AVERAGE REUSES TO 15 TO 20

MISSIONS DRIVE NUMBER OF TUGS REQ'D.





MAIN ENGINE, ACPS ENGINES & MLI HAVE INHERENT LIFE < 100 REUSES

DURATION OF LIFE TESTS (STRUCTURE, TANKS, ETC) HAS SMALL EFFECT ON DDT&E COST

18093CVD4618

This chart shows sensitivity of program costs to ground turnaround time for Program 1. The basic assumption derived from the operations analyses is that regardless of crew size, Tug turnaround serial time is constant at 270 hours. Of this time, 154 hours are constrained by the Orbiter timeline while the Tug is in the cargo bay. Thus, the variation in the number of shifts assigned (and resultant total crew size impact) can only be applied to the 116 hours when the Tug is outside the cargo bay. Work hours are converted to calendar days to evaluate this impact since the work week is five days. The result is shown in the upper righthand curve. With the further assumptions of an average two-day flight, even launch centers, and maximum Program 1 annual launch rates of 22 flights from KSC we can plot minimum active fleet size against turnaround time. As can be seen at the upper left, a total one-shift operation at KSC would require an additional vehicle in the active fleet inventory as long as the Tug is installed in the cargo bay while the Orbiter is in the MCF. Operations are based on two shifts, five days per week. Converting the crew size variations and additional vehicle to equivalent total program dollars we obtain the curves in the lower left. Here we see that going to three shifts to reduce turnaround time does not reduce the number of vehicles required, but does add manpower costs. Conversely, reducing to one shift would save manpower dollars, but add one vehicle to the active fleet requirements. While this would appear to save total program dollars, it reduces operational flexibility by reducing manpower to the level where it is all but impossible to accommodate the uneven launch center cases. On the other hand, pad installation of the Tug would permit reducing to one shift and still accommodate uneven launch center cases.

(Reference: Vol. V, 5.9.3)

GROUND TURNAROUND TIME SENSITIVITY

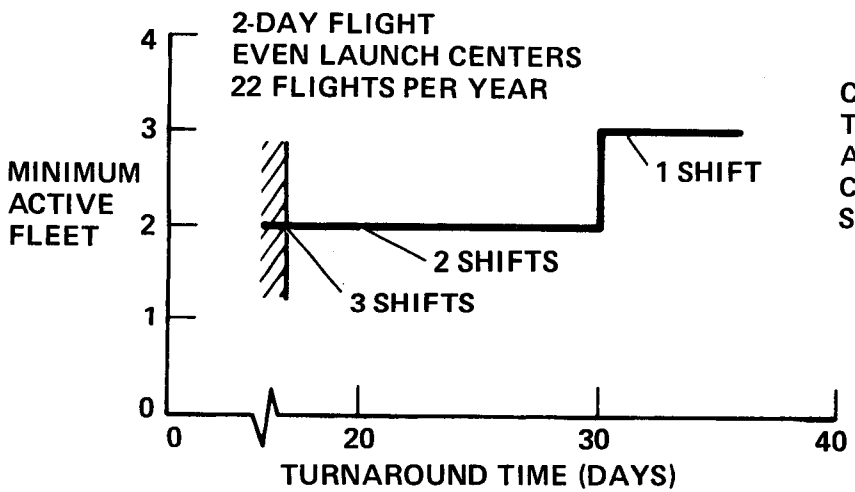
GENERAL DYNAMICS
Convair Aerospace Division

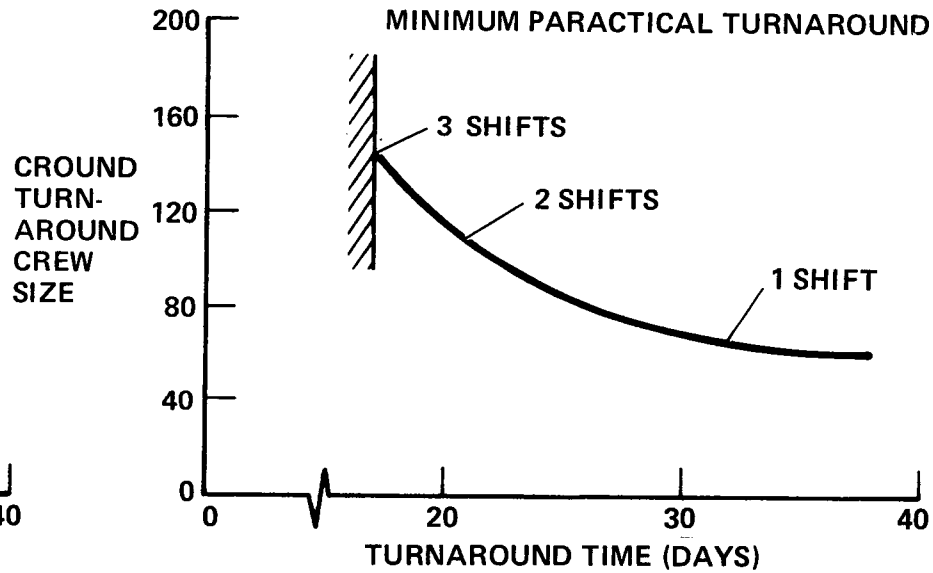
ASSUMPTIONS:

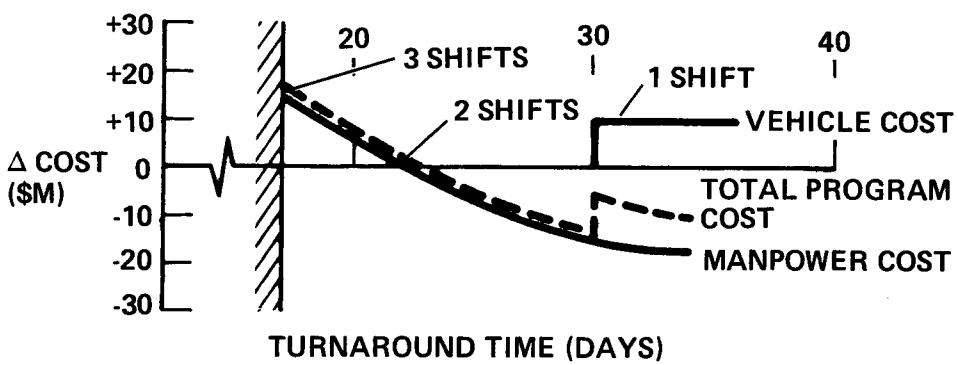
TURNAROUND MANHOUR REQUIREMENTS ARE CONSTANT

TUG IN ORBITER 154 OF 270 WORKING HOURS: 14 HR. POSTLANDING, 140 HR. PRELAUNCH

EFFECT OF GROUND TURNAROUND TIME (VARY TIME OUTSIDE ORBITER)







CONCLUSIONS:

TUG-ALONE TURNAROUND TIME HAS MINOR EFFECT UPON COST

PAD INSTALLATION OF TUG WOULD PERMIT ONE-SHIFT OPERATION AT KSC

18093CVD4657

The cost per energy level was developed for the Tug for Program 2. The basic reusable Tug flight mode used for 228 flights is defined as the low energy mode. Cost per flight for this mode is determined for each user at each site. The medium energy flight mode, used for ten flights by NASA at ETR, is the reusable Tug with an expendable velocity package. The high energy flight mode, used for 5 flights by NASA at ETR, is an expendable Tug. In addition to cost per flight for the Tug a total cost per payload is developed for each user, site and applicable flight mode. This cost includes the cost of the Shuttle flight at $10.5 million.

The WBS is such that some costs are common to all sites and users, some costs are common to sites, and some costs are common to users. Each cost model output is therefore allocated to the site and user by the proper ratio of flights. Cost per flight for the low energy mode is shown and are lower for each user at ETR due to the higher flight rate compared to WTR. Costs for DOD are lower than NASA due to the savings in flight support software attributed to more flights of each mission. The medium energy mode has the velocity package cost added to the basic low energy mode. The high energy mode has the cost of the Tug added to the low energy mode. This allows for the Tug ground turnaround activities and launch operations prior to the flight and flight operations during the flight.

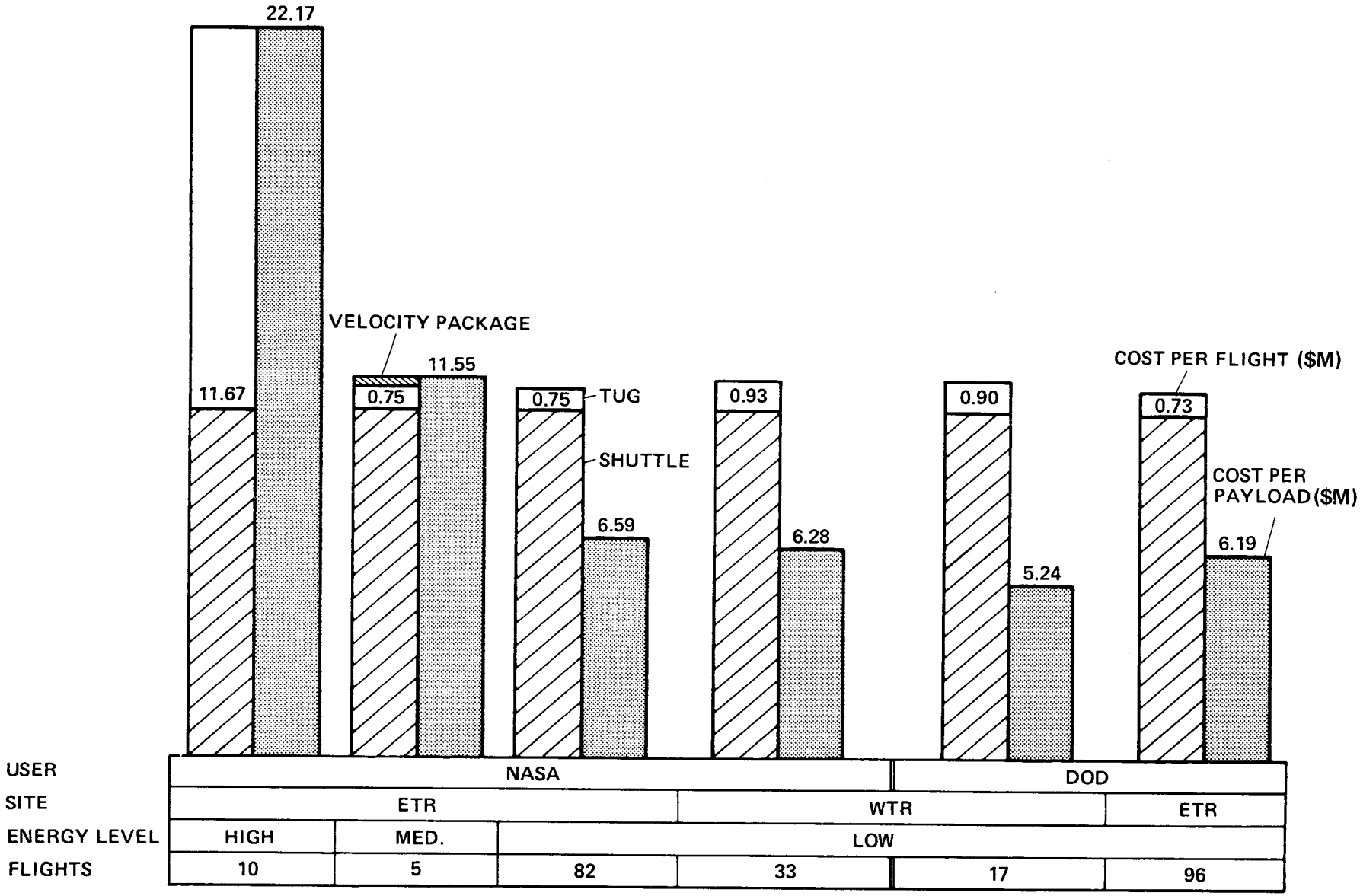
The figure also summarizes the total operations cost per payload for all flight modes. This cost is composed of the Tug cost plus the Shuttle cost of $10.5 million per flight divided by the payloads delivered or retrieved. Substantial savings are exhibited by the reusable Tug due to its high multiple payload mission capture. The medium and high energy levels deliver only single payloads and hence the cost is the same as the cost per flight. The range of cost per payload for the low energy mode is $5.3 to 6.6M. This low cost is due to the large number of multiple payload deliveries. The varistions between users primarily reflect this with slight differences due to the Tug cost per flight. These results illustrate the cost benefits of high vehicle performance capability.

Details of the results are presented in Volume 6, Operations.

COST PER ENERGY LEVEL

GENERAL DYNAMICS
Convair Aerospace Division

PROGRAM 2



18093CVD4660

Several other special sensitivity studies were performed as indicated on the chart. These involved defining the vehicle changes associated with certain capability features and the resultant payload and development cost impact.

Providing 300w of payload power in program 1 does not affect the weight or cost but merely requires a slight increase in fuel cell reactants. The addition of rendezvous and docking capability requires adding a 77 lb docking frame and 60 lb laser radar plus software changes. Payload spin or despin capability requires a spin kit plus software changes and an increase in ACPS propellant.

There are 3 sensitivities under DOD communications. Increasing the communication rate requires 3 antennas. SCF communication requires adding Tug to Ground SGLS equipment which includes the 10 lbs for the secure communications encryptor and decryptor.

The addition of payload service capability requires software changes for the modes when the payload is attached to the Tug. Payload communication, when the payload is detached, requires a Tug payload RF link.

The performance increment associated with these capability features is presented on the chart. The rendezvous and docking payload is the total payload and not the increment. One of the reasons this retrieval payload is low is that the Program 1 Tug is sized for the deployment mission and only has a propellant capacity of about 50,000 lbs.

Reference Sections 5.9.2(1) and 5.9.2(2)

OTHER SENSITIVITY STUDIES

SENSITIVITY AREA	REQUIRED CHANGES	Δ INERT WT. (LB.)	Δ DDT&E ($M)
PAYLOAD POWER (300W)	INCREASE FUEL CELL REACTANTS (3 LB.)	—	—
RENDEZVOUS & DOCKING	ADD DOCKING FRAME, LASER RADAR, SOFTWARE	137	13.2
PAYLOAD SPINUP	INCREASE ACPS PROPELLANT (7 LB.) ADD SPIN/DESPIN KIT, SOFTWARE	87	~1.0
DOD COMMUNICATIONS			
256 Kbps	ADD 3 ANTENNAS	10	.4
SCF COMM.	ADD TUG/GROUND SGLS EQUIPMENT	42	1.8
SECURE COMM.	ADD ENCRYPT. & DECRYPTER	10	—
PAYLOAD SERVICES	SOFTWARE, TUG/PAYLOAD RF LINK	44	6.3

	PROGRAM	4 GEOSYNCHRONOUS PAYLOAD (LB.)	
		DEPLOY	RETRIEVE
PAYLOAD POWER	1	-3	
RENDEZVOUS & DOCKING	1	NA	1,720*
PAYLOAD SPINUP/DESIGN	1, 2, 3	-264	-160
DOD COMMUNICATIONS			
256 KBPS	1, 2, 3	-29	-18
SCF COMM.	1, 2, 3	-123	-73
SECURE COMM.	1, 2, 3	-29	-18
PAYLOAD SERVICES	1, 2, 3	-128	-77

*TOTAL RETRIEVAL PAYLOAD OF PROGRAM 1 TUG

This chart presents a comparison of Program 1 and Program 3I which have the same minimum payload requirement and IOC. Program 1 is a direct development program while Program 3 is a phased program. An objective with both programs is to minimize the development cost. The Program 1 configuration is sized to maximize deployment payload within the Shuttle capability constraints while the initial vehicle in Program 3 is sized to the final retrieval mission.

The table indicates the major subsystem differences. The structure and main propulsion are the same except for size. The Program 3I vehicle has larger tankage due to sizing for final retrieval. The ACPS systems are identical except for the size of the propellant bottles. Larger bottles are used with the 3I configuration in order to reduce the number of bottles in the final program. The retrieval mission for the final vehicle has the highest ACPS propellant requirement and would require an impractical number of the smaller bottles used on Program 1. The insulation systems are different. Program 1 uses the Centaur type while Program 3 uses MLI-Superfloc. The superfloc was selected for Program 3 since it is a superior insulation for the longer missions with the final and initial vehicle. Insulation phasing did not seem justified. The astrionics systems are different. Program 1 uses a Centaur derived system while the Program 3I vehicle uses a new system which lends itself much better to phasing to the required advanced lightweight final system.

The burnout weight of the 3I vehicle is slightly heavier than the Program 1 vehicle resulting in a slightly lower deployment payload capability.

The Program 3I development costs are higher primarily as a result of the different astrionics and insulation systems.

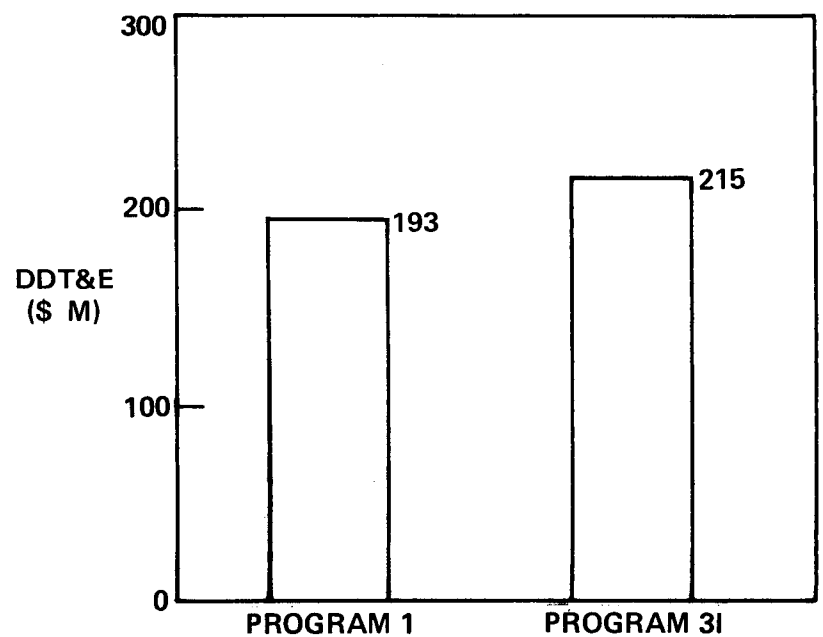
PROGRAM 1 VS PROGRAM 3I COMPARISON

SIZING

- PROGRAM 1 CONFIGURATION SIZED TO MAXIMIZE DEPLOYED PAYLOAD
- PROGRAM 3I CONFIGURATION SIZED FOR FINAL RETRIEVAL MISSION

SUBSYSTEM	PROGRAM 1	PROGRAM 3I	REASON
STRUCTURE	Al TANKS/Al S/S SHELL	Al TANKS/Al S/S SHELL	SAME
MAIN PROPULSION	RL10 CAT. I	RL10 CAT. I	SAME
ACPS	N_2H_4 – 22.5 IN. BOTTLE	N_2H_4 – 29 IN. BOTTLES	REDUCE NO. OF BOTTLES FOR 3F
THERMAL	MLI – DIMPLAR	MLI – SUPERFLOC	LONGER MISSION/PHASING CONSID.
ASTRIONICS	CENTAUR – DERIVED	NEW SYSTEM	BETTER SYSTEM FOR PHASING

ITEM (LB.	PROGRAM 1	PROGRAM 3I
STRUCTURE	2,339	2,375
PROPULSION	1,332	1,376
THERMAL CONT	427	407
ASTRIONICS	1,198	1,171
GROSS DRY WT.	5,826	5,862
BURNOUT WT.	6,579	6,643
USABLE PROPELLANT	49,715	49,820
DEPLOY PAYLOAD	5,352	5,183



18093CVD4513

Programs 2 and Program $3F_{mod}$ have identical minimum retrieval payload requirements. The programs have somewhat different objectives however in that Program 2 emphasizes total program cost effectiveness while Program 3, which is a phased program emphasizes low total program cost. In defining these configurations performance. was therefore given more emphasis on Program 2 than Program $3F_{mod}$.

The upper table compares the major subsystems. The primary difference is in the body shell. Program 2 uses a composite shell to reduce weight and improve performance. Program $3F_{mod}$ uses the same aluminum skin stringer shell that is used on the initial vehicle to minimize development cost. Phasing to a composite shell on the final vehicle was not believed to be justified. The insulation and astrionics systems are the same.

The weight comparison indicates that the Program $3F_{mod}$ vehicle has a burnout weight about 450 lbs heavier than Program 2 which results in significantly lower retrieval payload. The weight difference comes primarily from the structural weight difference with a small part from the different ACS propellant bottles.

PROGRAM 2 VS PROGRAM $3F_{mod}$ COMPARISON

SUBSYSTEM	PROGRAM 2	PROGRAM $3F_{MOD}$	REASON
STRUCTURE	Al TANKS/COMPOSITE SHELL	Al TANKS/Al S/S SHELL	HIGH PERF. VS. LOW DDT&E
MAIN PROPULSION	RL10 – CATEGORY IIB	RL10 – CATEGORY IIB	SAME
ACPS	N_2H_4 – 22.5 IN. BOTTLES	N_2H_4 – 29 IN. BOTTLES	LARGE BOTTLES REQ. FOR 3I
THERMAL	MLI – SUPERFLOC	MLI – SUPERFLOC	SAME
ASTRIONICS	LIGHTWT. SYSTEM	LIGHTWT. SYSTEM	SAME

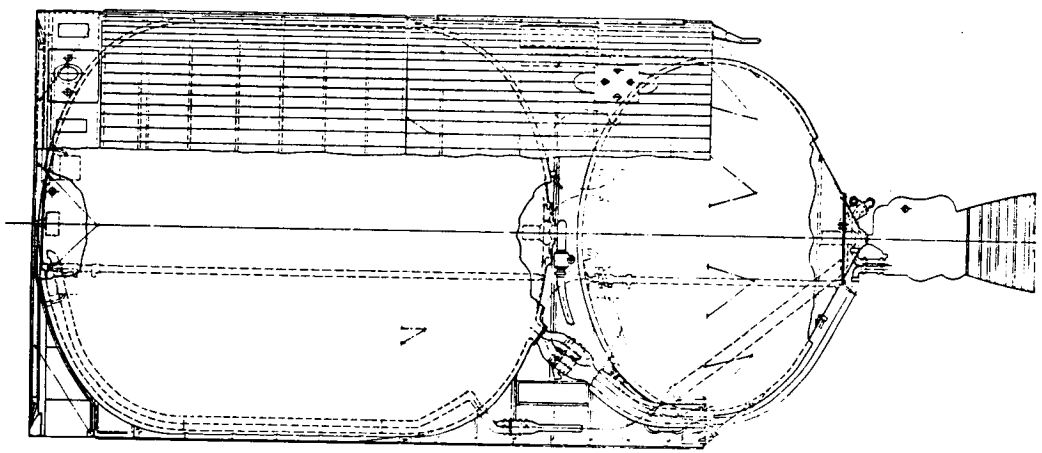
ITEM (LB.)	PROGRAM 2	PROGRAM $3F_{MOD}$
STRUCTURE	2,094	2,472
PROPULSION	1,466	1,500
THERMAL CONT.	416	415
ASTRIONICS	984	984
GROSS DRY WT.	5,456	5,908
BURNOUT WT.	6,231	6,676
USABLE PROPELLANT	56,303	55,701
DEPLOY PAYLOAD	5,204	4,435

18093CVD4512

CONCLUSIONS

The primary conclusion with regard to Program 1 is that a system can be developed for less than $200M provided maximum utilization is made of existing vehicle components, facilities and technology.

PROGRAM 1 CONCLUSIONS



- REUSABLE TUG WITH DEPLOY CAPABILITY CAN BE DEVELOPED FOR LESS THAN $200 MILLION
- CENTAUR PROPULSION, ASTRIONICS & THERMAL COMPONENTS CAN BE USED WITH MINIMUM MODIFICATION
- OTHER EXISTING COMPONENTS – i.e., SHUTTLE FUEL CELL & ACPS – CAN BE USED WITH MINIMUM MODIFICATION
- DDT&E COSTS ARE REDUCED BY MODIFYING EXISTING KSC FACILITIES FOR TUG MAINTENANCE

18093CVD4707