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Volume 1

Final Report

January 1974

Overview Presentation

Space Tug Systems Study (Storable)

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Presented to;
George C. Marshall
Space Flight Center

MARTIN MARIETTA

[redacted]

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OVERVIEW PRESENTATION

SPACE TUG SYSTEMS STUDY (STORABLE)

Presented to:

George C. Marshall
Space Flight Center

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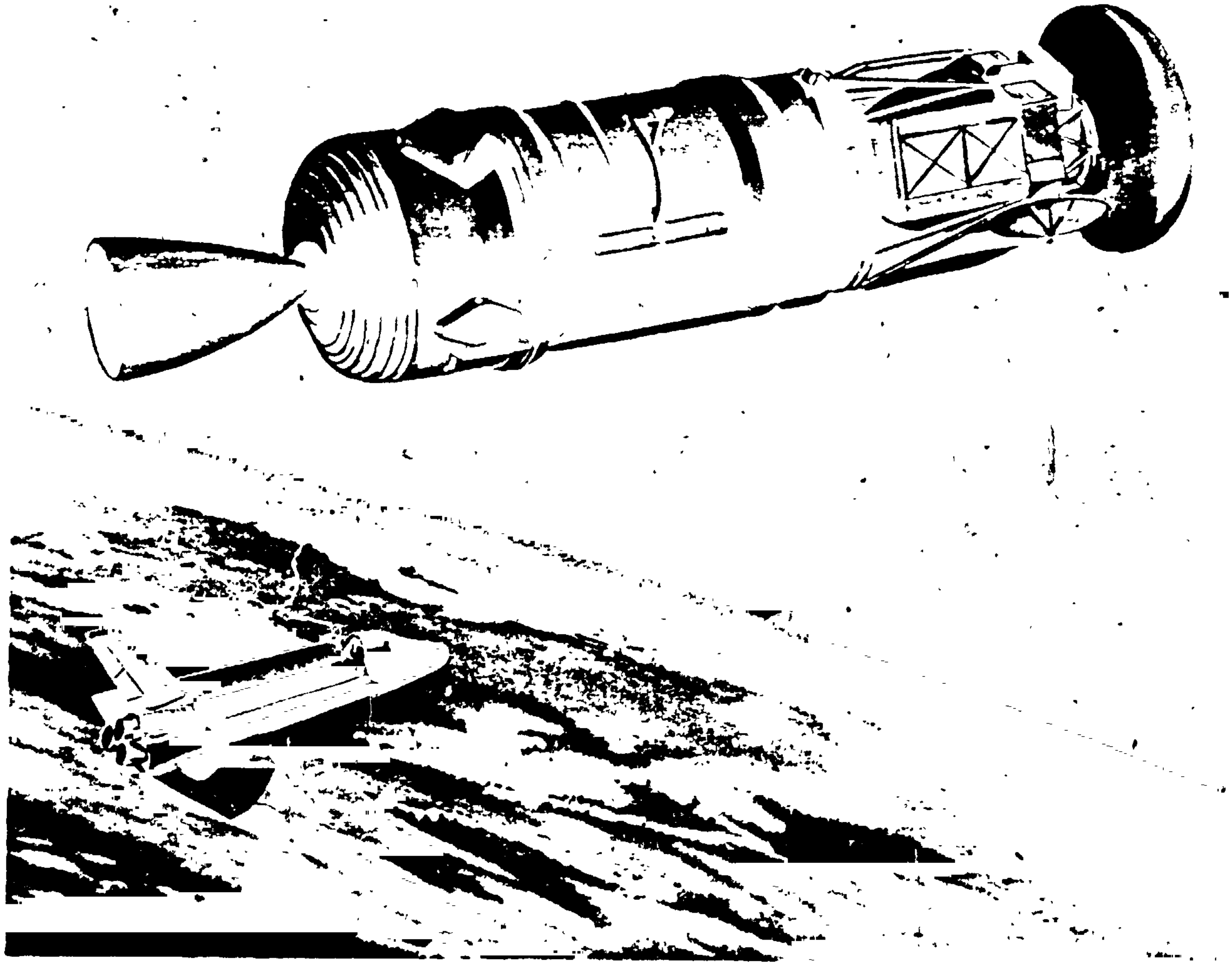

Martin Marietta Version of Space Tug (Storable) with Spacecraft

FOREWORD

This final report is submitted in accordance with the requirements of Data Requirement MA-02-G of the Data Procurement Document of contract NAS8-29675, as clarified by NASA letters No. PD-TUG-C-73-207 dated October 26, 1974, and PD-TUG-C-74-6, dated January 17, 1974, signed by Robert J. Davies, Study Manager.

This final report is submitted in three volumes:

Volume 1 - Overview Presentation

Volume 2 - Compendium

Volume 3 - Executive Summary

ABSTRACT

Program plans are established for a storable propellant space Tug used to perform high energy orbit transfers from the Space Transportation System (STS) Orbiter. The mission model for the STS in the 1980's is analyzed. Performance and mission requirements are determined. Various flight operations modes are evaluated and selected. Subsystems are selected and synthesized into various Tug configurations. Program options for these configurations are defined, analyzed and selected. Selected program options are further defined and optimized, including program requirements, Tug vehicle definition, mission accomplishment, ground and flight operations, programmatics and costs.

SPACE TUG SYSTEMS STUDY (STORABLE)

FINAL PRESENTATION

JANUARY 15, 1974

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FINAL PRESENTATION AGENDA

1. Technical and Programmatic Review of Option 2
2. OOS/Tug Transition

   Orbital Operations
   Orbiter to Tug Interfaces
   Tug to Spacecraft Interfaces
   Ground Operations
   Safety

3. Stage Length vs Performance (Sensitivities/Implications)
4. Special Programmatic Considerations

   Sensitivity to Duration of Development Program
   Assessment of Impact If OOS Is Retained in the Stable

5. SR&T Requirements/Recommendations for Option 2

   Simulator/Demonstration Hardware Recommendations for Concept Verification Prior to Option 2 Development

PART 1

TECHNICAL AND PROGRAMMATIC REVIEW OF OPTION 2

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GROUND RULES AND CRITERIA

Option 2 Configuration Baselined Autonomy Level II

Minimum Titanium Tank Wall Thickness 0.018 in.

Structural Design, Leak Before Burst

Land Loaded, Tug Tanks Full

Provide Dump Capability in Horizontal and Vertical Position

Docking Adapter Length and Weight Chargeable to Tug

Required Reliability of 0.97 (Geosynchronous Missions)

Load On-Pad But Out of Orbiter

Provide Double Isolation of Liquids and Gases

Avionics & ACPS Systems Designed Fail Operate, Fail Safe

Main Propulsion System Designed Fail Safe

All Spacecraft Cantilevered from Front of Tug

OPTION 2 SUMMARY

This chart summarizes the Option 2 Program Definition. The vehicle consists of a single-stage high-technology Storable Space Tug that is direct developed. Delivery and retrieval capability is provided at ETR and WTR in December 1983. The vehicle used for delivery weighs 2750 pounds and the retrieval vehicle weighs 2982 pounds. A kit concept is used to convert from delivery to retrieval.

The retrieval vehicle can deliver as well as retrieve, but has less delivery capability due to the higher weight of the rendezvous and docking kit.

OPTION 2 SUMMARY

Single-Stage High Technology Space Tug (Storable)

Direct Developed

IOC December 1983 (ETR and WTR)

Dry Weight	- Delivery Vehicle		2,750 pounds
	- Retrieval Vehicle		2,982 pounds
Propellant Weight			59,800 pounds
Payload Capability			
Delivery -	Delivery Vehicle		6,000 pounds
	Retrieval Vehicle		4,900 pounds
Retrieval			1,800 pounds

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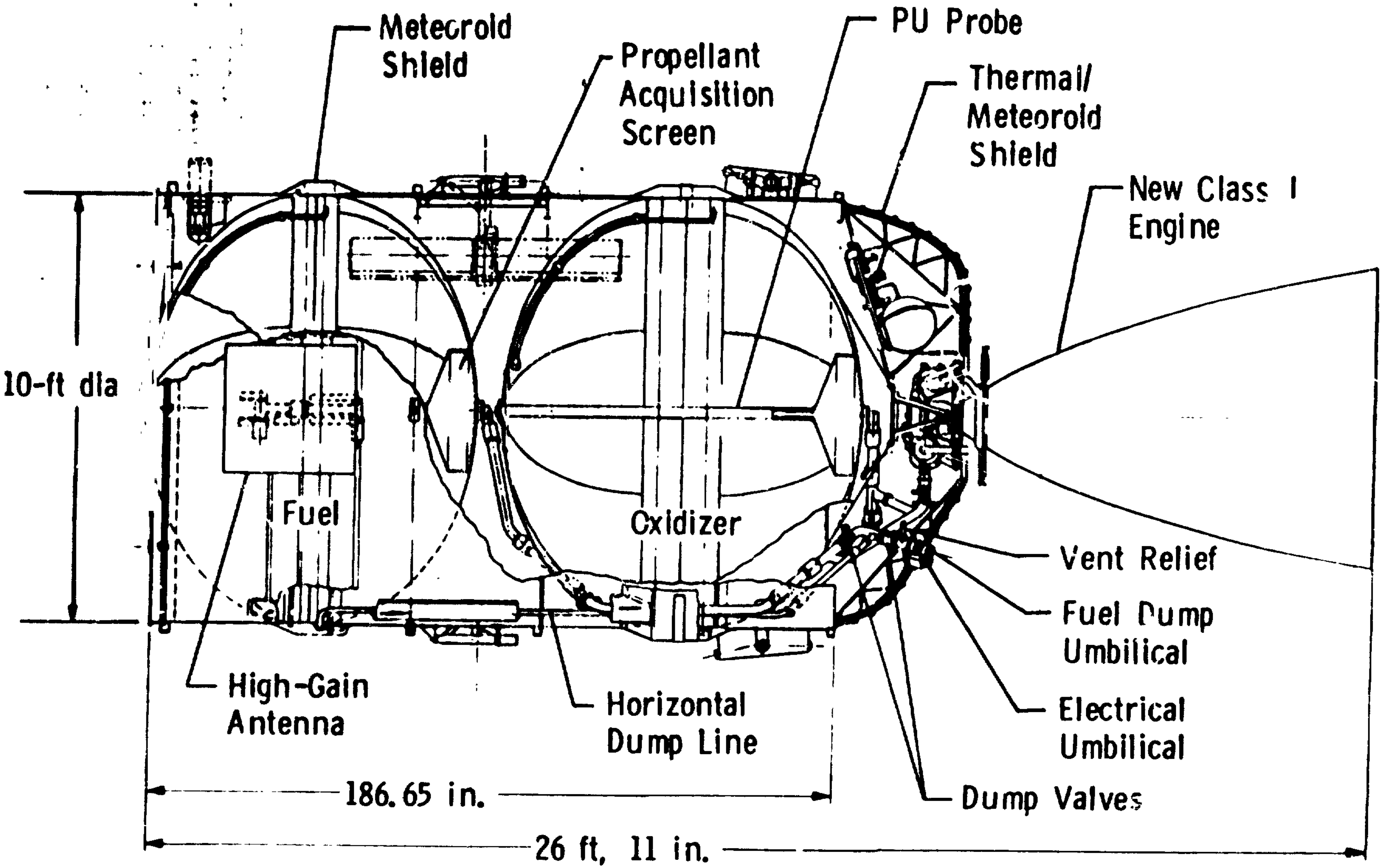
INBOARD PROFILE - OPTION 2

The facing viewgraph illustrates the main features of this configuration. The high-gain antenna is shown in a stowed position. The propellant dump system for both horizontal and vertical dump is included. The aft end located components for pressurization and ACPS are protected by a thermal-meteoroid shield made of aluminum with ring beads and multi-layer insulation.

INBOARD PROFILE - OPTION 2



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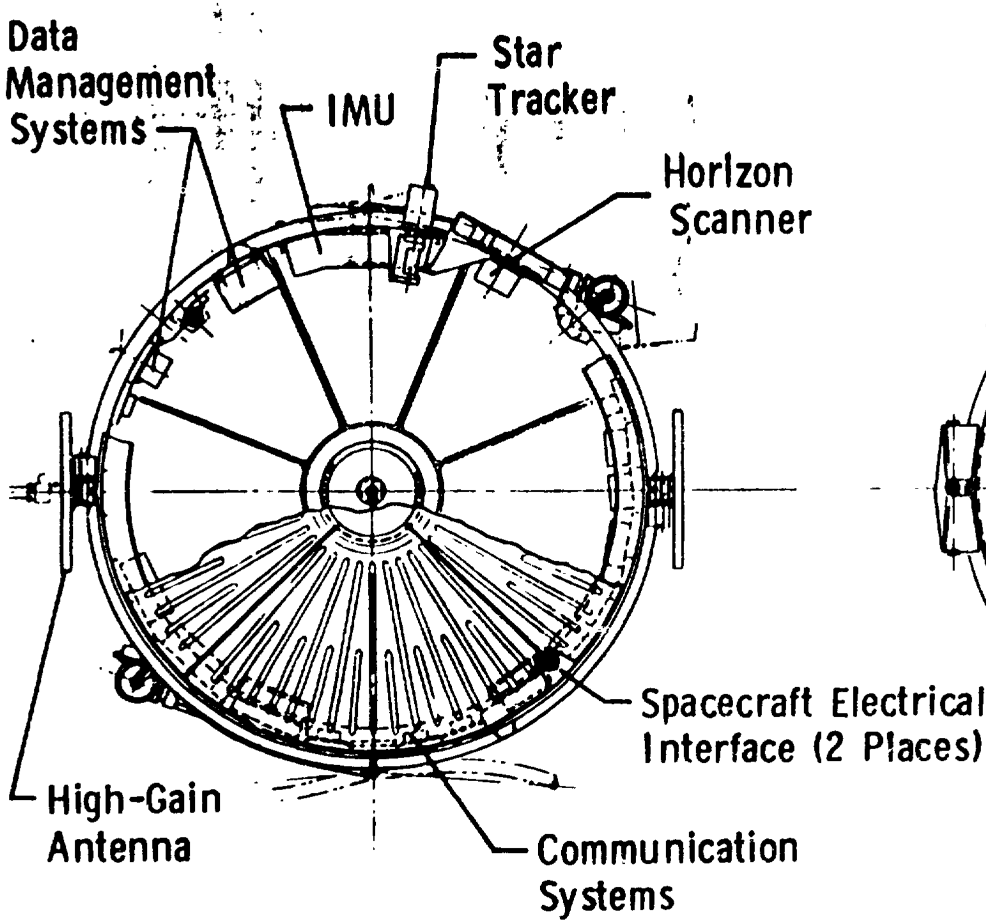
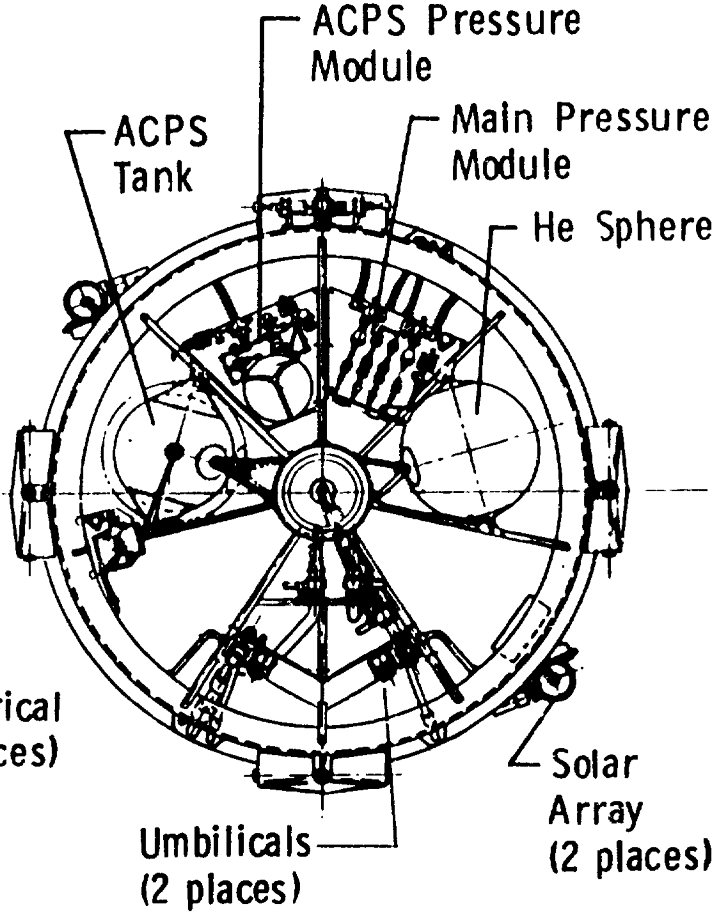
INBOARD PROFILE - OPTION 2

The facing viewgraph illustrates the inboard profile end views. The protective shields and engine are omitted for clarity. This configuration employs dual solar arrays shown in the stowed position. The high gain antennas are also shown in the stowed positions. This view illustrates the simple interfaces required for the Storable Tug. The interface requires only two normally dry dump lines (one oxidizer, one fuel) and two (for redundancy) eight-pin electrical connectors.

INBOARD PROFILE - OPTION 2 (END VIEWS)



Front View



Rear View
(without Shield & Engine)

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OPTION 2 - STRUCTURES AND THERMAL

Materials selected for the Option 2 Tugs are as snown. The vehicle arrangement is single stage with stacked tanks, with the oxidizer tank aft for CG optimization. Isolated tank configurations were selected over common bulk head configurations because of safety considerations. Thermal analyses resulted in the avionics arrangement in the forward compartment and the propulsion systems arrangement in the aft compartment. An aluminum skin forward skirt and heat pipes connecting the avionics to the fuel tank are used for optimum heat balance. MLI was used to provide heat shields for the front and aft ends to thermally shield the avionics and propulsion components.

OPTION 2 - STRUCTURES AND THERMAL

Vehicle Arrangement

- Single Stage
- Oxidizer Tank Aft
- $\sqrt{2}$ Domes, Short Barrel Sections
- 10 ft Diameter, 27 ft Long

Materials

- Titanium (Main Propellant Tank, ACPS Pressure Sphere, ACPS Propellant Sphere, Main Engine Thrust Cone)
- Aluminum (Forward Skirt)
- Graphite Epoxy (Between Tank, Aft Skirts, Main Propulsion Pressurization Sphere)

Thermal

- Passive (MLI, Heat Pipes, Coatings)
- Avionics Forward, Propulsion Aft
- Aluminum Forward Skirt

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OPTION 2 - PROPULSION

Main Propulsion System

The fuel candidates considered for Tug were UDMH, N_2H_4, A-50 and MMH. MMH was selected for its superior thermal stability, greater cooling capacity, lower freezing point, and commonality with the orbiter OMS and RCS.

The engine selected was the Class I, due to its high performance and minimum risk. Although the Class II engine can reduce total program costs by reduced Shuttle flights, there is a higher risk associated with the higher Class II performance.

A propellant utilization (PU) system consisting of point level sensors and integrator will reduce non-usable propellants and shows a performance increase when compared to no PU system. In addition, the PU system can compensate for propulsion system component performance deviations and allowing relaxation of component tolerances, thus improving reliability and reducing cost. Propellant acquisition is by a screen surface tension device offering unlimited life with little or no maintenance.

The pressurization system is regulated helium stored at ambient temperature in a sphere constructed of composite materials.

OPTION 2 - PROPULSION

Main Propulsion System

- Propellants
  - N_2O_4/MMH
- Engine
  - Class I, 800 P_c, 338 I_{sp}, 12,000 lb Thrust, 1.9 MR
  - Integrated Hydraulic Actuators
- Propellant Management
  - Propellant Utilization System
  - Screen Acquisition
- Pressurization
  - Regulated Ambient Helium

OPTION 2 - PROPULSION

Auxiliary Control Propulsion System (ACPS)

The ACPS is designed to be fail-operate/fail-safe. The hydrazine system was selected over a bi-propellant system based on a trade study and the total impulse required. The nozzle arrangement selected has 16 thrusters with 4 nozzles per quadrant; similar to that used on Apollo. This arrangement provides control in all six degrees of freedom for complete Tug control during Orbiter separation, spacecraft release, and Orbiter retrieval of the Tug.

OPTION 2 - PROPULSION

Auxiliary Control Propulsion System

- Propellant
  - Hydrazine (125,000 lb-sec Impulse-Retrieval)
- Engine
  - 16 Nozzles, 25 lb Thrust Each
- Propellant Management
  - Screen Acquisition
- Pressurization
  - Regulated Ambient Helium

OPTION 2 - AVIONICS

Data Management System - A time-division multiplexed Flexible Signal Interface (FSI) design is used for all inter-vehicle and intra-Tug caution and warning, control, data collection, timing, redundancy control, and checkout functions. A redundant full duplex FSI cable system is used that requires a total of eight connector pins (including four for power) at the vehicle or component "Black Box" interfaces. A single central processor with internal redundancy and a four-megabit memory is used.

Power System - The power system consists of two roll-up solar arrays, two (165 AH and 25 AH) battery chargers, load regulators and distributors. For the deploy-only mission, the average power over a six-day flight is 671 watts, the peak power is 1647 watts and the total energy 96.7 KWH. This goes up to 711W, 1570W, and 102.4 KWH on deploy and retrieve missions. Each solar panel has a peak output of 1180 watts and weighs 52 pounds. The power distribution system consists of two (redundant) main buses and four feeder buses.

Navigation and Guidance System - The inertial measurement unit is a skewed redundant version of the Micron strapped down IMU made by Autonetics. Micron is currently being flight tested in a brassboard configuration. The final packaged Micron will weigh 10 pounds, including a 4000 word computer and power supply. Our skewed redundant version should weigh about 20 pounds. The star tracker used for attitude update, and the horizon sensor (position update option for Autonomy Level I) are rigidly attached to the Micron package to preserve the relative angular integrity. The star tracker selected was the Ball Brothers CT 401; the horizon sensor, for Autonomy Level I, was the Quantic ETD-321A Model IV. For Autonomy Level II, position update is obtained via one-way doppler, the electronics for which are built into the data management and communication system.

Rendezvous and Docking - The rendezvous and docking sensors consist of the star tracker, mentioned above, for long range acquisition; the ITT scanning laser radar (SLR) for mid and close range, and a video camera as a docking aid. The video data will be processed on board for Autonomy Levels I and II.

Communications - A modular all S-band system was selected in order to gain multi-function utilization under constraints of weight, power, cost and reliability requirements. A 10W amplifier feeding a 3 foot square flat planar array, can transfer 16 Kbps of data to a similarly configured relay satellite for continuous communication with a single ground based control center. Use of error correcting coding could increase the bit rates. Other power and antenna combinations can be used for inter-vehicle and Tug to/from ground communications.

OPTION 2 - AVIONICS

Data Management System

Flexible Signal Interface, 4 Megabits Memory

Power System

Solar Array/Battery

G&N Systems

Redundant Strapdown IMU
Star Tracker (Attitude Update)
One-Way Doppler

Rendezvous and Docking

Laser Radar
Star Tracker

Communications

Modular S-Band
2 and 10 Watts
2 and 16 kB (Via Relay Satellite)
Omni and Steerable High-Gain Antennas

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INBOARD PROFILE - AUXILIARY STAGE CONFIGURATION (KS 10)

The facing page presents an outline of a Kick Stage to be employed for planetary missions. The motor has 10,000 pounds of low burning rate solid propellants with a total impulse of 2.9 million pound-second and a thrust of 15,000 pounds. It features a 40% submerged nozzle for length effectiveness.

The stage has vehicle steering and three axis stabilization capability made possible by three pulse rebalanced displacement gyros, three velocity meters and a twelve nozzle (redundant) hydrazine attitude control system.

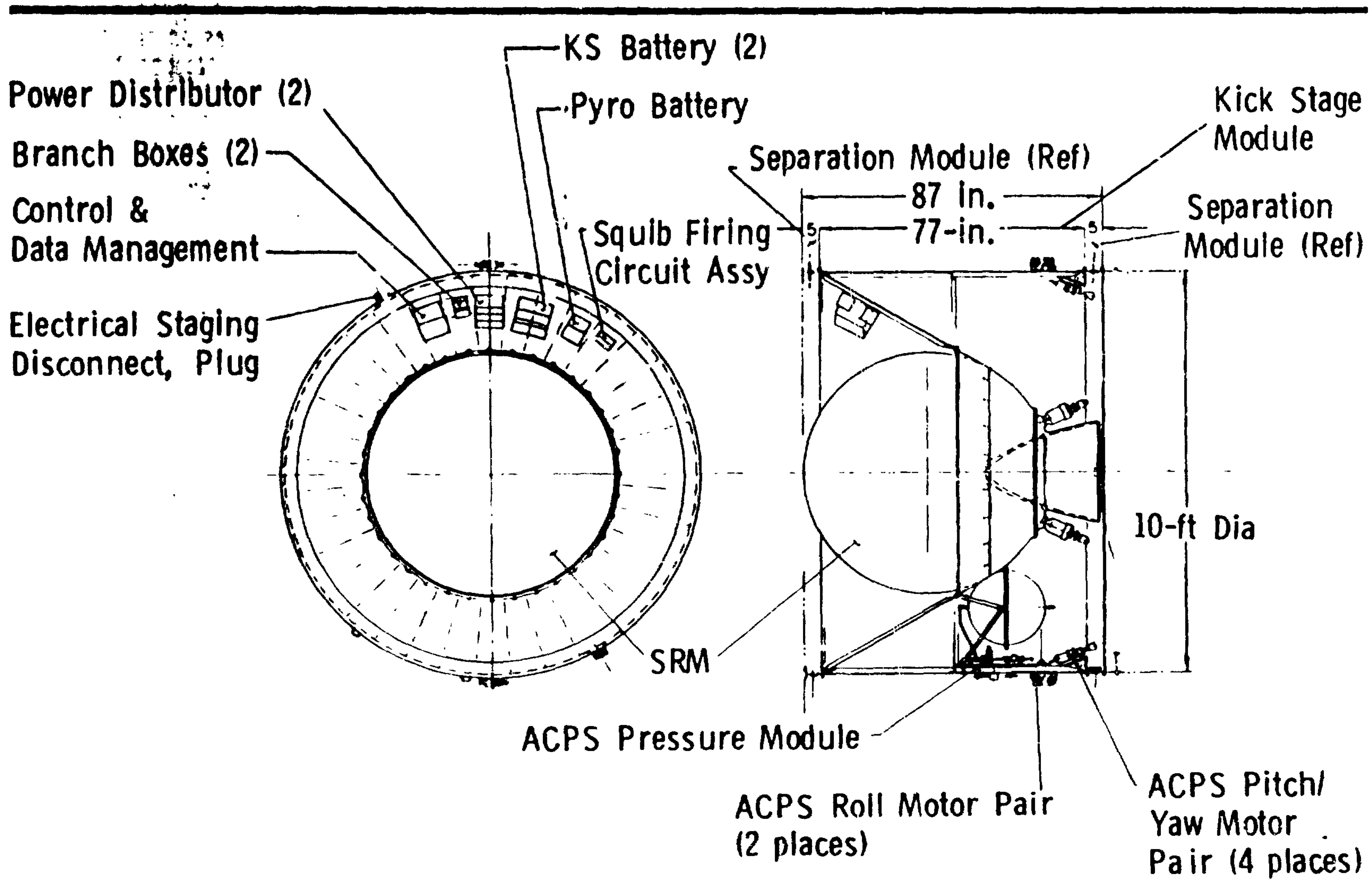
The main components used for ACPS are available from other projects and qualified (pitch and yaw thrusters from Transtage; roll thrusters from Viking; hydrazine propellant tank from P-95 Project; nitrogen vessel from ATS). The feed system is a regulated nitrogen system.

The structure is aluminum with provisions for attachment to separation modules forward and aft.

Power Supply: Two five-ampere-hour batteries and one two-ampere-hour pyro battery.

Thermal Protection: Thermal paint and selected applications of multi-layer insulation.

AUXILIARY STAGE CONFIGURATION (KS-10)



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AUXILIARY STAGE (KS-10) SUBSYSTEM DESCRIPTION

Subsystem	Description
General	10-ft-diameter, 77-inch-long Lightweight Motor Case, Partially Submerged Nozzles, Expansion Ratio, 50:1
Structure	
Skirt	Aluminum Skin-Stringer
Thrust Structure	Aluminum Skin-Stringer
ACPS Propellant Tank	Titanium
ACPS Pressurization Vessel	Titanium
Avionics	
GN&C	Pseudo Strapdown IMU, All Controls via ACPS, No Separate Communications
Power	Ag-Zn Battery(s)
Main Engine Data	
Thrust	15,000 pounds
Impulse	I_{sp} = 290 sec; 2,900,000 lb-sec total
Motor Dimensions	Diameter = 72 in.; Length 86 in.
Motor Weight	Propellant = 10,000 lb; Case = 900 lb
Propellant	Class II, Slow Burning
ACPS	
Type	Monopropellant, N_2H_4; Pressurant, N_2
Thrusters - Pitch & Yaw	4 Sets of 2; 27 lb Thrust; I_{sp}, 227 sec; Minimum Impulse Bit, 0.4 lb-sec
Thrusters - Roll	2 Sets of 2; 5.3 lb Thrust; I_{sp}, 224 sec; Minimum Impulse Bit 0.1 lb-sec
Thermal Control	Thermal Paint and Some Multilayer Insulation

SPACECRAFT INTERFACE - STANDARD SEPARATION MODULE

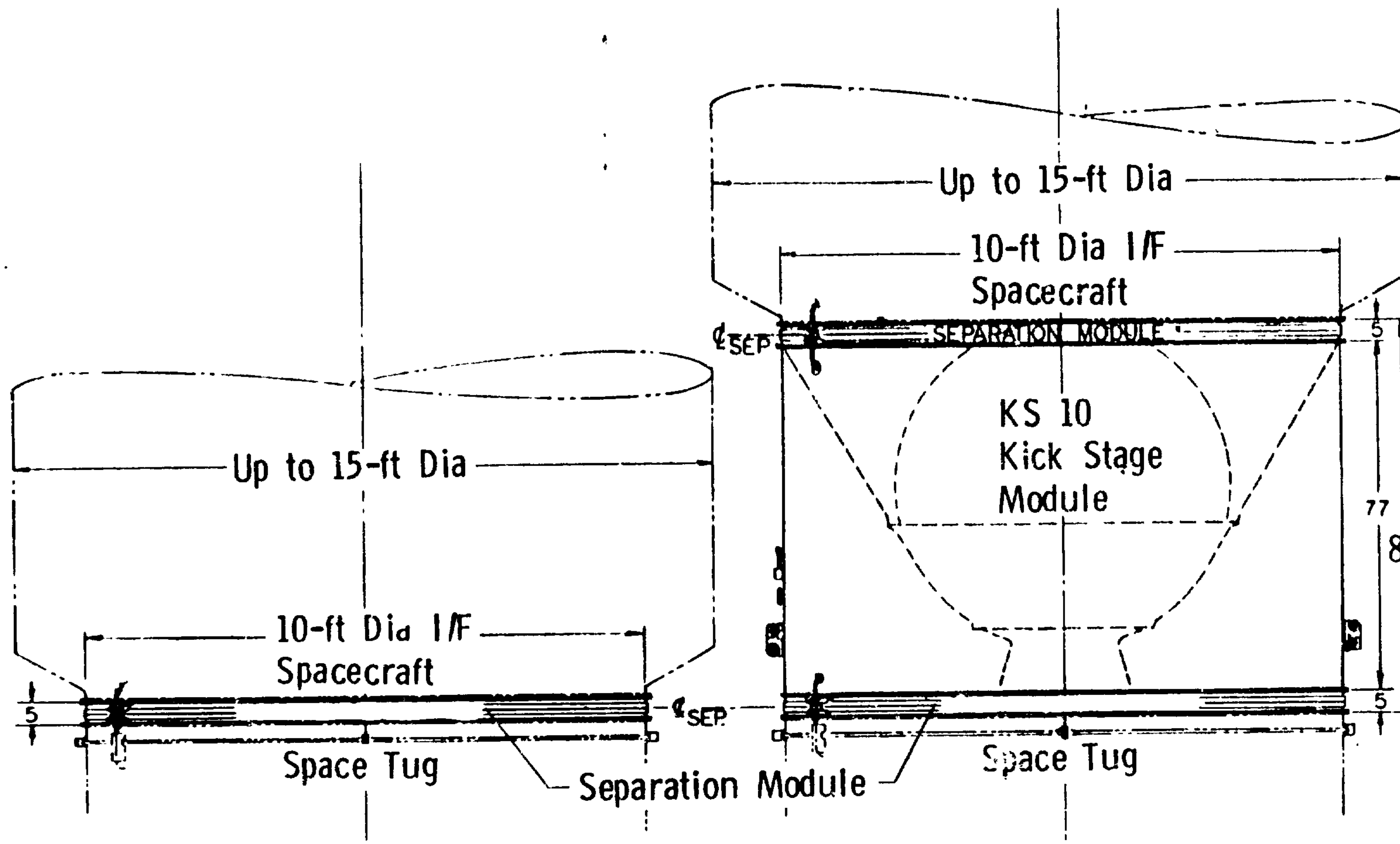
The facing page illustrates the standard separation module for a Tug-to-Spacecraft and a Tug-to-KS 10-to-Spacecraft interface, respectively.

The separation module consists of a five inch high ring, ten feet in diameter, containing a totally encapsuled low intensity explosive cord within a frangible section.

The separation mechanism is non-contaminating and has been successfully demonstrated. The separation forces are uniformly distributed resulting in minimum shock effects to nearby structures.

Loads are uniformly distributed through the separation module.

SPACECRAFT INTERFACE - STANDARD SEPARATION MODULE



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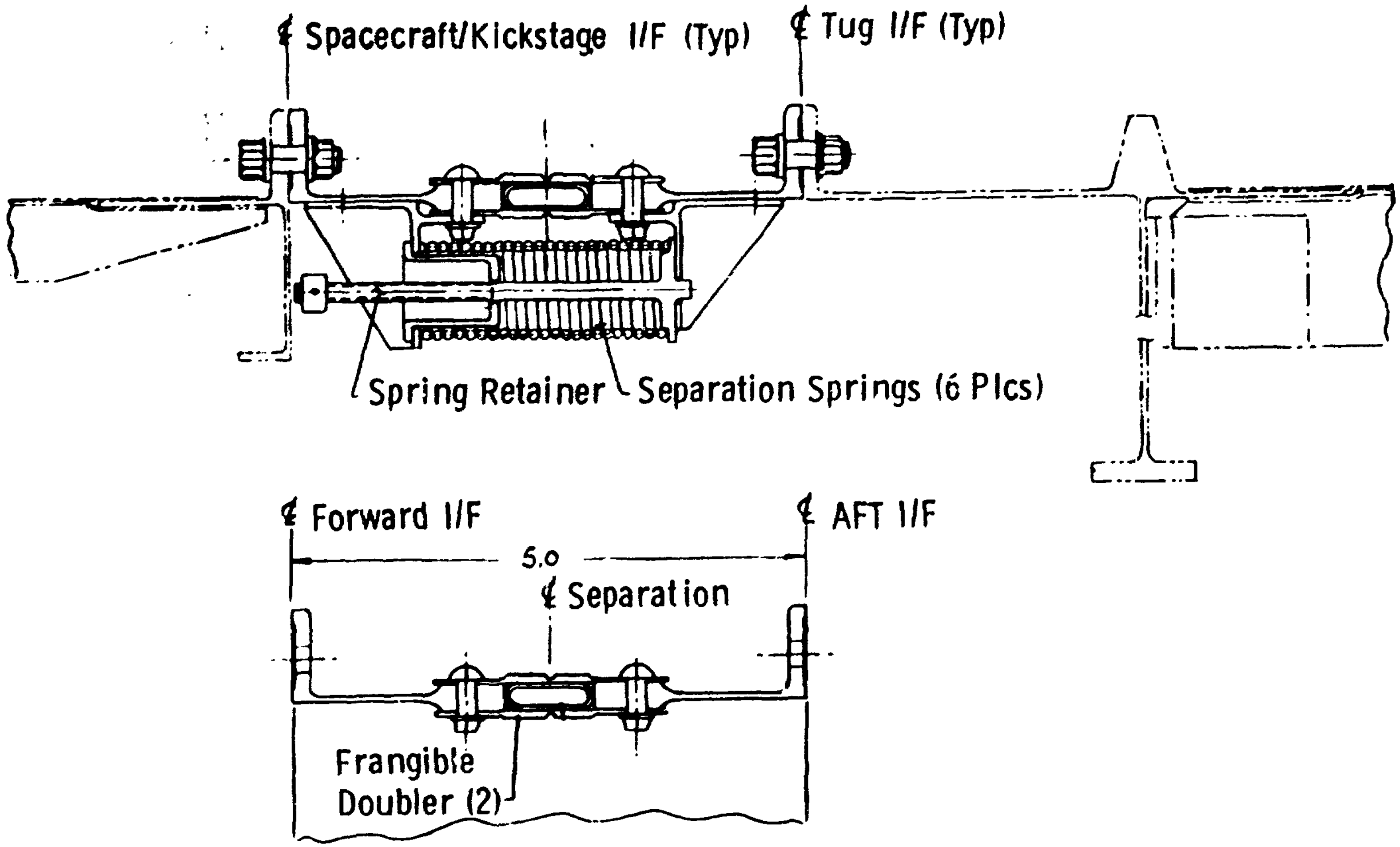
SPACECRAFT INTERFACE - STANDARD SEPARATION MODEL - DETAILS

The facing viewgraph presents a cross-section of the standard separation model and illustrates the details of the separation mechamism.

SPACECRAFT INTERFACE - STANDARD SEPARATION MODULE - DETAILS



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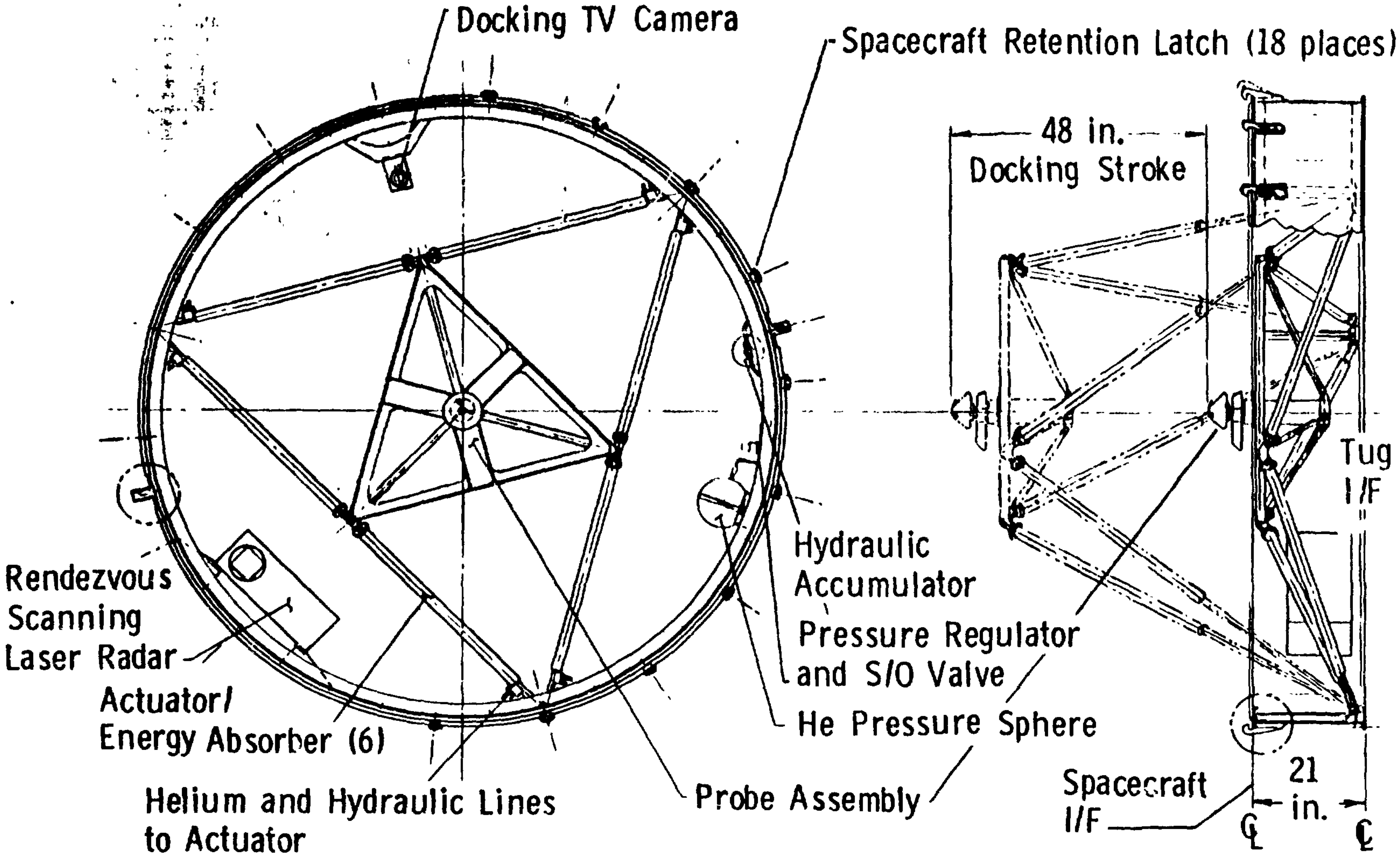
SPACECRAFT INTERFACE - STANDARD DOCKING MODULE

The facing viewgraph shows the standard docking module used for retrieval missions. This module is added as a kit to the basic Tug for retrieval missions and removed for delivery-only missions in order to save weight and gain delivery performance. The module contains a docking frame with a probe assembly. The frame is designed with actuator/energy absorption capability having a 48 inch docking stroke. The rendezvous and docking avionics (scanning laser radar and camera) are mounted on the module as shown.

SPACECRAFT INTERFACE -- STANDARD DOCKING MODULE



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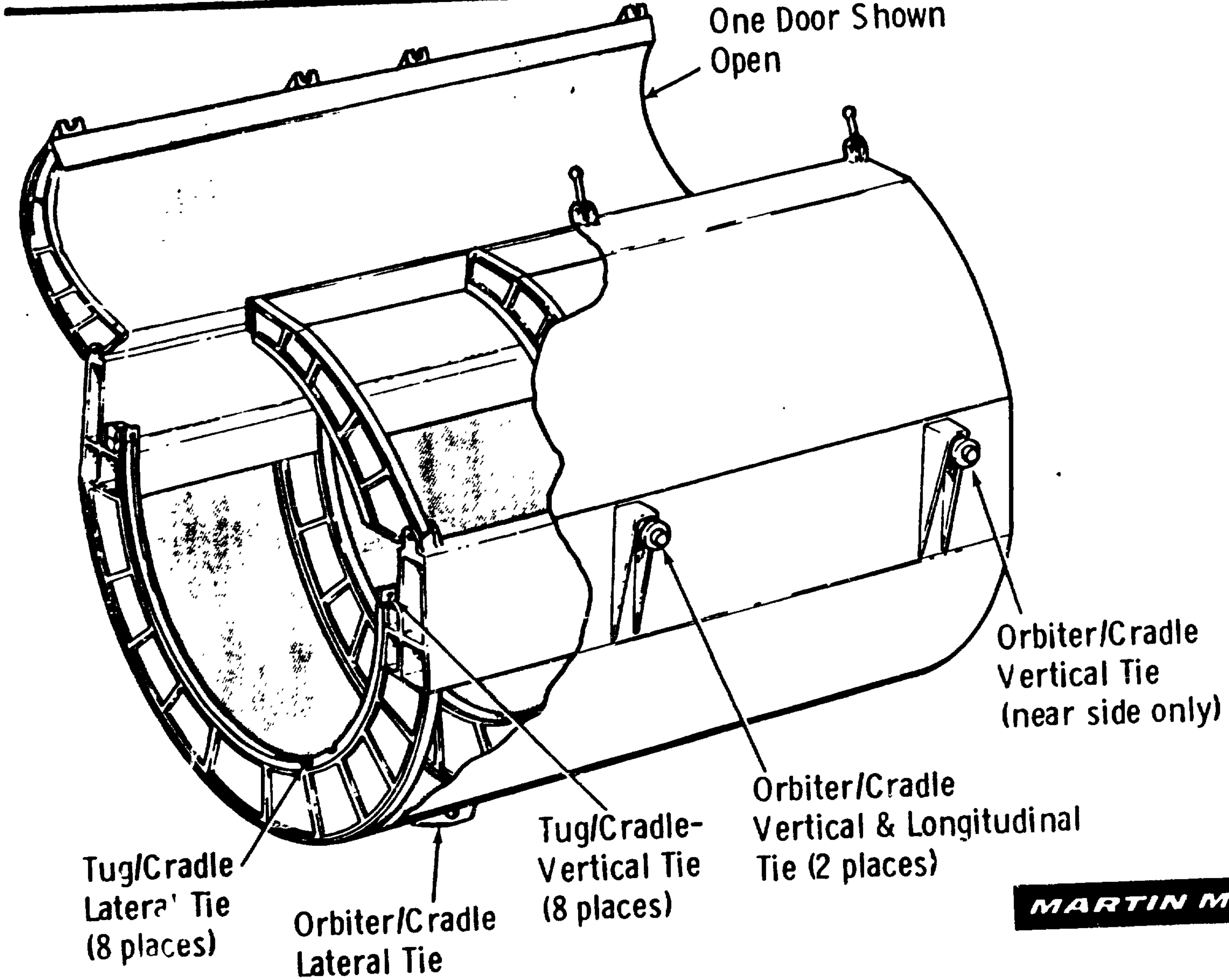
TUG CRADLE - TION 2

The facing viewgraph shows the Option 2 cradle. Four fitting locations provide the statically determinant orbiter interface arrangement. The eight Tug/Cradle lateral and eight Tug/Cradle vertical ties are shown with the clam-shell door arrangement used to provide Tug support on the upper and lower halves.

OPTION 2 CRADLE CONCEPT



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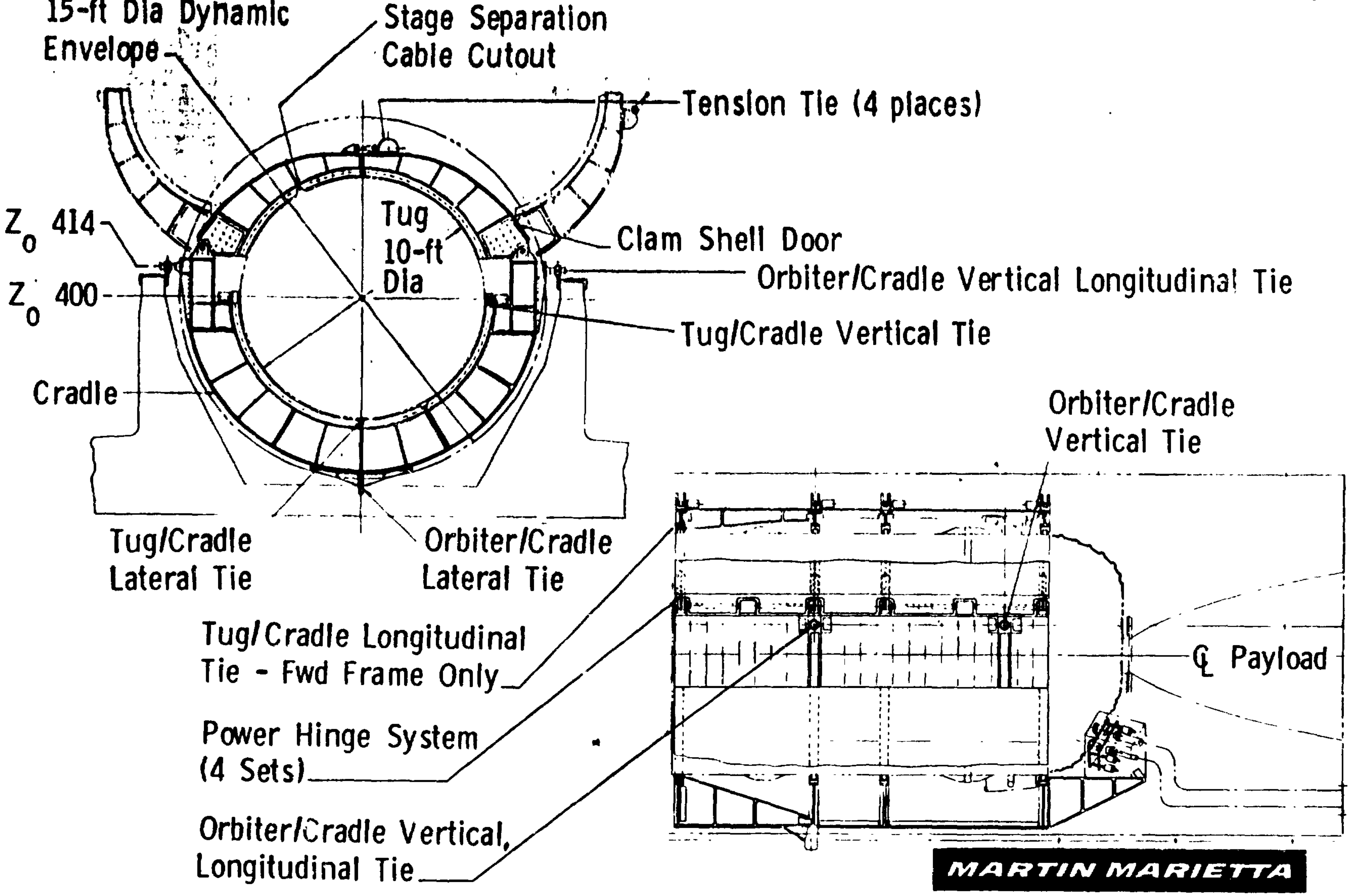
OPTION 2 CRADLE CONCEPT



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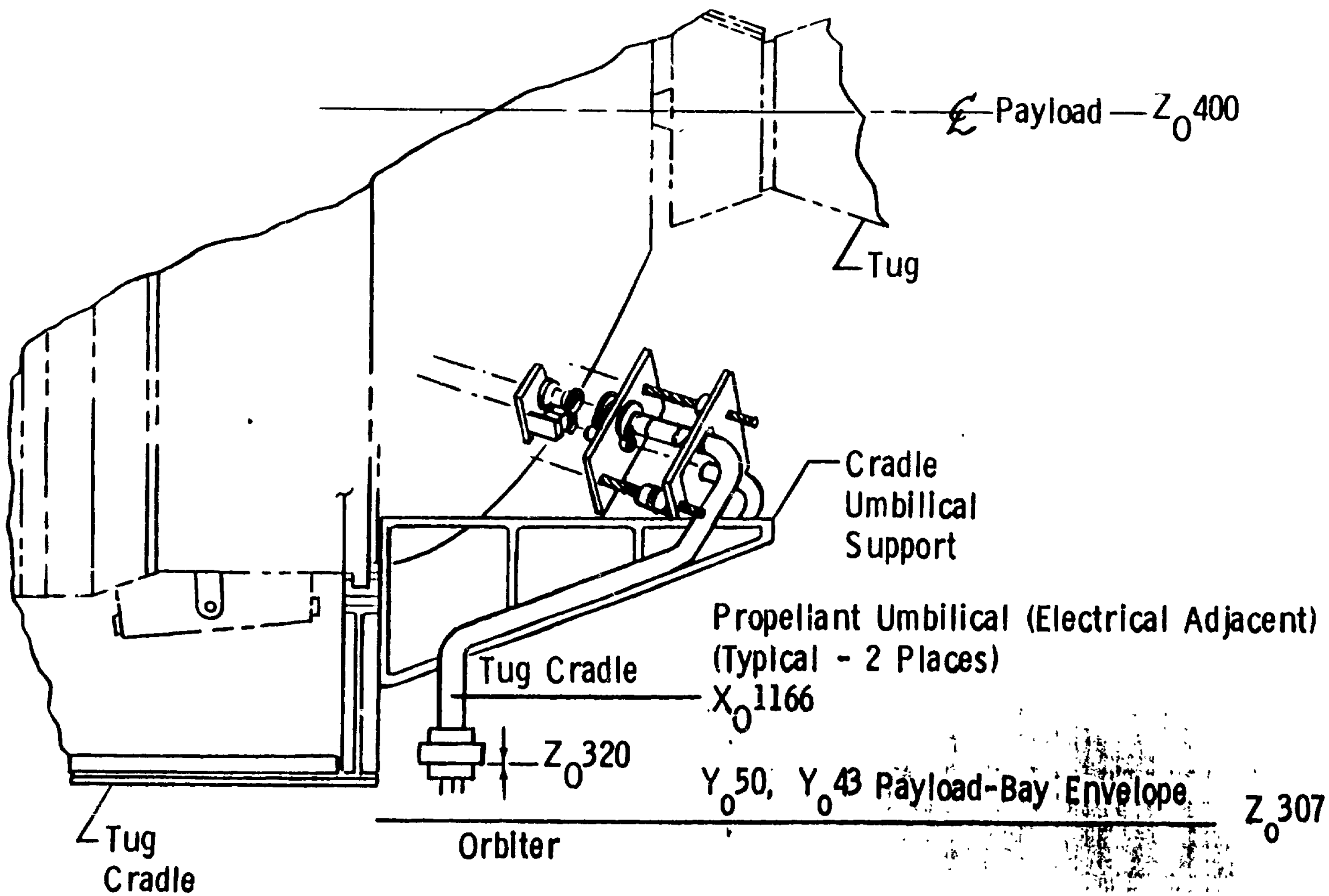
UMBILICAL INTERFACE SIDE VIEW

The facing viewgraph shows the aft portion of the Tug as it appears when supported on its cradle in the Orbiter Payload Bay. It depicts the Tug/Cradle umbilical disconnect concept, in which an electromechanical actuator drives the movable halves of both propellant and electrical umbilical connectors, such that they mate with fixed connectors on the Tug. The Cradle/Orbiter umbilical interface, both propellant and electrical, then is a hard bolted concept without quick disconnects. The proposed locations of these hard connections are a X_o 1166 and Z_o 320. The two propellant connections are located at Y_o + 50 and - 50, while the two electrical connectors are located at Y_o = + and - 43.

UMBILICAL INTERFACE SIDE VIEW



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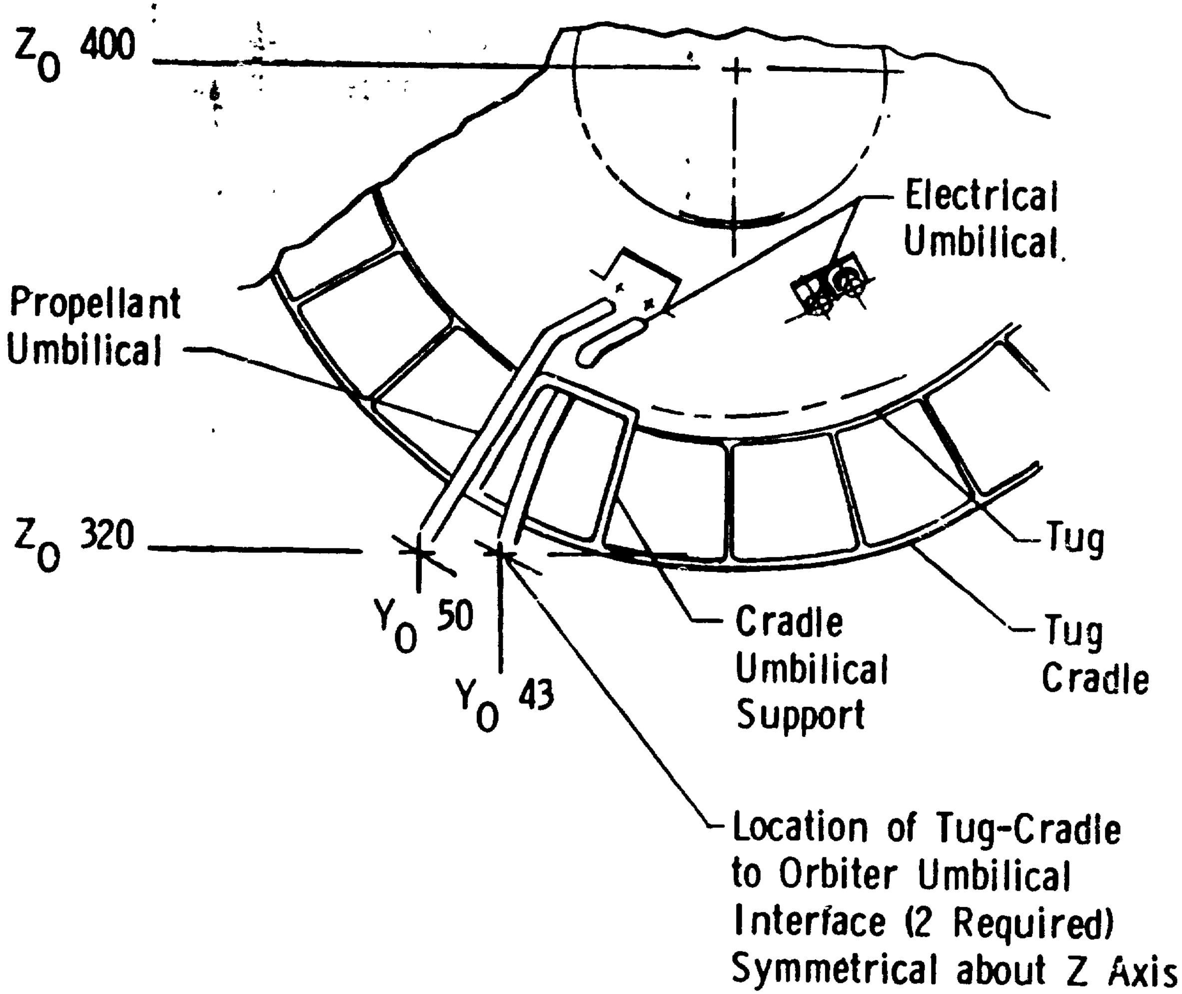
UMBILICAL INTERFACE

The facing viewgraph shows the end view of the Tug with the propellant and electrical umbilicals as they run from the Cradle to the proposed interface location in the Orbiter Payload Bay.

UMBILICAL INTERFACE

View Looking Forward



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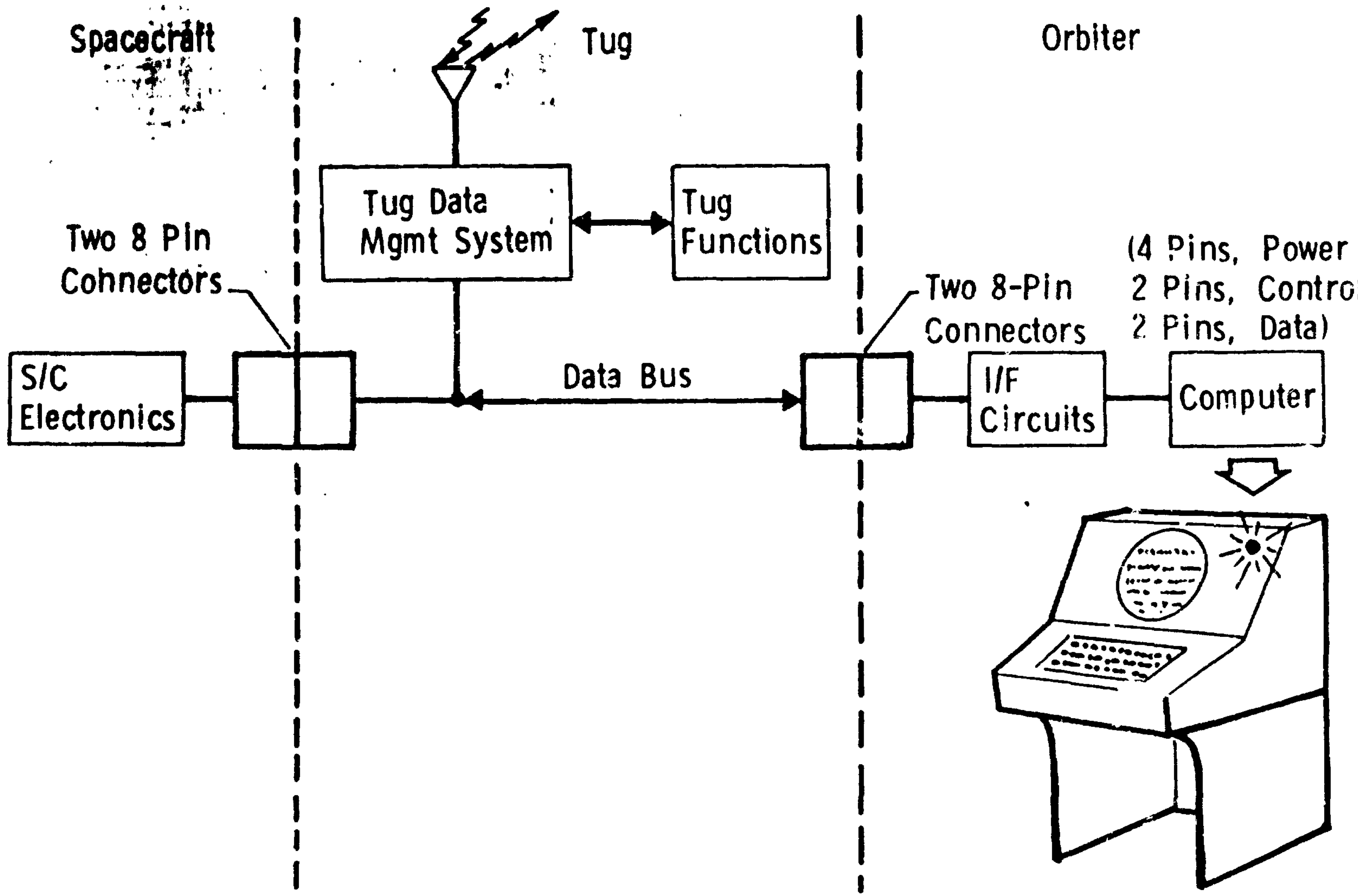
TUG ELECTRONIC INTERFACE

The primary Tug inter-vehicle electronic interfaces use two redundant eight-pin connectors. Four pins in each are for power transfer (1000 watts Orbiter-to-Tug and 300 watts Tug-to-Spacecraft). The remaining four pins serve a full duplex time division multiplexed Data Management Subsystem (DMS). The DMS is called a Flexible Signal Interface (FSI) design due to its ability to provide channels for a very large number of caution and warning, control, data collection, checkout and timing services with a simple four-pin connection. It uses standard interface hybrid circuit sets weighing 33 grams (1.2 ounces) each integral to the component served. Approximately one pound of buffer circuitry would be needed to provide the Tug FSI to standard orbiter computer interface. The standard orbiter computer (with display and keyboard), assigned for payload support, would be programmed to give detailed Tug and Tug Payload C&W data and control on a priority interrupt basis if/when required. Standard limit checks of critical parameters command (single warning light and/or audible signal) would alert Orbiter crewmen of interface conditions warranting their attention. The same or similar checks would initiate corrective action (like redundancy, temperature or pressure control) by internal Tug circuitry. Provision is made for Orbiter crew access to all data and control points internal to Tug or Tug payload after transfer of the appropriate priority (override) command.

TUG ELECTRONIC INTERFACE



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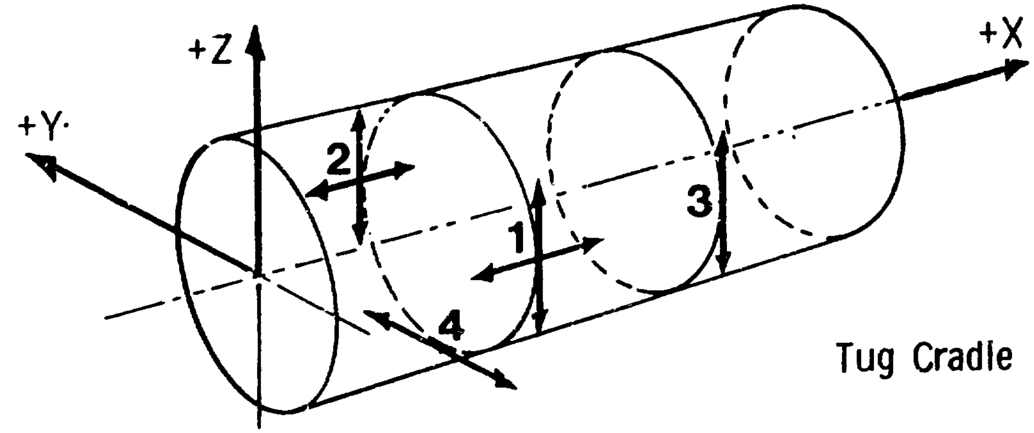
TUG ORBITER INTERFACE LOADS

The facing viewgraph shows the four Tug Orbiter interface points, the allowable orbiter loads, and the maximum applied Tug loads (which result from abort landing when fully loaded). It shows loads exceeding the Orbiter allowable at three "Z" load points and at the one "Y" load point. The "X" loads are within the "X" load allowables at both support points.

TUG ORBITER INTERFACE LOADS

Point	Coordinates			Allowable Loads, lb			Maximum Tug Loads, lb		
	X_0	Y_0	Z_0	P_X	P_Y	P_Z	P_X	P_Y	P_Z
1	1041	-95.5	414	±253,000	0	±90,000	+ 86,199 -146,543	0 0	+ 97,494 - 59,364
2	1041	+95.5	414	±253,000	0	±90,000	+ 90,024 -146,121	0 0	+171,566 - 22,906
3	1134.5	-95.5	414	0	0	±90,000	0 0	0 0	+104,798 - 59,950
4	1040	0	307	0	±109,000	0	0	±130,229	0

Exceeds Orbiter Allowables and Are For An Abort Case Fully Loaded.



Tug Cradle

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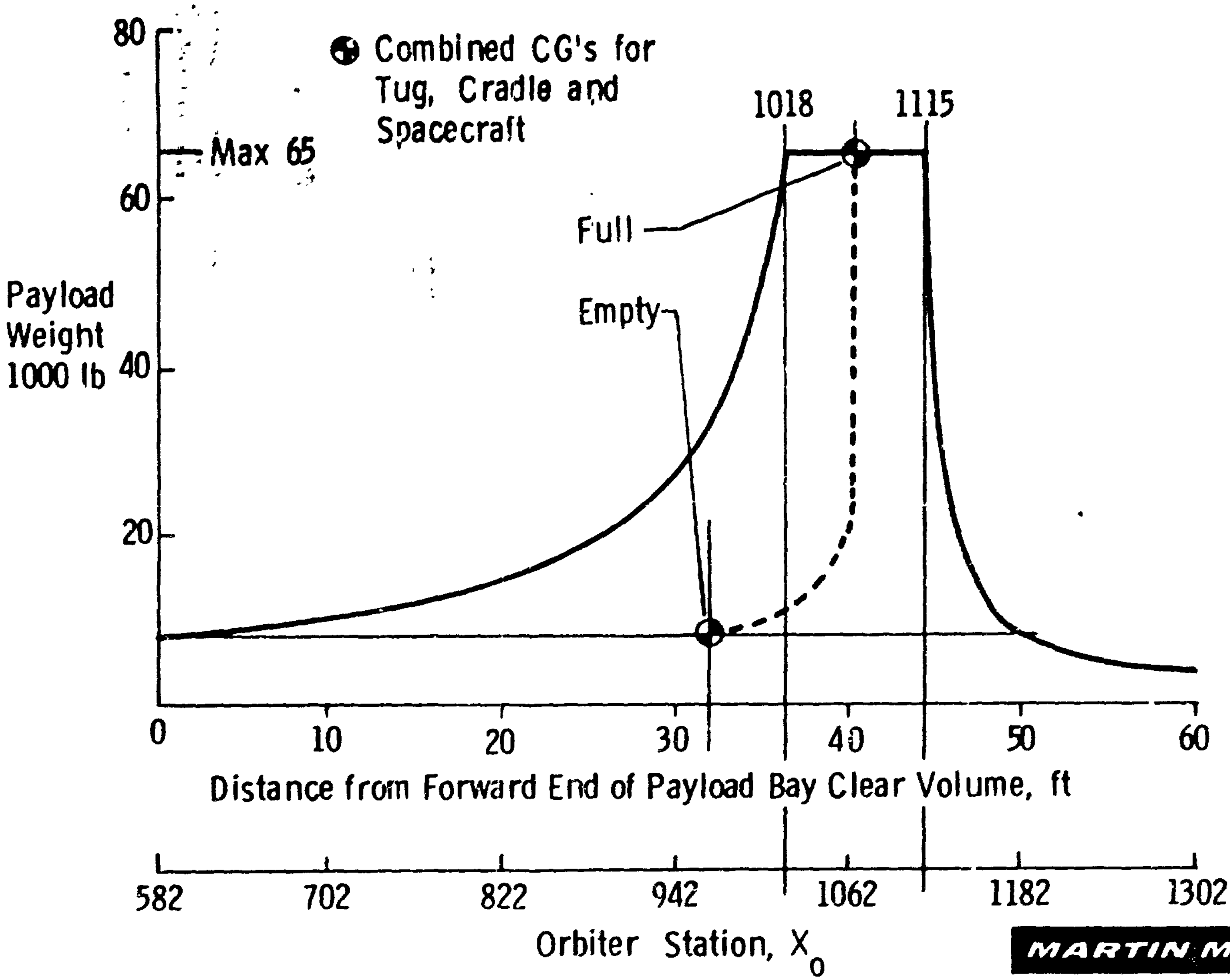
ALLOWABLE PAYLOAD LONGITUDINAL CG ENVELOPE

The facing viewgraph shows the Option 2 CG for the fully loaded and empty cases with a typical 3500 pound spacecraft. The CGs for all possible combinations of given mission model spacecraft (with kick stages where necessary) fit within the allowable envelope. The dashed line presents a locus of CG travel during a simultaneous propellant dump abort case.

ALLOWABLE PAYLOAD LONGITUDINAL CG ENVELOPE



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DUMP PHILOSOPHY

The propellant dump philosophy during ascent abort is to dump during powered flight above 150,000 feet. This period was selected because it provides the highest beneficial g's, eliminates possible dump-flow/boundary-layer interaction, and will not produce a change in center of gravity during Orbiter glide-back. For the Storable Tug to land empty, simultaneous dumping of propellants is almost a requirement. Sequential dumping of both propellants in the time allowed (5 minutes) results in an intolerable weight penalty to Tug (larger lime sizes would add approximately 100 pound dry weight over N_2O_4 dump only). To meet the Orbiter landing weight of 32,000 pound maximum, it is possible to dump oxidizer only in the allocated time. Since the Tug can land full, redundancy in the dump system is not required.

Abort on-orbit requires initial settling of propellants; however, settling is not required during dump due to the thrust from the exhausted propellants. This assumes the dump ports are aft-facing.

Since the OMS payload bay kits require dump provisions, as well as Tug, the requirements should be integrated to achieve one set of lines. The propellants are the same; however, the Tug requirements would probably dictate line size.

DUMP PHILOSOPHY

Ascent Abort

- Dump During Powered Flight (Above 150,000 ft)
  - Highest Beneficial "G's"
  - Eliminates Possible Dump Flow/Boundary Layer Interaction
  - No CG Change During Orbiter Glideback
- Simultaneous Dump to Land Empty
- N_2O_4 Dump (Only) to Meet Landing Payload Weight Goal of 32,000 lb Maximum

On-Orbit Abort

- No Orbiter Settling Thrust Required During Dump

Integrated Tug/OMS Kit Dump Lines

- Same Propellants
- Tug Line Size Governing (3-3/4-in. vs 2-1/2-in.)

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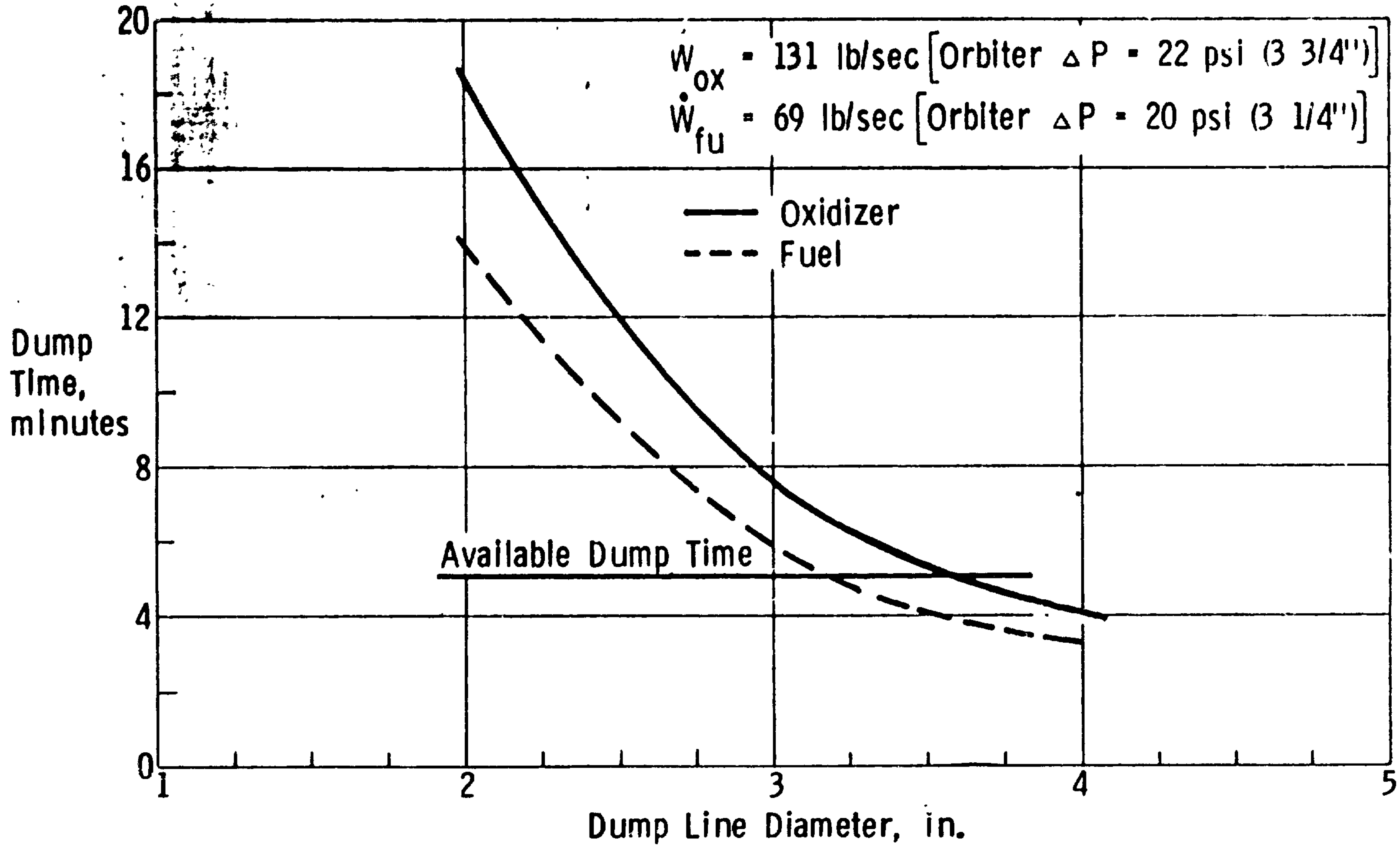
ASCENT ABORT DUMP TIME VERSUS LINE DIAMETER

During ascent abort, the dump time available is five minutes. The accompanying chart shows the vertical dump line size required to dump all of the Tug propellants within this time. The orbiter ΔP is for the flow rates indicated based on assumed line routings.

ASCENT ABORT DUMP TIME vs LINE DIAMETER



OPTION 2 ORBITER INTERFACE SUMMARY

The Storable Tug offers the advantage of simple interfaces and, therefore, minimum impact to Orbiter design.

OPTION 2 - ORBITER INTERFACE SUMMARY

No CG Constraints

Two Dry Propellant Line Connections

Two 8-Pin Connectors

Four Cradle Ties

FINAL OPTION 2 - WEIGHTS IN POUNDS

Facing viewgraph presents the weight data for Option 2 in both delivery and retrieval configurations. A kit concept (standard docking module) is used for the retrieval missions. The kit is not necessary and is not used for delivery only missions resulting in significant dry weight reduction and, therefore, higher delivery performance capability. The weights are presented by subsystem and the total includes a 10% contingency factor. The mass fraction for the two Tug configurations are shown.

FINAL OPTION 2 – WEIGHTS IN POUNDS

Item	Tug Configuration	
	Delivery	Retrieval
Structures	1,063	1,176
Thermal Control	101	101
Avionics	593	669
Propulsion	743	765
Dry Weight	2,500	2,711
Dry Weight + 10% Cont.	2,750	2,982
Mass Fraction	0.953	0.949

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OPTION 2 MISSION MODEL AND TUG PERFORMANCE

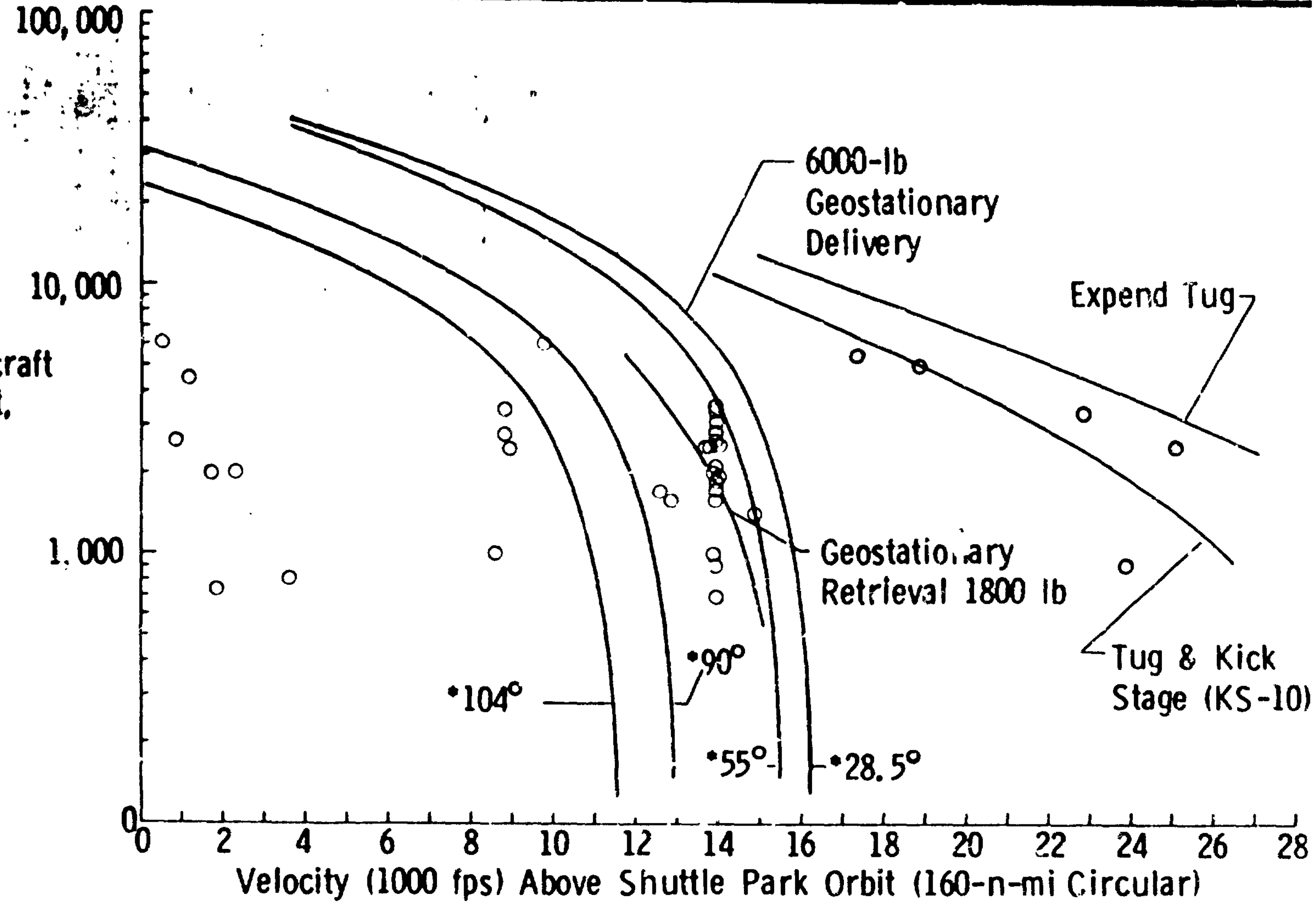
The spacecraft/velocity curves shown on the facing page outline the performance capability of the Option 2 selected configuration Tug and the spacecraft in the Option 2 Mission Model. All spacecraft can be captured by the Tug configuration as shown under each curve, either singularly or in combination.

The Option 2 Tug has the capability of delivering 6000 pounds to geostationary orbit from an Orbiter park orbit of 160 nautical miles. Its geostationary retrieval and round trip capability at geostationary orbit is 1800 pounds and 1350 pounds, respectively. The performance curve labeled 28.5° is the geostationary capability curve of this Tug, flying with full propellant load due east from ETR (28.5° latitude and earth inclination). The performance curves labeled 55°, 90° and 104° are the performance of this Tug off-loaded to meet Shuttle limitations while flying at these corresponding inclinations to the earth.

The entire mission model can be captured primarily by reusable flights of the Tug and in a few cases of planetary missions, by using a solid propellant kick stage (10,000 pounds), or by expending the Tug. Only five kick stages and six expended Tugs are required for 100% capture of the seven year mission model.

The entire Option 2 Mission Model of 437 spacecraft missions can be accomplished by only 293 Shuttle/Tug flights, due to the multiple spacecraft delivery capability of the Option 2 Tug.

OPTION 2 MISSION MODEL AND TUG PERFORMANCE



*Orbiter Inclinations

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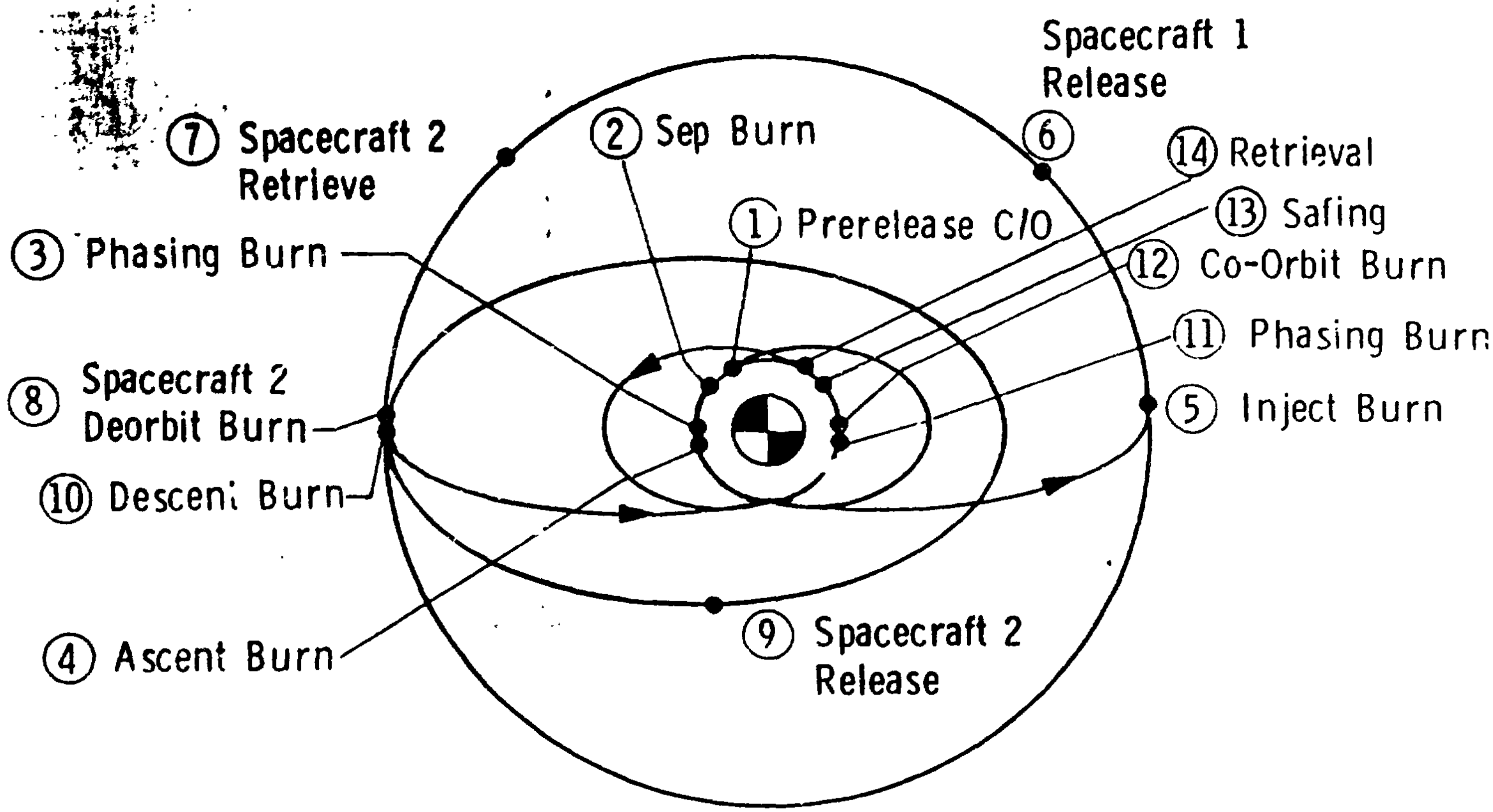
GEOSTATIONARY DELIVERY AND DELAYED RETRIEVAL

Since the retrieval capability of the Option 2 Tug is 1800 pounds, same technique was necessary to recover spacecraft larger than 1800 pounds. This was accomplished by a technique known as delayed retrieval. The principal of this technique is to convert the residual propellants available after spacecraft delivery into reducing the energy of the orbit of a spacecraft which is to be retrieved. Residual propellants are generally available since the Option 2 Tug delivery capability is significantly greater than the largest spacecraft in the mission model (4900 pounds versus 3500 pounds). This viewgraph shows the mission profile for a standard geostationary delivery mission. After spacecraft release (point 6) the Tug rendezvous with a spacecraft (point 7) to be retrieved (similar to a round trip mission). The Tug then burns the excess propellant from the delivery mission and deorbits the spacecraft to a lesser energy orbit. It then releases the spacecraft and returns to orbiter.

The spacecraft, now in a lesser energy orbit, is then recovered at some later date in exactly the same fashion as it would be in a normal retrieve only mission.

GEOSTATIONARY DELIVERY AND DELAYED RETRIEVAL



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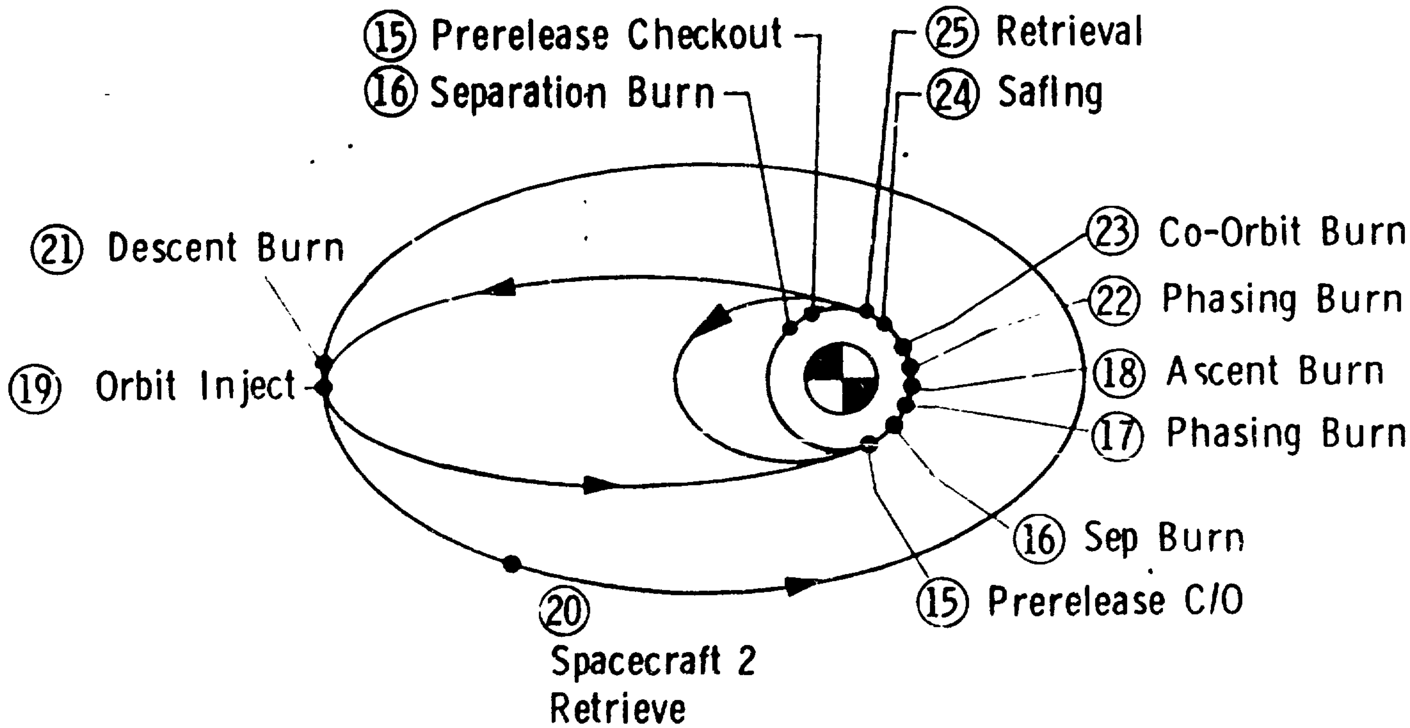
GEOSTATIONARY DELIVERY AND DELAYED RETRIEVAL

This is the second half of the delayed retrieval mission profile. It is the same profile as for a geostationary orbit retrieval mission profile. No additional operations are required. Software is the same. Ephemeris information requirements for the profile and a geostationary retrieval profile are the same. The net impact of the entire delayed retrieval operation is extending the effective spacecraft retrieval from 1800 lbs to more than 6000 lbs at the expense of only one additional rendezvous and docking operation.

This technique enables the storable tug to do the entire retrieval aspect of the mission model without incurring any additional flights or any additional operational or hardware complexities save for one additional rendezvous and docking.

GEOSTATIONARY DELIVERY AND DELAYED RETRIEVAL



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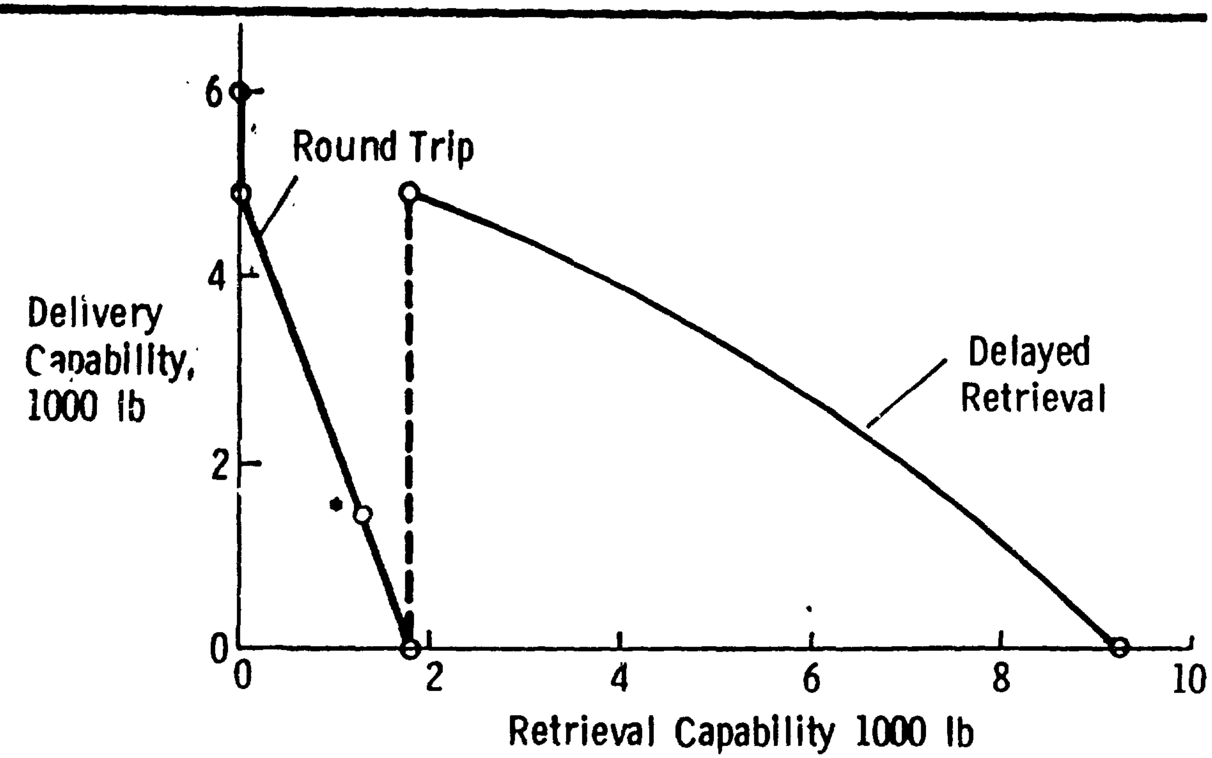
GEOSTATIONARY PERFORMANCE - PROGRAM OPTION 2

The viewgraph presents the geostationary performance of the Option 2 Tug. The Tug can deliver 6,000 lbs. in the delivery only configuration and 4900 lbs with the rendezvous and docking kit. The Tug can retrieve 1,800 lbs. and round trip equal spacecraft weighing 1,350 lbs. In the delayed retrieval scenario, the Tug could deliver a spacecraft weighing, for example, 4000 lbs. The Tug delivery capability is 4900 lbs. Therefore, there is 900 lbs. excess of delivery capability in the form of excess propellant. This excess propellant can be used to partially deorbit a spacecraft which is to be retrieved later. In its new lower energy orbit, this spacecraft could weigh 4000 lbs. and be retrieved with a single Tug retrieval flight. The curve graphically illustrates how retrieval capability is augmented from 1800 lbs to well over 6000 lbs (maximum delivery capability) by delayed retrieval.

GEOSTATIONARY PERFORMANCE - PROGRAM OPTION 2



	Geostationary Capability, lb		
Configuration	Delivery	Retrieval	* Equal Round Trip
Delivery	6,000	NA	NA
Retrieval	4,900	1,800	1,350

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OPTION 2 FLIGHT RATE

This chart compares the flight rate for 100% capture with that used for programmatic considerations.

Since it does not seem reasonable to drive the program directly to 100% capture (45 flights) in the initial year of operation, a build up in flight rate was used for programmatic considerations. This results in fewer total flights with programmatics as compared to that required for 100% capture.

The build-up rate was arrived at as being the optimum with respect to crew sizing, production rate of Tugs, and minimizing cost in the production phase. At KSC, a launch rate of 9 increasing to 18 and eventually to 24 allows a single-shift operation to gradually build to the full two shifts. This build up also allows the fabrication of subsequent production Tugs to progress at the most economical rate; i.e., without two shifts or overtime, yet at a rate which equates to good production standards. A lower production rate would not reduce costs; however, a high rate would escalate costs. Finally, the build-up rate increases the active fleet size one Tug per year to the maximum of four at midprogram.

The WTR build-up rate dictates similar type economics, except to a lesser degree in that after one year a 100% capture can be realized.

OPTION 2 FLIGHT RATE

100% CAPTURE:

	1984	1985	1986	1987	1988	1989	1990	Total
ETR	32	30	24	27	20	28	33	194
WTR	13	13	17	14	16	14	12	99
Total	45	43	41	41	36	42	45	293

DETERMINED FROM PROGRAMMATICS:

	1984	1985	1986	1987	1988	1989	1990	Total
ETR	9	18	25*	27	20	28	34*	161
WTR	6	13	17	14	17*	14	12	93
Total	15	31	42*	41	37*	42	46*	254

*Includes one (1) reliability loss.

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SUMMARY OF MISSION ACCOMPLISHMENT - OPTION 2

The data shown on this viewgraph is a brief summary of the Option 2 Mission Model with a spacecraft breakdown of delivery/retrieval and by user agency.

The data in the left-hand column represents how the Mission Model would be accomplished if all missions were flown by Shuttle/Tug, beginning in 1984 (100% capture).

The data in the right-hand column describes how the Mission Model would, more probably be accomplished, giving consideration to launch rate build up of Shuttle and Tug flights during the early years of the program and during a corresponding transitional phase of Launch Vehicle to Shuttle/Tug or Interim Tug to Full Capability Tug Operations.

As can be seen between the two columns, there are 37 fewer spacecraft delivered and 21 fewer spacecraft retrieved during this transitional or early period. These reductions occur during the years of 1984 and 1985 and consist of missions with highest degrees of difficulty, risk factors, and reliability considerations, such as multiple geostationary delivery, delayed geostationary retrieval and high energy long duration planetary missions. Beginning in 1986 and throughout the remainder of the program, all Option 2 Missions are accomplished.

SUMMARY OF MISSION ACCOMPLISHMENT - OPTION 2

	100% Capture	With Programmatics
Spacecraft Delivered		
NASA	136	110
DOD	122	111
Total	258	221
Spacecraft Retrieved		
NASA	90	79
DOD	89	79
Total	179	158
Total Spacecraft Missions	437	379

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OPTION 2 FLIGHT SUMMARY (WITH PROGRAMMATICS)

The data shown on the facing page is a detailed breakdown of the Option 2 Mission Model Capture Analysis after Programmatic Consideration for launch rate buildup and reliability losses.

Flights are categorized by mission type and show the reduction from 100% capture during the first two years. The delivery flights show 24 multiple payload deliveries and 40 single payload deliveries; 25 of which are planetary missions. The retrieval number of 36 indicates dedicated flights where single spacecraft are retrieved. Round trip flights are separated into equal and unequal payload weights: equal round trip being where, for example, a 900 pound spacecraft is delivered and an identical 900 pound spacecraft is retrieved; whereas unequal denotes, for example, a delivery of 2100 pounds and a retrieval of 900 pounds. The 66 delivery and delayed retrieval flights consist of delayed retrieval flights and flights where spacecraft are delivered and enough excess performance exists on the Tug to partially deorbit another spacecraft for later delayed retrieval by another Tug. Dedicated deorbit flights (3) occur in certain years due to unavailability of spacecraft needing delivery in those years, not because of energy requirements on the Tug.

Reliability losses (3) are added as a function of the overall planned flight program (1 per 100 flights) and bring the total flight number to 254.

OPTION 2 FLIGHT SUMMARY (WITH PROGRAMMATICS)

Number of Flights by Type	
Round Trip	82
Equal (73)	
Unequal (9)	
Delivery	64
Multiple (24)	
Single (40)	
Retrieval	36
Delivery and Delayed Retrieval	66
Dedicated Deorbit for Delayed Retrieval	3
Reliability Losses	3
Total Flights	
NASA	139
DOD	115
Total	254

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OPTION 2 FLIGHT SUMMARY (WITH PROGRAMMATICS)

The facing viewgraph presents the fleet size as determined from expended stages, reliability losses, and required active fleet. Also, shown are the number of kick stages that are required for the duration of the seven year mission model.

OPTION 2 FLIGHT SUMMARY (WITH PROGRAMATICS)

Fleet Size

Main Stages Expended	6
Reliability Losses	3
Remaining Active Fleet	3
Fleet Size	12
Kick Stages Expended (KS 10)	5

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PROGRAMMATICS - GROUND RULES AND ASSUMPTIONS (REVISED)

Additional Analyses conducted subsequent to the September Data Dump included a review of the ground rules and assumptions used which we felt were too conservative and resulted in high costs. The resulting program definition presented in our Final Report is referred to as the Revised Option 2 Definition and is based on the ground rules and assumptions shown.

Based on the ICC Sensitivity Study presented at the September Data Dump, DDT&E is started one year earlier (November 1978) to reduce peak year funding.

It is assumed that the DDT&E phase is preceded by an extensive SRT and Phase B effort resulting in a final systems specification and preliminary end item specifications (no change).

Proof of life cycle capability can be accomplished by analysis and coupon testing. Thermal effects can be proven using the prototype flight vehicle and analysis.

The September Data Dump assumed loss of cradles similar to the reliability loss of Tug vehicles, which was felt to be too conservative.

Trade studies conducted subsequent to the September Data Dump showed that use of a Centralized Tug Maintenance and Checkout Facility (CTMCF), propellant loading on pad (but out of orbit), and acceptance testing in the CTMCF were cost effective.

Use of existing control center equipment and crew, provided by the government, is more realistic than assuming that all new equipment and crews would be provided by the contractor. Cost savings can be achieved by training NASA and DOD crews jointly.

PROGRAMMATICS - GROUND RULES AND ASSUMPTIONS (REVISED)

DDT&E Optimized for Peak Year Funding (Start November 1978)

DDT&E Preceded by Extensive SRT and Phase B Effort

Life Test Article and Thermal Effects Test Model Deleted

Cradle Attrition Deleted

Use Central Tug Maintenance and Checkout Facility (CTMCF)

Load Propellants On-Pad, But Out of Orbiter

Use Existing Facilities (Modified)

Perform Acceptance Testing in CTMCF

Control Center Equipment, Maintenance, and Crew Provided by Government

NASA and DOD Crews Trained Jointly

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TUG SUMMARY SCHEDULE - REVISED PROGRAM OPTION 2

A summary schedule for Option 2 as revised by the new programmatic ground rules is presented in the facing viewgraph. The significant schedule items relative to the schedule presented at the September Data Dump are:

DDT&E

1. Eleven months longer span to initial IOC with same complete date.
   a. Increased preliminary design time from ATP to PRR (specifications complete) by two months and from PRR to PDR by one month.
   b. Increased detail design time from PDR to Engineering Release by one month.
   c. Build major test articles and Tug No. 1 (Prototype) on a one-shift basis requiring an increased span of seven months.

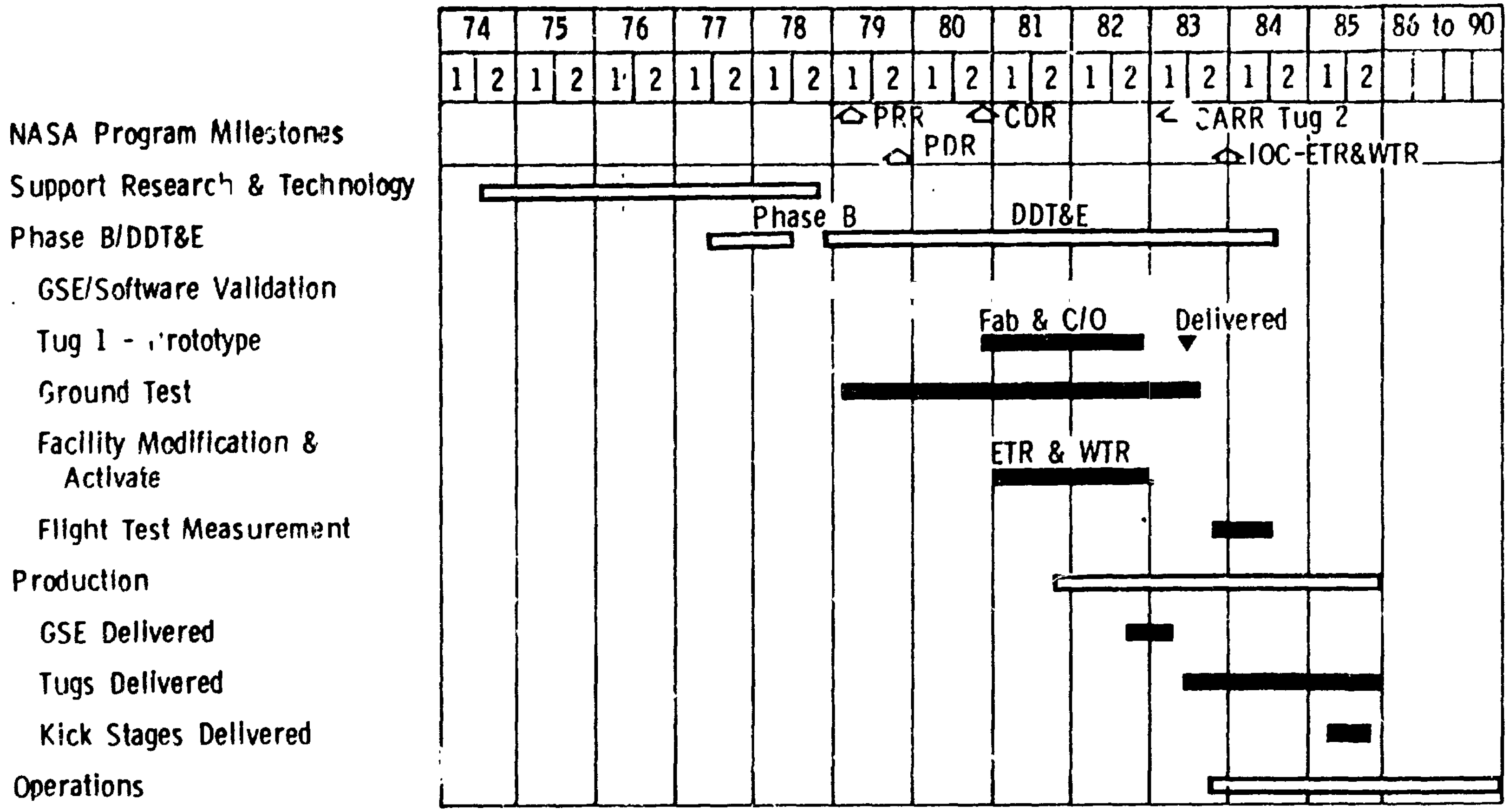
Production

1. Start four months earlier to build Tug No. 2 on a one-shift basis (subsequent Tugs originally planned for one-shift build).
2. Reduce quantity of Tugs required by one due to CTMCF.

Operations

1. Accept remaining Tugs after Tug No. 2 at CTMCF.
2. CTMCF reduces the active fleet requirement from five to four.

TUG SUMMARY SCHEDULE - REVISED OPTION 2



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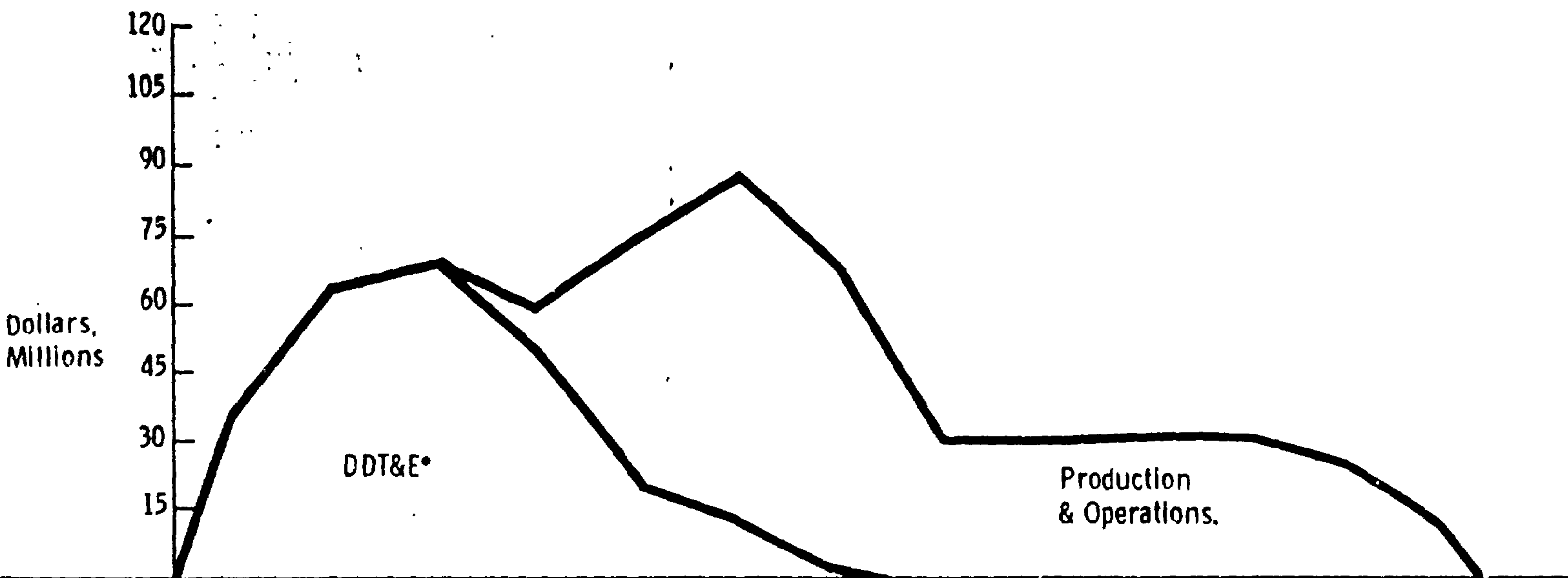
REVISED OPTION 2 FUNDING REQUIREMENTS

This chart shows the estimated annual funding requirements for the Revised Option 2 Program Definition. The Revised Option 2 differs from the September Data Dump in that certain ground rules and assumptions were revised to reduce costs. DDT&E is started one year earlier to reduce peak funding.

Since all OOS candidates use Kick Stages, it is not clear how much development will be required for the Tug; therefore, DDT&E costs for the Kick Stages cannot be determined and are not included. Production and Operations costs for the five Kick Stages are included.

REVISED OPTION 2 FUNDING REQUIREMENTS



FY	79	80	81	82	83	84	85	86	87	88	89	90	91	Total
DDT&E	37.4	62.6	69.7	50.3	20.9	13.0	0.7							254.6
Production				9.0	54.1	54.5	34.7	0.5						152.8
Operations						21.1	31.0	28.5	28.7	30.6	30.8	24.6	12.3	207.6
Total/Year	37.4	62.6	69.7	59.3	75.0	88.6	66.4	29.0	28.7	30.6	30.8	24.6	12.3	615.0

*Kick stage DDT&E cost not established.
SRT & Phase B Not Included

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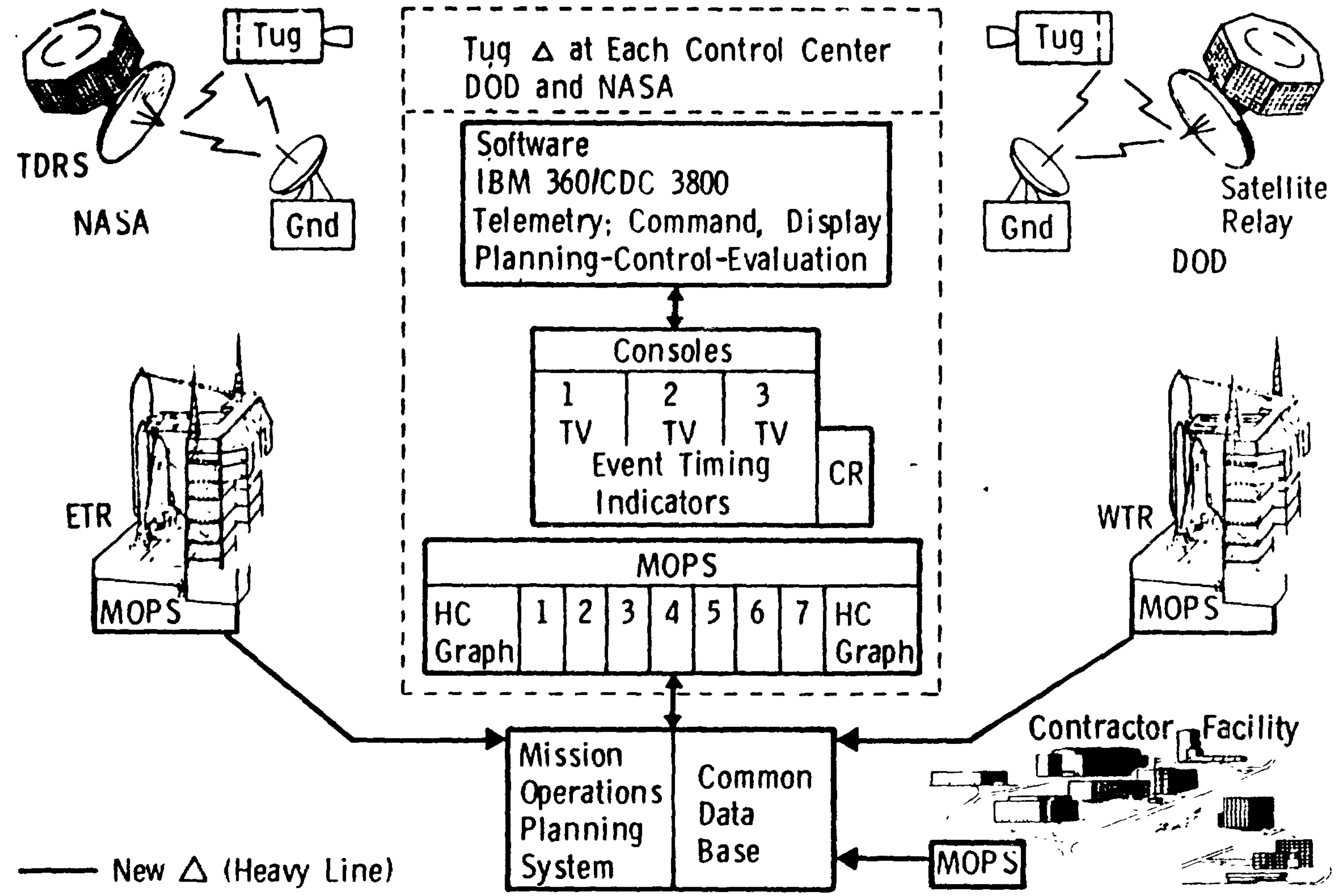
SUPPORT REQUIREMENTS

The facing viewgraph illustrates the support requirements concept used to develop operations costs. The mission control center hardware and software requirements are shown in the dotted section of the sketch. It was assumed that both DOD and NASA would have such facilities. Tug operations control is maintained from this facility with interface to the mission operations center of the Shuttle system at Houston. Interface is also shown with the two launch sites and the contractor facility. Approximately 23 people were judged necessary to operate the tug control center during a tug flight.

SUPPORT REQUIREMENTS



PROPELLANT HANDLING CONCEPT - REVISED OPTION 2 DEFINITION

Storable tug propellant loading was initially baselined off-pad with Tug installation in the vertical assembly building. Recent trade studies which considered some 13 different factors such as safety, timelines, interfaces, spill during loading, etc., resulted in the selection of loading at the launch pad but prior to Tug installation in the Orbiter. The spacecraft would be integrated at the pad and the loaded payload (Tug and Spacecraft) placed into the Orbiter via the planned payload changeout unit. This technique reduces cost, improves safety, and provides greater operational flexibility over the baseline concept without compromising Tug performance.

The Tug provides both vertical and horizontal dump capability: vertical dump for prelaunch and horizontal dump for post launch should the Tug return with loaded propellant tanks.

Normal post launch Tug safing will involve the draining of residual propellants and the application of a dry nitrogen purge. If the system requires entry due to unscheduled maintenance, a more involved decontamination process will be used.

PROPELLANT HANDLING CONCEPT - REVISED OPTION 2 DEFINITION

Load Propellants On Pad (But Out of Orbiter) In Vertical Position

Vertical and Horizontal Dump Capability Provided

Residual Propellants Unloaded and Tanks Dried With Nitrogen in Shuttle Safing Area

Tank Decontamination Not Required Except for Unscheduled Maintenance

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SAFETY OF STORABLE TUG

Study Background - During Tasks 1, 2, and 3, safety was provided by applying data package criteria to subsystem selection and by individual designer safety emphasis. Systematic Safety analysis was initiated at the onset of task 5 to insure the safety of the configurations selected. The methodology employed was to define all of the potential hazards (documented in a potential hazard matrix; September Data Dump) and to conduct hazard analyses from that matrix to determine the status of each, i.e., its criticality, should it be eliminated by design, should monitors be provided, can the hazard be reduced by procedure, or finally, should the risk of the hazard be accepted. Documentation and cataloging of each hazard was provided and will be maintained and updated throughout the entire program (recognizing that safety analysis and assurance is an iterative process).

Principal Concern - The propellants themselves were the source of principal concern as their characteristics would indicate: e.g., they are corrosive, toxic, react on contact, etc. However, over ten years of a successful design, test and operational experience (Titan II and Titan III) has proven that the propellants are quite safety manageable. Procedures and hardware exist to routinely handle and eliminate leaks and spills. Design and manufacturing techniques developed in the Titan II and III programs minimize the leak potential. Propellant transfer procedures have been proven. Historically, months go by after loading propellants before leaks appear (leak rates 250 ppm and smaller).

Other areas of concern include: 1) Category I SFPs - Every effort has been made to eliminate them; those not eliminated - pressure vessels; 2) Caution and Warning - Flexibility has been provided in the design to accommodate a great number of monitors to the ground and Orbiter to continuously indicate Tug status; 3) the fail-operate/fail-safe criteria of the study data package was strictly enforced.

Conclusion - The storable Tug is safety manageable*.

* Safety Manageable - We know what the hazards are, we understand them, we know how to handle them.

SAFETY OF STORABLE TUG - HOW PROVIDED

Safety Conscientiousness Applied Throughout Study

Strict Adherence to Design Study Data Package Requirements

Designer's Elimination of "Least Safe" Choices During Subsystem Selection

Systematic Analyses to--

- Identify Energy Sources
- Identify Single-Point Failures
- Identify Hazards in Design and Operations
- Analysis of Above to Determine Criticality and Eliminate, Control/Monitor, Establish Procedures, or Accept
- Document and Catalog Identified Hazards

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SAFETY OF STORABLE TUG

Energy Sources	Remarks
Propellants N_2O_4, MMH, N_2H_4, Class II Solids	10-Year History of Handling, Transferring, Leak Checking, Pressurizing, etc. Operating Procedures Developed. Known and Proven Design and Operating Principles Incorporated.
Pressurization He: 300 psi, 3600-psi Storage; 25 to 50-psi, Operating Engine Start Accumulator	State-of-the-Art Concept and Subsystem Selection Consistent With Manned Vehicles on Previous Programs.
Batteries Ag-Zn, 165 A-H, 25 A-H	Vent and Relief Provided; Overpressure Protection, Leak Protection; State-of-the-Art Design
Ordnance Squibs, Detonators, Detonating Cord SRM Igniters	Arm/Safe provisions; State-of-the-Art Design Consistent With Manned Vehicles on Previous Programs

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SAFETY OF STORABLE TUG

Issues	Control
Oxidizer	Material Selection, Inert Gas Blanket, Purge, Procedure and Operational Discipline Established
Fuel	Inert Gas Blanket, Procedure and Operational Discipline Established, Water Deluge
Propellant Handling	Protective Clothing During Transfer, Warning Indicators, Established Contingency Plans, Procedure and Operational Discipline
Operational Errors	Procedure and Operational Discipline, Continuous Training
Vehicle Status	Continuous Monitor - Orbiter and/or Ground
Unprogrammed Vehicle Motion	"Fail Operate/Fail Safe" ACPS and Avionics
Crew Hazard SFPs	Eliminated Except for Pressure Vessels
Fail Operate/Fail Safe Criteria	Design Complies

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SAFETY OF STORABLE TUG

Storable Propellant History

Over 10,000,000 Gallons of Propellant Transferred

More Than 1700 Propellant Tanks Fabricated

Propellant Leaks (Titan II History)

- Shortest Time from Load to Leak, 4 Months
- Average Time from Load to Leak, 40 Months
- 3 Vehicles Loaded in Operational Status - 58 Months with No Leaks
- All Leaks Extremely Small (Not Visible, Detected by Periodic Check With Special Probes)
- Components and Seals have been Replaced With Tanks Loaded

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OPTION 2 SUMMARY

The key conclusions from this study are presented on the facing viewgraph. At the onset of the study, the key issue to be addressed was whether the performance limits inherent with the Storable Tug would prevent a Storable Tug from successfully meeting basic Tug requirements. This study has shown the performance limitation is not a factor and that Storable Tug can in fact effectively accommodate all mission model requirements. With the performance question having been answered affirmatively, inherent advantages of a storable propellant Tug make this concept feasible for all-up Tug considerations.

OPTION 2 SUMMARY

Storable Tug Offers--

- Simple Design
  - Single Stage, 10 Foot Diameter
  - Passive Thermal
  - Out-Of-Orbiter Loading
- Safe & Reliable Design
  - Isolated Tanks
  - Land Loaded Or Full
  - Horizontal And Veritical Dump
  - Redundant Systems
- Simple Interfaces
  - Two Dry Fluid Lines, Two 8-Pin Connectors
  - No Purges, Venting Or Topping
- Effective Use Of Cargo Bay
  - Meets All CG Constraints
- Effective Performance
  - Minimum Need Of Kick Stages
  - Deorbit Any Spacecraft Via Delayed Retrieval
  - Length & Performance Optimize Multiple-Mission Capability

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PART II - OOS/TUG TRANSITION

In order to determine the impact of transitioning from the interim Orbit-to-Orbit Shuttle (OOS) to the full capability Tug, we have selected the Growth Transtage as representative of a storable OOS.

PART II

OOS/TUG TRANSITION

Orbital Operations

OOS/TUG TRANSITION MISSION CAPABILITY

Major mission capability differences are presented which have an operations impact. Functions necessary to be accomplished or statused by control center personnel along with applicable onboard and ground software are primarily responsible for these mission capability differences. For example, the capability to rendezvous and dock with a payload for retrieval implies additional major onboard system functions which must be simulated premission and monitored for backup/override during the mission.

OOS/TUG TRANSITION
MISSION CAPABILITY

	OOS	Tug
Mission Duration	20 Hours	7 Days
Kick Stage Usage	Planetary and Geostationary Deployment	Planetary Deployment
Payload Retrieval	None	All Earth Orbit
Expendable Modes	Planetary	Some Planetary
Navigation	Autonomy Level III	Autonomy Level II
Override	Limited	Onboard Redundancy and Consumables Management With Ground Backup and Workarounds

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OOS/TUG TRANSITION SUBSYSTEM OPERABILITY

Functional requirements are detailed by subsystems to the level considered necessary for relative sizing of ground software and crew for mission support activities during the preparation and actual mission support. The Main and Auxiliary Propulsion subsystem operational differences are addressed with respect to override and monitor of engine burns which are constrained for the OOS to the ground network by the communications system configuration/capability.

OOS/TUG TRANSITION
SUBSYSTEM OPERABILITY

	OOS	Tug
Main Propulsion System		
Engine	Vent and Purge	Same
Safing	Vent and Repressurize	Land with Residuals
Dump	Simultaneously or Sequentially	Simultaneously or Oxidizer Only
Ascent Abort	Dump Above 150,000 ft	Same
On-Orbit Abort	Orbiter Thrust Required for Propellant Settling to Initialize Dump	Same
Umbilicals	Reconnect Not Required Due to Vent and Purge	Reconnect Required when Landing with Residual Propellants
Activation	1 Mile from Orbiter	Same
Override	Shutdown	Shutdown/Restart
Auxiliary Control Propulsion System		
Activation	Orbiter Proximity	Same
Recovery	Minor Translation	Stationary
Safing	Isolation	Same
Override	Limited	All (Rendezvous & Docking)

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OOS/TUG TRANSITION SUBSYSTEM OPERABILITY (CONCLUDED)

The major operational impact in the Avionics subsystems is the override (monitor/control) requirement for backup of the rendezvous and docking automated system along with the backup capability for individual functions, such as Solar Array deploy/retract and High Gain antenna articulation for workaround corrective action in contingency situations. The tug data bus system provides the capability for monitor and control of any or all functions while the OOS data system is hardwired and allows monitor and control of a fixed or limited number of functions.

OOS/TUG TRANSITION
SUBSYSTEM OPERABILITY (CONCLUDED)

	OOS	Tug
Avionics		
Command/Control	Network Dependent	Continuous (Relay Satellite)
Self-Check	Limited	Extensive
Data Management	Hardwire	Data Bus
Rendezvous & Docking	None	Automated With Ground Backup
Power Source	Batteries	Solar Panels/Batteries

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OOS/TUG TRANSITION MISSION PLANNING

Functional areas are presented which impact the mission planning capabilities; and therefore, the mission planning crew size and software complexity.

Small differences are seen in preflight planning; however, the capability for tug realtime replanning is seen as the major impact due to the flexibility of the onboard systems for control from the ground in off-nominal or contingency cases. This flexibility could provide for achieving alternate mission objectives and thereby, enhance mission success.

OOS/TUG TRANSITION
MISSION PLANNING

	OOS	Tug
Premission	Mission Dependent	Same
Real Time	Limited	Extensive
Onboard Software	Limited Memory Preplanned Application Limited Functions Mission Peculiar	4 Megabits Extensive Reconfiguration Varied Functions Flexible
Constraints	Systems - Limited Workarounds	Systems - Effective Workarounds

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OOS/TUG TRANSITION - FLIGHT OPERATIONS SUPPORT

The major areas of impact are ground software, ground c. ew, and network utilization.

The network utilization constraint is relieved for Tug due to communications system compatibility with relay satellite, which provides almost continous communications coverage.

C-2

OOS/TUG TRANSITION
FLIGHT OPERATIONS SUPPORT

	OOS	Tug
Ground Software	Simple - Few Functions	Complex - Many Functions
Ground Crew	Nominal	Slight Increase - System Monitor and Redundancy Management Backup
Network Utilization	Time Constrained	No Time Constraints

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DOS/TUG TRANSITION - FLIGHT OPERATIONS IMPACT SUMMARY

Areas of ground software/facilities and associated crew increases are presented.

Small differences are seen in the areas of crew size and hardware for transition. The major area of impact is in software development due to changes in onboard software impacting ground software for mission simulations and checkout; changes in ground processing for uplink/downlink; and additional ground programs to accommodate flexible design in redundancy and consumables management.

OOS/TUG TRANSITION
FLIGHT OPERATIONS IMPACT SUMMARY

Tug Ground Crew Size

- Added Functions Require Increased Monitor & Control for Backup/Override (e.g., Rendezvous and Docking)
- Added Capability for Real Time Preplanning (Alternate Missions) to Enhance Mission Success
- Added Training and Simulations for More Complex, Longer Duration Missions

Tug Ground Software

- Small Increase in Ground Processing to Accommodate Increased Functional Monitoring (TM Decommutation) and Control Backup (Command Generation)
- Increase in Mission Simulation Software Used to Check Out Ground Software and Larger Increase in Ground Simulation Software Used to Check Out Mission Software
- Increase for Redundancy/Consumables Management Ground Programs

Tug Ground Facilities

- Increased Displays/Consoles for Added Monitor/Control Capability

Orbiter To Tug Interfaces

OOS/TUG TRANSITION - ORBITER TO TUG INTERFACE - STRUCTURES

The facing viewgraph shows the general configuration and structural interface comparisons between the OOS and Tug. It is noted that both the OOS and Tug are compatible with the Orbiter requirement of a 4 point statically determinant interface. Although the same four points are not used by both the OOS and Tug, they are all standard orbiter points.

For abort loads, when fully loaded, both the OOS and Tug reactions exceed Orbiter allowables in the Z direction, while the Tug, due to its heavier gross weight, shows Y direction reactions also exceeding orbiter allowables.

Both OOS and Tug are within Orbiter constraints on length, diameter, c.g., and manipulator handling.

OOS/TUG TRANSITION
ORBITER TO TUG INTERFACE - STRUCTURES

Item	OOS	Tug
Interface Points	X_0 = 1041, 1181, 1181, 1162	X_0 = 1041, 1041, 1134.5, 1040
Interface Loads	Some OOS Loaded Abort Loads Exceed Orbiter Allowables	Some Tug Loaded Abort Loads Exceed Orbiter Allowables
Stage Length	19 ft 2 in.	Deploy Configuration, 27 ft 4 in. Retrieve Configuration, 28 ft 8 in.
Stage Nominal Diameter	10 ft	10 ft
Cradle Type	Nonpivoting	Nonpivoting
Longitudinal CG	Within Allowable Envelope at All Times	Within Allowable Envelope at All Times

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OOS/TUG TRANSITION - ORBITER TO TUG INTERFACE - FLUIDS

The fluid interface with the Orbiter during OOS/Tug transition should have little or no impact on Orbiter design. Although the line size requirement for Tug is larger, the line in the Orbiter could be sized for the most severe requirement. Tug line size requirements and separation for deployment would be accommodated via the cradle. It is assumed the Orbiter interface would be a bolted flange located in the aft end of the payload bay.

OOS/TUG TRANSITION
ORBITER TO TUG INTERFACE - FLUIDS

Item	OOS	Tug
Line Quantity & Size	One 2-1/2 in., Fuel One 2-1/2 in., Oxidizer	One 3-1/4 in., Fuel One 3-3/4 in., Oxidizer
Line Routing	Via Cradle to Aft End of Payload Bay	Via Cradle to Aft End of Payload. Bay

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OOS/TUG TRANSITION - ORBITER TO TUG INTERFACE - AVIONICS

The Orbiter-to-Tug avionic interface is simplified with the more advanced Tug vehicle. This would be expected inasmuch as the Tug avionics system was designed with the Orbiter interface requirement.

The Tug vehicle is essentially self checking with adequate redundant components and redundancy control logic to assure a fail operate/fail operate condition in many of the critical systems. The fail operate/fail safe condition is assured for all critical systems. This, plus the C&W limit checking and FSI to standard Orbiter computer interface system (hardwire plus logic), leaves the orbiter crew virtually free of routine Tug monitoring tasks up to the point of manipulator arm deployment.

OOS/TUG TRANSITION
ORBITER TO TUG INTERFACE - AVIONICS

Item	OOS	Tug
Umbilical Connectors	Nonredundant - 100 Pin	Redundant - 8-Pin (4 Pins for Power)
Data Management	Interface Data Available from RMIS Via Orbiter Data Bus	Full Data and Interface Control Allowed by FSI Capability
Communications	2 kbps Command and 16 kbps Telemetry to Orbiter or Ground	Same Plus Continuous All-Altitude Coverage Using Relay Satellite Links
Caution and Warning	Dedicated C&W Lights Hardwire Connected Limited Data and Contingency Control Available Via Hard-wire and Orbiter Data Bus Interface	Tug FSI Limit Checks Single Warning Light Full Data Display & Override Control Uses Standard Orbiter Display and Keyboard on As-Needed Basis
Power	500 Watts Average from One Orbiter Bus	417 Watts Average Combined from Two Orbiter Buses

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OOS/TUG TRANSITION
ORBITER TO TUG INTERFACE IMPACT SUMMARY

No Major Orbiter to Tug Interface Impact During OOS/Tug Transition

Tug To Spacecraft Interfaces

OOS/TUG TRANSITION - TUG TO SPACECRAFT INTERFACE

The next two viewgraphs assess the impact on the interfaces with the spacecraft. The OOS structural interface with the spacecraft consists of 8 hard points which are separated by explosive nuts. There is no spacecraft retrieve capability for the OOS. The tug interface concept is based on achieving a uniform or near uniform loading which is accomplished by using different modules for Deploy Only and for Deploy and Retrieve. The Deploy Only module is uniformly attached to both the Tug and spacecraft. An encapsulated detonating fuse separates the spacecraft for deployment. The Tug Deploy and Retrieve module is a modified Apollo type docking probe mounted to a triangular frame, an actuator-damper assembly, and 18 mechanical latches. All flight loads are transmitted through the latches and outer structure rather than the docking mechanism. The transition from OOS to Tug spacecraft interface would be accomplished by using a different spacecraft adapter.

The Tug provides additional capability for the spacecraft such as power, flexibility in data management, spacecraft control and direction, and caution and warning. This improved capability is not considered a significant impact.

OOS/TUG TRANSITION
TUG TO SPACECRAFT INTERFACE

	OOS	Tug
Structural	Deploy - Hardpoint Attachment	Deploy - Frangible Section, Uniform Load
	Retrieve - None	Retrieve - Standard Docking Module
Spacecraft Power	Provide Bus for Orbiter-to-Spacecraft	Provides 300 Watts
Spacecraft Data	Via Remote Multiplex Instrumentation System	Adaptive - Using 4-Pin FSI Connection

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OOS/TUG TRANSITION
TUG-TO-SPACECRAFT INTERFACE (CONCLUDED)

	OOS	Tug
Spacecraft Control	Limited to Hardwire Circuits Available	Full Capability Through FS1
Spacecraft Checkout	Limited	FS1 Limit Checks Plus Stimulus Control
Spacecraft C&W for Orbiter	Provide Needed Hardwire Interconnection	FS1 Limit Checks Plus Full Display and Control of Spacecraft Parameters

OOS/TUG TRANSITION
TUG TO SPACECRAFT INTERFACE - IMPACT SUMMARY

Spacecraft Structural Attachment Should be Designed for Both the 4/8 Point Loads for OOS and the Uniform Loads for Tug

No Other Tug-to-Spacecraft Interface Impact During OOS/Tug Transition

Ground Operations

OOS/TUG TRANSITION - GROUND OPERATIONS

The following five viewgraphs highlight the major differences in ground operations between the OOS and the Tug. Some OOS GSE may be modified and some new GSE will be required to support the Tug turn-around cycle. A modification to the fuel transfer system will be required since the Tug uses MMH instead of A-50 as main propulsion fuel. New checkout software and new and modified checkout procedures would be required. Since crew size is dependent on launch rates, the crew size to turn around the Tug would be larger than that required for the OOS, due to the addition of the down traffic.

The technical impact to ground operations caused by COS to storable Tug ransition is minimal.

OOS/TUG TRANSITION GROUND OPERATIONS

Work Area/Consideration	OOS	Tug
Safing Area Activity	OOS Safing	Same (Plus Propellant Drain)
	OOS-Orbiter Demate	Same
		Tug-Spacecraft Demate
CTMCF Area Activity	Inspections Systems Acceptance (Initial Receipt Only) Scheduled/Unscheduled Maintenance Subsystem Checkout Kick Stage Mate (If Required) Systems Verification	Same (Checkout Includes Rendezvous & Docking Systems)
Propellant Loading Area Activity	Load Propellants	Same
	Load Pressurants	Same

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OOS/TUG TRANSITION
GROUND OPERATIONS (CONTINUED)

Work Area/Consideration	OOS	Tug
Cleaning Area Activities	Cleaned to 100,000 Cleanliness Specs	Same
Launch Pad Activities	OOS-Spacecraft Mate and Verification	Same
	Payload-Shuttle Mate and Verification	Same
Facility Requirements	Safing Area	Same
	CTMCF	Same
	Kick Stage Storage	Same
	Propellant Loading Area (A-50, N_2O_4)	Same, Except MMH Instead of A-50
	Pad Change-Out Unit	Same

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OOS/TUG TRANSITION
GROUND OPERATIONS (CONTINUED)

Work Area/Considerations	OOS	Tug
GSE Requirements	Handling Equipment	New/Modified Handling Equipment
	Avionics Test Set	New Checkout Set
		New Guidance System Alignment Set
	Engine Handling Equipment	New/Modified Engine Handling Equipment
	Engine Test Set	New Engine Test Set
	ACPS Test Set	New/Modified ACPS Test Set
Logistic Requirements	OOS Spares	Equivalent Tug Spares
	Training	Equivalent .
	Commodities - Power - Propellants - Pressurants	Same, Except MMH Instead of A-50
Software and Procedures	OOS Oriented	New/Modified for Tug

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OOS/TUG TRANSITION
GROUND OPERATIONS (CONTINUED)

Work Area/Consideration	OOS	Tug
Crew Size (Approximate)	140 to 150	170 to 180 (Increase Due to Launch Rate Increase)
Ground System Test Procedure/ Activation	OOS-Ground GSE-Ground	Equivalent

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OOS/TUG TRANSITION
GROUND OPERATIONS (CONCLUDED)

Impact Summary

- New/Modified GSE
- New Ground Checkout Software
- New/Modified Refurbish and Checkout Procedures
- Modification of Storable Fuel Transfer System
- Crew Size Will Increase Due to Launch Rate Increase

Safety

OOS TO TUG TRANSITION - SAFETY

An item by item comparison of OOS to Tug of the principal hazards (from the Tug September data dump and the OOS Safety Analysis) identified reveals no new hazards in the transition. The principal impact of the transition is an increased perimeter of Quantity-Distance control in and around the Tug after propellant and pressurization loading due to the increased quantity of propellants in Tug. The safety analysis work that has been conducted in both the OOS and Tug studies has shown that both are safety manageable* systems and on that basis, the transition, too, is safety manageable*.

* Safety Manageable - We have identified the hazards, we understand the hazards, we know how to handle the hazards (design, operation, procedures).

OOS/TUG TRANSITION
SAFETY

Item	OOS	Tug
Propellants (Main Tank)	Type and Characteristics Similar to Tug (Oxidizer - N_2O_4, Fuel, - A-50); Hazards and Solutions Well Known Based on 10-Year Use	Oxidizer - N_2O_4, Fuel - MMH, Quantity Greater Than OOS; Greater Quantity-Distance Control Required
Propellants (ACPS)	N_2H_4	N_2H_4; Quantity Greater Than OOS;
Propellants (Engine Start Tank)	None	Same as Main Tank; Quantity Very Small
Propellants (SRM)	Class II Propellant	Class II Propellant; Quantity Greater Than OOS; Greater Quantity-Distance Control Required

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OOS/TUG TRANSITION SAFETY (CONTINUED)

Item	OOS	Tug
Pressurization (Main Tank)	Helium - High Pressure	Helium - High Pressure Comparable to OOS; Smaller Quantity Than OOS;
Pressurization (ACPS)	GN_2 - 340 psi	Helium - 3600-psi; Greater Quantity-Distance Control Required
Pressurization (Main Tank, Blanket)	Helium - 50 psi	Helium - 17/28 psi
Propulsion System "Fail Safe"	Engine Isolation Valve	Same
Propellant Tanks	"Leak Mode" Failure Design In and Around Orbiter; "Burst Mode" Failure Design Inflight	"Leak Mode" Failure Design All Conditions

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OOS/TUG TRANSITION SAFETY (CONTINUED)

Item	OOS	Tug
Abort Propellant Dump	On-Pad, On-Pad in Orbiter, Ascent, and On-Orbit	Same
Orbiter Dump Umbilicals (Propellant)	Do Not Require Hookup at Orbiter Retrieval; Residuals Dumped Prior to Retrieval, Tanks Purged and Helium Blanketed	Require Hookup After Orbiter Retrieval; Residuals Under Helium Blanket Pressure
Unprogrammed Motion	Vehicle Design is "Fail Safe"	Vehicle Design is "Fail Operate/Fail Safe"
Caution & Warning	Critical Parameters Hardwired; Orbiter and/or Ground Monitored	FSI Permits Flexibility in Parameter Selection; Orbiter and/or Ground Monitored

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OOS/TUG TRANSITION SAFETY (CONCLUDED)

Item	OOS	Tug
Ordnance	Squibs, Separation Nuts	Squibs, Detonating Blocks, Detonating Cord; Quantity Less Than OOS
Batteries	Two 165-AH Ag-Zn One 25-AH Ag-Zn	One 165-AH Ag-Zn One 25-AH Ag-Zn

OOS/TUG TRANSITION
SAFETY IMPACT SUMMARY

The Increased Quantity of Propellants and Higher ACPS Storage Pressure Will Increase the Perimeter of the Quantity-Distance Control for Tug

No New Hazards are Introduced in the Transition

Both OOS and Tug Are Safety Manageable.

PART III

STAGE LENGTH VS PERFORMANCE

LENGTH VERSUS PERFORMANCE

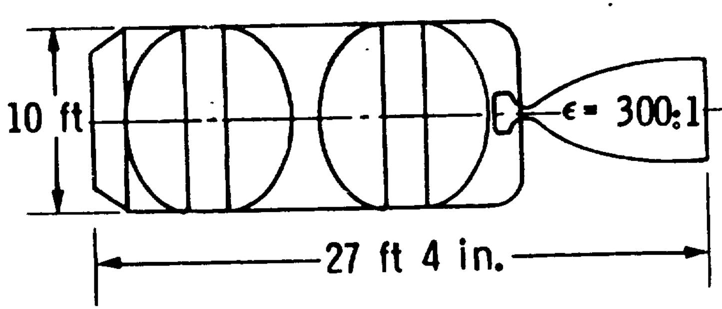
OPTION 2 BASELINE

The maximum allowable payload length available in the Orbiter cargo bay is 60 feet. The maximum spacecraft length in the Option 2 mission model is 25 feet. This leaves 35 feet available for the Tug.

We drove the Tug length down to provide maximum multiple spacecraft delivery capability. Since Tug performance capability is also a driver (both for delivery and retrieval) Tug length must be traded with performance capability.

The 27 foot 4 inch Tug provides maximum performance capability with the minimum practical length, resulting in a minimum number of flights for the Option 2 mission model.

LENGTH VS PERFORMANCE
OPTION 2 BASELINE DESIGN



Maximum Allowable Payload (Tug + Spacecraft) Length = 60 Feet

Maximum Spacecraft Length = 25 Feet (Option 2 Mission Model)

Allowable Tug Length = 35 Feet

Tug Length Minimized to Provide Maximum Multiple Spacecraft Delivery - Minimize Number of Flights

Tug Performance Capability (Weight) is Also a Primary Driver

Tug Length and Performance Capability Optimized for Option 2 Mission Model

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LENGTH VERSUS PERFORMANCE
SUBSEQUENT SELECTED SPACECRAFT DRIVERS

For the purposes of this presentation, we were requested to consider the impact of adding a relatively few spacecraft which exceed 25 feet.

The Option 2 Tug configuration can accommodate the 30 foot and 32 foot spacecraft without any impact. The 35 foot spacecraft mission would drive the Tug length from 27 feet 4 inches, to 25 feet, which is a reduction of 28 inches.

We have considered two approaches to accomplish this reduction:

1. Reduce the Tug length only for the 35 foot spacecraft missions, without changing the basic Tug configuration for other missions.

2. Reducing the length of the basic Tug.

LENGTH VERSUS PERFORMANCE
SUBSEQUENT SELECTED SPACECRAFT DRIVERS

Diameter/Length of Spacecraft (ft)	Spacecraft Weight (lb)	Destination	Tug Impact
10/30	3200	Geostationary	None
10/32	2500	Geostationary	None
10/35	2400	Midinclination	Drives Tug Length to 25 Feet (28 Inch Reduction)

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LENGTH VERSUS PERFORMANCE

REDUCED TUG LENGTH FOR SELECTED SPACECRAFT DRIVERS ONLY

Since only a relatively few missions require a reduced Tug length, we could replace the engine nozzle with a shorter one for these specific missions only. No change would be made to the basic Tug which would still use the longer nozzle for other missions.

As shown on the accompanying viewgraph (next page), the shorter nozzle reduces the geostationary delivery capability from 6000 pounds to 5700 pounds, which is more than adequate for the 2400 pound payload. In fact, we could even accommodate a 40 foot spacecraft by removing the nozzle extension for this specific spacecraft only.

The only impact on the Tug is the additional shorter nozzle and a means for rapid and easy change out. There would be no impact on the basic Tug used for other missions.

There would be some impact to the Orbiter interface since two positions would be required for the cradle and the propellant and electrical umbilicals. Further study is required to determine the extent of the impact and provide a solution to the problem. For example, it may be feasible to move the stage within the cradle, rather than move the cradle when using the Tug with the shorter nozzle.

LENGTH VERSUS PERFORMANCE
REDUCED TUG LENGTH FOR SELECTED SPACECRAFT DRIVERS ONLY

Replace Engine Nozzle with Shorter Nozzle for Specific 35 foot/2400 pound Missions Only

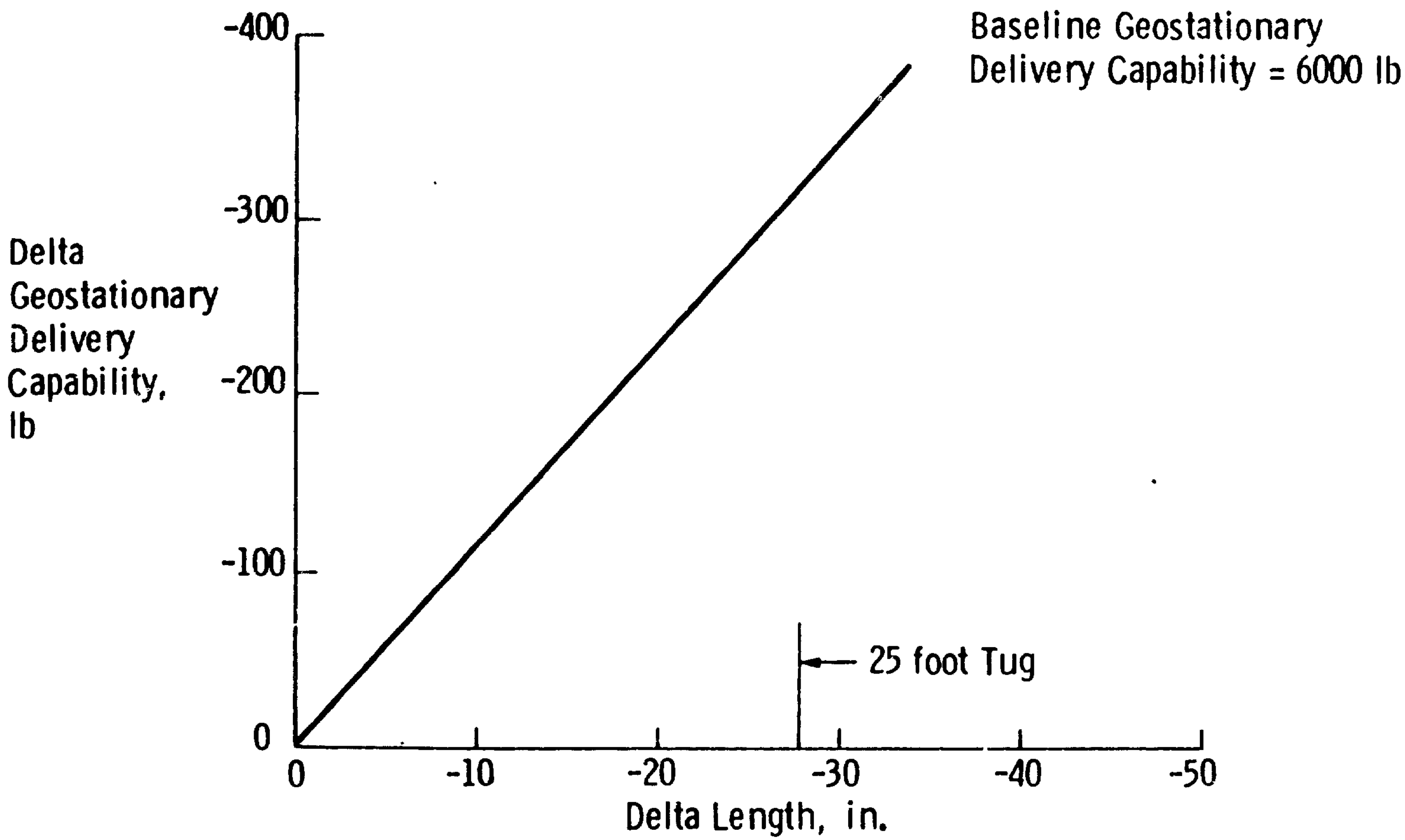
Provides 5700 pound Delivery Capability to Geostationary Orbit

Impact - Provide Additional Nozzle and Provisions for Change Out

Orbiter-to-Tug Interfaces

No Impact to Basic Tug Configuration or Performance for Other Missions

Length Versus Performance
Replace Engine Nozzle for Specific Missions



LENGTH VERSUS PERFORMANCE

REDUCED BASIC TUG LENGTH

If it is desired to reduce the basic Tug length to 25 feet for all Tug flights, there are several candidates that could be used. Extensive design and trade-off studies would be required to select the optimum combination of candidates to be used. However, we are confident that this can be achieved without reducing propellant weight. There would probably be some impact on performance capability

LENGTH VERSUS PERFORMANCE
REDUCED BASIC TUG LENGTH

Configuration Candidates

Modification		Reduced Length, Inches	Remarks
Common Domes		41	Safety Hazard
Side-by-Side Tanks		112	Excessive Weight Penalty
Increase Stage Diameter by Eliminating Barrel Sections	$R/\sqrt{2}$ - Domes	16	Further Studies required - Probably Weight Penalties
	$R/\sqrt{3}$ - Domes	36	
	R/ 2 - Domes	49	
Shorter Thrust Cone		6	Probable, Effective Increment
Reduction in Engine Length	Decrease Area Ratio Recontour Nozzle 2-Position Nozzle Foldout Nozzle Reduction in Thrust	Greater Than 28	Length Versus Performance Illustrated in Following Graph
	Use of 2 Engines Toroidal Engine	Greater Than 28	Extensive Engine and Stage Integration Studies Required

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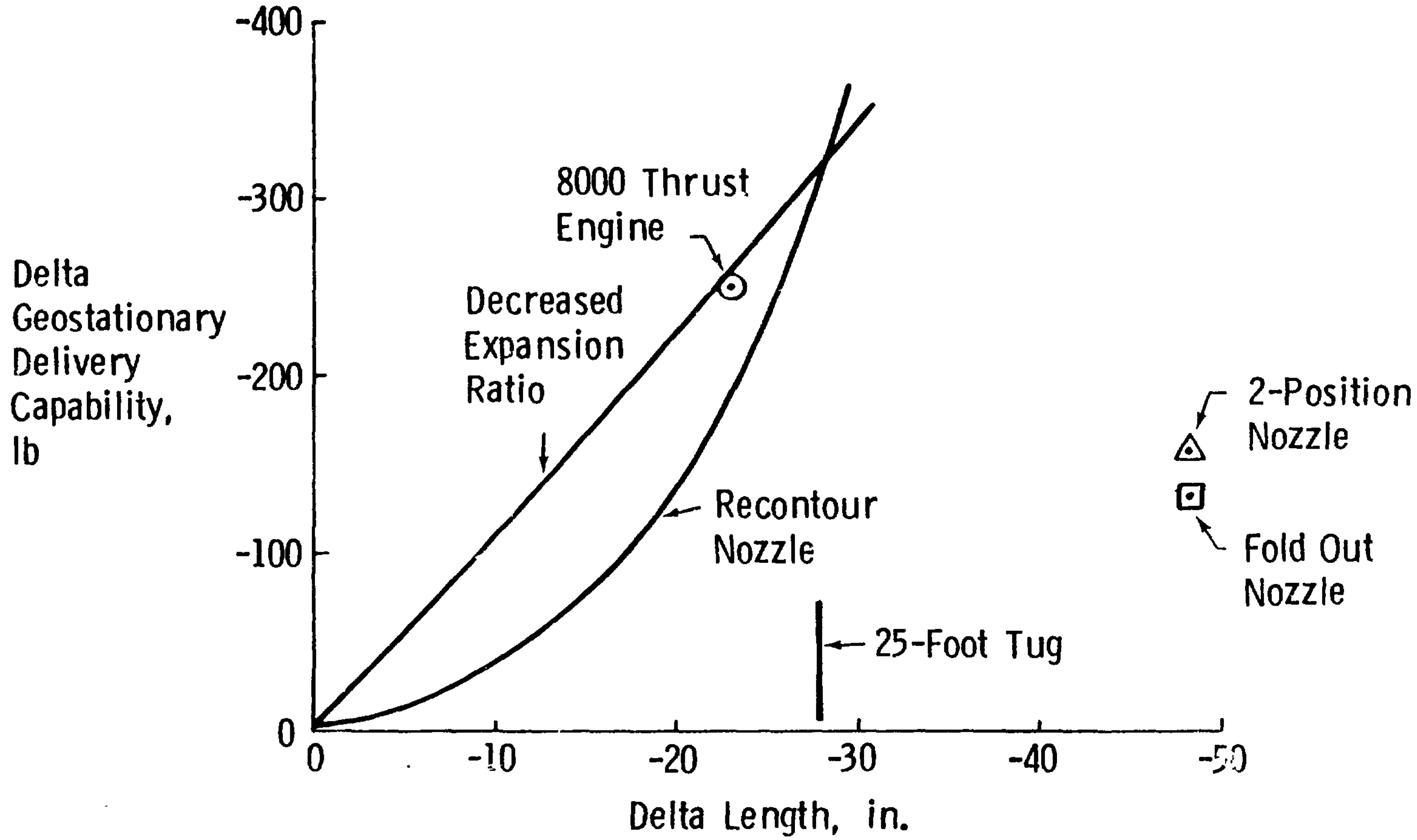
LENGTH VS PERFORMANCE
ENGINE MODIFICATION CANDIDATES



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LENGTH VERSUS PERFORMANCE
CONCLUSIONS

Tug Length (27 feet 4 inches) and Performance Capability is Optimized for Option 2 Mission Model

To Shorten Tug for Specific Missions Only - Replace Engine Nozzle (I/F Impact)

To Shorten Basic Tug

- 28 inch Reduction Can Be Accomplished Without Reducing Propellant Capacity
- Several Candidates are Available to Reduce Length
- Extensive Design and Trade-Off Studies are Necessary to Select the Optimum Combination and Optimize Performance and Mission Capture

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PART IV

SPECIAL PROGRAMMATIC CONSIDERATIONS

SPECIAL PROGRAMMATIC CONSIDERATIONS

Sensitivity To Duration Of Development Program

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SPECIAL PROGRAMMATIC CONSIDERATIONS

SPECIAL SENSITIVITY STUDY - OPTION 2

START DDT&E ONE YEAR EARLY

FUNDING REQUIREMENTS - SEPTEMBER DATA DUMP

This chart is taken from the September Data Dump and compares the results of a special IOC sensitivity study, wherein DDT&E is started one year earlier, with the Option 2 baseline presented at the September Data Dump.

The Option 2 Baseline (Solid Line) presented at the September Data Dump was otpimized for minimum total DDT&E costs, which resulted in high peak year funding requirements.

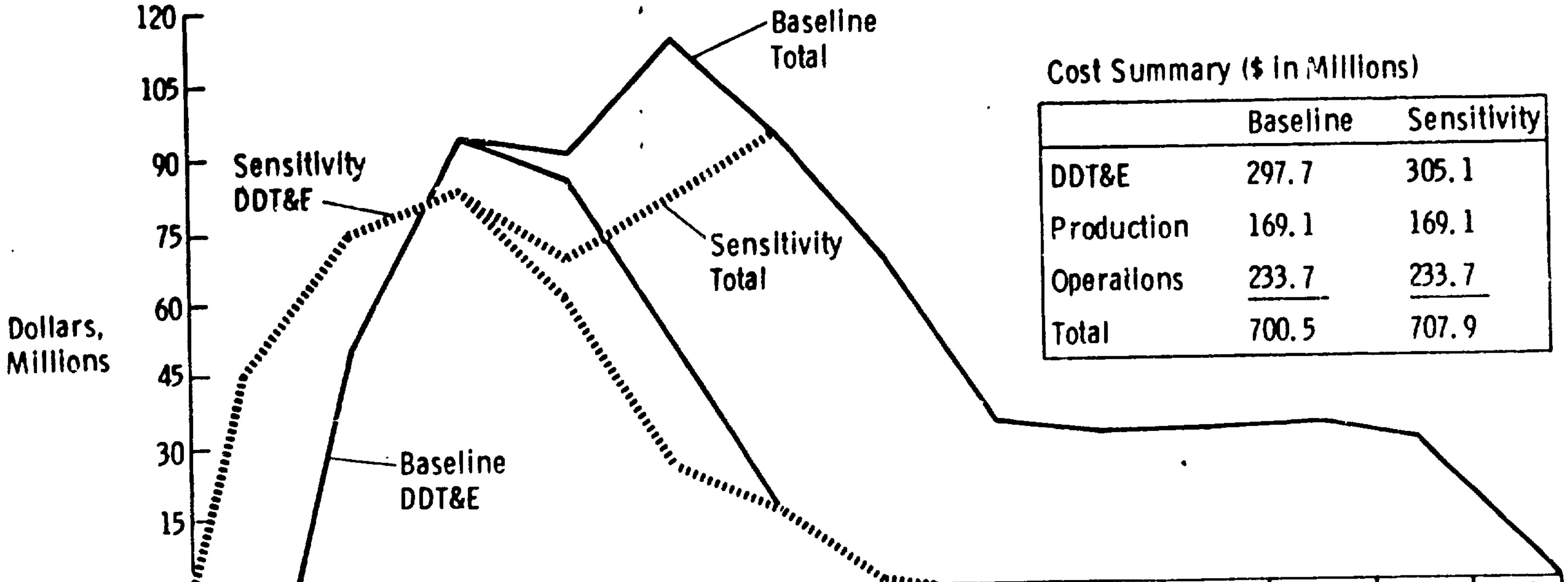
Starting DDT&E one year earlier than the baseline (dashed line) reduces the first peak in FY 1981. The second peak is also reduced and delayed a year. Starting DDT&E one year earlier provides a more reasonable funding distribution; however, the total DDT&E costs are increased by $7.5 million due to the extension of level-of-effort tasks such as Project Management and Systems Engineering.

We see no advantages of starting DDT&E any sooner than November 1978 (start of dashed line), since there would be no further reduction in peak year funding and the total DDT&E costs would be increased due to the further extension of level-of-effort tasks.

The DDT&E span time used in the IOC sensitivity study (start DDT&E in November 1978) has been adopted in our Revised Option 2 Definition previously shown in Part I. Although there is a small penalty in total DDT&E cost, the yearly peak funding requirements are substantially reduced.

SPECIAL PROGRAMMATIC CONSIDERATIONS
SPECIAL SENSITIVITY - OPTION 2 - START DDT&E ONE YEAR EARLY - FUNDING

Requirements - September Data Dump



Cost Summary ($ in Millions)

	Baseline	Sensitivity
DDT&E	297.7	305.1
Production	169.1	169.1
Operations	233.7	233.7
Total	700.5	707.9

FY	79	80	81	82	83	84	85	86	87	88	89	90	91
DDT&E													
Baseline	-0-	49.8	93.6	85.8	51.9	15.6	0.9						
Sensitivity	44.8	75.0	83.5	60.3	25.0	15.6	0.9						
Total													
Baseline	-0-	49.8	93.6	90.2	115.4	97.2	72.0	35.4	33.1	35.0	35.2	28.9	14.5
Sensitivity	44.8	75.0	83.5	69.3	83.9	97.2	72.0	35.4	33.1	35.0	35.2	28.9	14.5

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Assessment Of Impact If OOS Is Retained In Stable

SPECIAL PROGRAMMATIC CONSIDERATIONS

IMPACT IF OOS IS RETAINED IN THE STABLE-GROUND OPERATIONS

The areas of impact to flight operations caused by retention of both OOS and Tug are associated with the following activities - mission planning, onboard systems support, onboard software systems preparations and the flight support crew.

The key consideration is ground software differences and reverification each time the software is switched from one operational module to the other.

SPECIAL PROGRAMMATICS CONSIDERATIONS
IMPACT IF OOS IS RETAINED IN THE STABLE - GROUND OPERATIONS

Checkout--

Little Change in Checkout Cycle
Crew Size Changes Dictated by Launch Rate

Flight Hardware--

Maintenance and Checkout of Two Vehicles; OOS and Tug
Maintenance and Checkout of Two Types of Cradles
Maintenance and Checkout of Two Types of Orbiter Interface Panels

GSE/Facilities--

Maintenance of Two Sets of GSE; OOS & Tug
Maintenance of A-50 and MMH Storage and Transfer Systems
Maintenance of Refurbish/Checkout Cells Configured for OOS and Tug

Logistics--

Maintenance of Two Sets of Maintenance and Checkout Procedures and Software for Flight Hardware and GSE
Maintenance of Two Sets of Spare Parts for Flight Hardware and GSE
Maintenance of Two Storable Propellant Fuels; A-50 and MMH
Maintenance of a Two-System Training Capability

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SPECIAL PROGRAMMATIC CONSIDERATIONS

IMPACT IF OOS IS RETAINED IN THE STABLE-FLIGHT OPERATIONS

An assessment of the ground operations impacts caused by retaining the OOS in the operations inventory after Tug IOC was performed. The results of this assessment show that the impacts are minor.

SPECIAL PROGRAMMATICS CONSIDERATIONS
IMPACT IF OOS IS RETAINED IN THE STABLE - FLIGHT OPERATIONS

Mission Planning--

- Maintain Two Sets of Performance Data
- Provide for Real Time Mission Management for Both

Onboard Systems Preflight Preparation--

- Control Center Crew Training and Simulations Software Maintained for Both
- Checkout and Verification of Onboard Software Different
- Maintenance of OOS Mission Peculiar Software Algorithms Different

Onboard Systems Flight Support (Ground Facilities)--

- Ground Processing Software for Monitor (TM Decommutation) and Override/Backup (Command Generation) Different
- Control Center Computer Capability Retention for Both OOS and Tug Software Required
- Verification Requirements After Switching Between Two Operational Modules Requires Consideration

Ground Crew for Flight Support--

- Retain Systems Engineering/Project Expertise for Both

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SPECIAL PROGRAMMATICS CONSIDERATIONS
IMPACT IF OOS IS RETAINED IN THE STABLE - CONCLUSIONS

Crew Sizes Dependent on Combined Launch Rate

Facilities Not Significantly Affected

Some Additional Logistics, Maintenance, and Training Required

Mission Planning More Complex

Flight Support More Complex

Software Interfaces More Complex

GSE Interfaces More Complex

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PART V

SUPPORTING RESEARCH & TECHNOLOGY (SRT) REQUIREMENTS/RECOMMENDATIONS FOR OPTION 2

SRT REQUIREMENTS/RECOMMENDATIONS FOR OPTION 2 - SUMMARY

We have identified a Supporting Research and Technology (SRT) program in depth. Specific manpower, materials, computer and facility requirements have been identified for each individual task.

This chart summarizes the tasks by grouping them into the areas shown. It has been revised from the chart shown in the September Data Dump by deleting a $150,000 manufacturing task that is not applicable to Option 2 and by adding the $3,400,000 Moving-Base Docking Simulation avionics task that is identified in Volume 2.0 of the Final Report.

Additional details are presented in Volume 5.0, Appendix A, September Data Dump.

SRT REQUIREMENTS/RECOMMENDATIONS FOR OPTION 2
SUMMARY

	Dollars in Thousands	Span in Months
Structures		
Analysis	1,003	18
Material Characterization	409	18
Manufacturing Techniques	731	22
Inspection Techniques	413	18
Avionics		
Rendezvous and Docking	5,956	36
Guidance and Navigation	1,989	24
Communication and Data Management	807	18
Electrical Power	1,122	18
Propulsion		
Main Propulsion	4,635	18
Attitude Control Propulsion System	599	15
Thermal	656	18
Manufacturing	214	18
Flight Operations	1,268	18
Total	$19,802	

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SRT REQUIREMENTS/RECOMMENDATIONS FOR OPTION 2

SCHEDULE BY CATEGORY

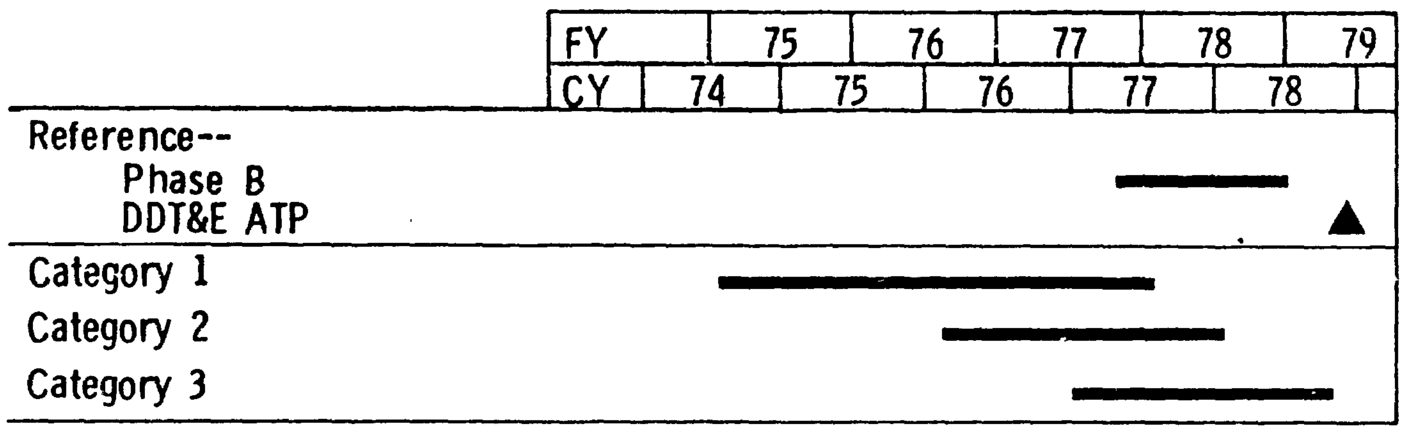
The SRT tasks have been grouped into three categories. This chart defines and schedules these categories. The referenced schedule for the Final Option 2 Phase B and DDT&E ATP is the SRT schedule driver.

SRT REQUIREMENTS/RECOMMENDATIONS FOR OPTION 2
SCHEDULE BY CATEGORY

Category 1 - Tasks That Are Long Term, High Risk, or High Potential Impact

Category 2 - Tasks That Are Not Configuration Sensitive

Category 3 - Tasks That Are Configuration Sensitive



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SRT REQUIREMENTS/RECOMMENDATIONS FOR OPTION 2 CATEGORY 1

Task No.	Task Title	Estimated Cost, $K	Schedule, Months
	Structures		
S-7	Lightweight Shell Structures	392	22
S-8	Investigate Fracture Toughness of Thin-Gage Titanium, 6Al-4V	240	18
S-16	Dock and Capture of Elastic Spin Satellites	127	16
	Avionics		
	Rendezvous and Docking		
A-1	Remote Manned and Autonomous Docking	1,070	16
A-2	Docking Strategies Assessment	815	36
A-3	Propellant Slosh Effects in Low-G Environment	257	18
A-19	Moving-Base Docking Simulation	3,400	36
	Guidance and Navigation		
A-6	Terminal-Phase Rendezvous Navigation and Guidance	257	24
A-13	Flexible Signal Interface	466	18
	Electrical Power		
A-18	Electromechanical Umbilical Connection System	255	14
	Flight Operations		
F-1	Operability Analysis (Rendezvous and Docking)	268	16
	Propulsion		
	Main Propulsion System (MPS)		
P-8	Propellant Dump Technology	128	12
	Total Category 1	7,675	

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SRT REQUIREMENTS/RECOMMENDATIONS FOR OPTION 2 CATEGORY 2

Task No.	Task Title	Estimated Cost, $K	Schedule, Months
	Structures		
S-1	Composite Material Characterization	169	18
S-2	Composite Joint Study	82	12
S-3	Failure Analysis for Composite Structures	264	18
S-4	Finite Elements for Composite Structures	316	18
S-9	Composite Helium Pressurization Vessel	73	9
S-10	Crack Detection Sensitivity for Thin-Gage Liners and Joints	105	18
S-11	Analytical Methods for Composite Pressure Vessels	211	18
S-15	Propellant Behavior in Elastic Tanks	85	16
	Thermal		
T-1	Reusability of Multilayer Insulation	323	18
T-2	Reusability of Tug Coatings	333	18
	Avionics		
	Rendezvous and Docking		
A-4	RF Target Signatures	220	15
	Guidance and Navigation		
A-7	Strategy Assessment for High-Volume Tug Operations	475	24
A-9	Autonomous Navigation Technology for Space Tug	106	12
	Communications and Data Management		
A-12	One-Way Doppler and Emergency Command Receiver	242	15
	Electrical Power		
A-14	Design of Roll-Up Solar-Array System	395	16
A-15	"Blue" Solar-Cell Evaluation	42	6
A-16	Battery Development and Evaluation	170	18

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SRT REQUIREMENTS/RECOMMENDATIONS FOR OPTION 2 CATEGORY 2 (CONCLUDED)

Task No.	Task Title	Estimated Cost, $K	Schedule, Months
	Flight Operations		
F-1	Operability Analysis (Systems)	1,000	18
	Propulsion		
	Main Propulsion System (MPS)		
P-1	Long-Life Turbopump Assembly	1,000	15
P-2	Demonstration of Engine Restart Capability with Mission Duty Cycle	1,500	18
P-3	High-Area-Ratio Nozzle Performance	1,000	12
P-4	Engine Life, Maintenance and Refurbishment	200	8
P-5	Evaluation of Inspection, Cleaning, Maintenance for Propellant Management Device	49	12
P-6	Propellant Management Device Evaluation	21	4
	Attitude-Control Propulsion System (ACPS)		
P-12	Hydrazine Thruster Life and Reuse Demonstration Program	400	12
P-14	Evaluation of Inspection, Cleaning, Maintenance for Propellant Management Device	50	8
P-15	Propellant Management Device Evaluation	17	4
	Manufacturing		
M-1	Improved Weld Technology, Domes and Barrels	74	18
M-2	Composite Structure Development	86	18
	Total Category 2	9,008	

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SRT REQUIREMENTS/RECOMMENDATIONS FOR OPTION 2 CATEGORY 3

Task No.	Task Title	Estimated Cost, $K	Schedule, Months
	Structures		
S-5	Composite Honeycomb Assurance	150	14
S-6	Honeycomb Core Optimization	66	9
S-12	Liner Bonding for Helium Pressurization Vessel	52	11
S-13	Liner Manufacturing for the He Pressurization Vessel	66	8
S-14	Composite Overwrapped Tank Assurance	158	11
	Avionics		
	Rendezvous and Docking		
A-5	SLR Receiver Application as a Star Tracker	194	12
	Guidance and Navigation		
A-8	Target Vehicle Signatures as Star Tracker Targets	94	12
A-10	Inertial Measurement Units Evaluation and Selection	1,055	13
	Communications and Data Management		
A-11	Planar Array Antenna	99	12
	Electrical Power		
A-17	Multiplexed Power Distribution Control and Monitoring System Development	260	12
	Propulsion		
	Main Propulsion System (MPS)		
P-7	Evaluation of Propellant Utilization	49	8
P-9	Propellant Compatibility and Corrosion	180	16
P-10	Effects of Engine Exhaust on Spacecraft	237	16
P-11	Fabrication Technology for Tug Propellant Management Devices	271	10
	Attitude Control Propulsion System (ACPS)		
P-13	N_2H_4 Propellant Compatibility and Corrosion	132	15
	Manufacturing		
M-4	Screen Surface-Tension Device, Tank	54	18
	Total Category 3	3,119	

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SRT REQUIREMENTS/RECOMMENDATIONS FOR OPTION 2

COST BY CATEGORY

This chart displays the cost by category for the three SRT categories defined and scheduled in the previous chart. The cost for each category is broken out into the major areas identified in the summary chart.

SRT REQUIREMENTS/RECOMMENDATIONS FOR OPTION 2
COST BY CATEGORY

DOLLARS IN THOUSANDS

	CATEGORY 1	CATEGORY 2	CATEGORY 3
Structures	$ 759	$1,305	$ 492
Avionics	6,520	1,650	1,704
Propulsion	128	4,237	869
Thermal	--	656	--
Manufacturing	--	160	54
Flight Operations	268	1,000	---
	$7,675	$9,008	$3,119

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SRT REQUIREMENTS/RECOMMENDATIONS FOR OPTION 2

FUNDING

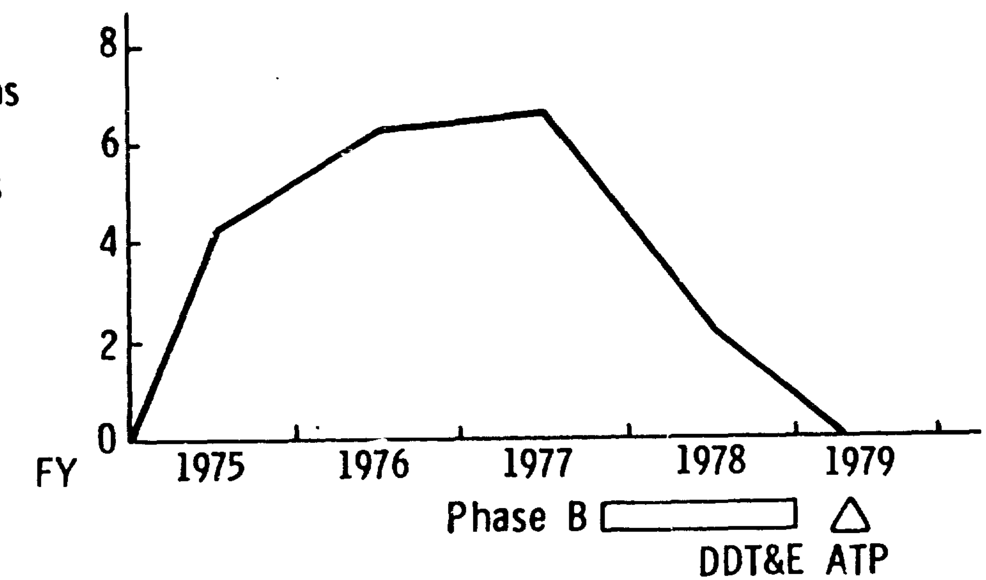
81% of the estimated Category 1 cost is directly related to rendezvous and docking. This is a higher risk technology area which includes two tasks with 36 month span requirements and require early input from some of the related tasks. The result is a high front end loading.

The Category 2 cost estimate is 117% of Category 1 and Category 3 is only 35% of Category 2. This accounts for the continued high expenditures for the first three years and the rapid drop in the last one and one-third years.

SRT REQUIREMENTS/RECOMMENDATIONS FOR OPTION 2 FUNDING

Option 2 Required SRT Expenditures by Category in Thousands of Dollars

	Fiscal Years					
	1975	1976	1977	1978	1979	Total $
Category 1	4,221	2,686	768			7,675
Category 2		3,603	4,684	721		9,008
Category 3			1,248	1,621	250	3,119
Total	4,221	6,289	6,700	2,342	250	19,802



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SRT REQUIREMENTS FOR OPTION 2

Simulator/Demonstration Hardware Recommendations for Concept Verification Prior to Option 2 Development

SIMULATION/DEMONSTRATION - AVIONICS

RENDEZVOUS AND DOCKING TO ROTATING OR STATIONARY TARGETS

A series of moving base simulation are required in order to study and perfect the remote and autonomous control of docking. Autonomy Level II should be baselined as it by definition, includes both blind and man-in-the-loop docking. The Tug dynamic model should be in six-degrees-of-freedom plus the significant slosh modes. The target model should include rotation and coning and, idealistically, induced precession due to contact dynamics.

The airborn algorithms will be expansions and iterations of the steering laws developed in SRT Task A-2, "Docking Strategies Assessment." The candidate snesor sets should be: 1) RF (short range) augmented by video, with both artificial intelligence (on-board processing) and man-in-the-loop; 2) SLR augmented, as above, by video and SLR on its own.

Nominal and perturbed docking runs should be made. The pertubations are intended to cover those deviations in initial conditions and sensor and communication performance that are within specification.

The effort should be begun in 1974 as the problems are unique. To the best of our knowledge, man-in-the-loop (but remotely) docking has not been accomplished by the U.S. Blind docking has never been accomplished at all. The effort involves a great deal of emperical work on rendezvous, docking, sensing hardware and the application of artificial intelligence. An especially difficult problem is determining the appropriate Tug steering and control strategies to be used without man involved, and proving the techniques in a realistic laboratory exercise.

MMC has been working in this area using our Space Operations Simulation (SOS) lab, a six-degree-of-freedom moving base simulator, for several years. The lab has been employed to develop a preliminary technique, visual aids, ranging devices, and docking gear for docking to a rotating coning vehicle.

SIMULATION/DEMONSTRATION - AVIONICS

Rendezvous and Docking to Rotating or Stationary Targets

Purpose

- Develop and Test Hardware and Software for Man-In-Loop and Autonomous Rendezvous and Docking

Methodology

- Model In the Space Operations Simulation Laboratory
  - Rotating Coning Target
  - Tug (With Slosh) Moving In 6 DOF
- Test Hardware
  - SLR
  - Short-Range RF
  - Video
  - Target Reflectors and Corner Cubes
  - Docking Heads
- Develop
  - Visual Aids Requirements
  - Steering Algorithms
  - Blind Docking Pattern Recognition Logic

Need

- Workable Techniques Must Be Established Early to Support Tug Development Span.

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SIMULATION/DEMONSTRATION - AVIONICS

TUG/ORBITER C&W DATA TRANSFER DURING RMS OPERATIONS

The MMC Tug design team considered it highly desirable to simplify the mechanical interface between their vehicle and the then somewhat undefined orbiter manipulation arm. For this reason, it was assumed that the "hardware" FSI (Flexible Signal Interface) connection would not be available for critical data, control, and C&W interfaces with orbiter during deployment operations.

This, in turn, implies either no interface data/control subsequent to Tug/cradle separation or reliance on an alternate RF, optical, or inductive link. The modular RF S-band communication system (recommended for MMC Tug) is a candidate. However, there are many potential problems with operating an RF system designed for long range in confined areas such as the orbiter cargo bay. Antennas do not perform normally; there are problems with reflective surfaces and other EMI radiators are potential interference hazards.

Therefore, it is recommended that a study, with laboratory simulated testing, of alternate interface systems including hardwire (e.g., 4 pin FSI associated with the RMS boom), RF (e.g., low power S-band with onmi antenna), and inductive be conducted in fiscal 1975. The results will help resolve final Tug and orbiter interface design details as well as demonstrate adequately safe deployment techniques.

SIMULATION/DEMONSTRATION - AVIONICS

Tug/Orbiter C&W Data Transfer During RMS Operations

Purpose

To Develop/Test Hardware/Techniques for Transferring C&W Data Plus Override Commands During Orbiter RMS Deployment/Retrieval Operations

Methodology

Compare - Alternative Approaches While Simulating Various Stages of Deployment and Retrieval Such as:

- After (Before) Cradle Disconnect (Reconnect)
- Tug Within Orbiter Bay
- Before (After) RMS Arm Extended
- During RMS Arm Extension (Retraction)

Investigate -

- EMI in Bay and Near Orbiter
- RMS Design With Four Wire Umbilical
- Mechanical Problems With Trailing Wire
- Adapting RF Subsystem for Close Proximity Operations

Need

To Minimize Orbiter Design Impact

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SIMULATION/DEMONSTRATION - AVIONICS - FLEXIBLE SIGNAL INTERFACE

The Flexible Signal Interface design concept for data management services has an inherent capability to substantially reduce overall program costs. However, this potential can only be realized if all system and subsystem personnel understand and make proper use of the capabilities. In addition, early feedback from potential interface designers is needed to assure that the final F.S.I. design will best meet requirements.

A second reason for this early (1975) start is to provide for an early "Design Freeze" of the interface Branch Circuit (Hybrid I.C.) modules. This will allow the "served" subsystem and component designers to confidently incorporate these dedicated circuits into their own designs (new or modified). This early incorporation will simplify all development, qualification, and acceptance testing. It will assure both the component and system cognizant engineers of compatibility prior to integration testing. It will also allow checkout software evolved during component development to be continuously used if/when needed,even during operational space missions.

The program would include some "breadboard" type circuit design aimed at establishing the final "form, fit, and function" for the interface Branch Circuit Hybrids. Other circuitry would be needed to interface between the Branch Circuits and a commercial G.P. Computer for the demonstrations. Three unique hybrid circuit packages would be designed, and a sufficient number fabricated for use by other interface component designers in their early development (or circuit modification) activities. No effort to design final F.S.I. Central Processor or memory circuits would be needed in 1975 as these circuits do not affect interfaces as long as format and functions are not changed.

The demonstrations would phase from Data Management only simulations (Electronic Dev. Lab.) to more integrated test and development activities (conducted in the Inertial Lab).

SIMULATION/DEMONSTRATION - AVIONICS

Flexible Signal Interface

Purpose

- Demonstrate System Benefits and Inherent Cost Savings

Methodology

- Simulate FSI Processor Using GP Computer
- Develop Timing and Address Formats
- Design and Fabricate Branch Circuit Hybrids
- Demonstrate/Coordinate Interface Services With Users
- Provide Dedicated Branch Circuit Hybrids for User Incorporation
- Phase From Electronic Development Laboratory to Integrated Inertial Laboratory Operations

Need

- Coordination of Interfaces Before Designs "Locked-In"
- Early Freeze on Branch Circuit Hybrids for User Incorporation

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SIMULATION/DEMONSTRATION - PROPULSION

The long range objective of this task is to demonstrate the ability and feasibility of rapidly dumping storable bipropellants simultaneously or sequentially in a space environment.

The approach will initially be analytical with limited subscale testing. Later, a full-scale demonstration to validate the analytical model is planned. The effort will deal with the thermodynamics of the propellants within the propulsion system when exposed to propellant dump in vacuum, and on-orbit purging and vacuum drying operation. The effort will also cover the chemo-thermal effects of the exhaust plumes during dump and purge external to the propulsion system.

This data will result in design criteria for Tug which can also affect the Orbiter detail design. Design details on the orbiter such as dump line size, location, exhaust vent design, and separation are only a few of the potential impact areas.

The importance of this item has been recognized by the Martin Marietta Corporation and is presently under study with company funds.

SIMULATION/DEMONSTRATION - PROPULSION

Propellant Dump Technology

Purpose

Demonstrate Feasibility/Safety of Simultaneous Dump
Verify No Impact On Orbiter Systems

Methodology

Develop Computer Model

Subscale Test to Confirm Model

Need

Design Criteria Must Be Established for Tug That May Also Influence Orbiter Detail Design

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SIMULATION/DEMONSTRATION - STRUCTURES

ANALYTICAL METHOD FOR DOCKING AND CAPTURE OF ELASTIC SPINNING SATELLITES

The facing viewgraph outlines the approach to be taken in developing analytical tools for handling the case of docking to a spin stabilized spacecraft. We currently have in use a program which handles the load/stroke characteristics of the Apollo type probe mechanism and also the motion of the bodies after impact. However, it contains no provisions for handling the case when one body is spinning.

Additional equations of motion will be written and incorporated into the program to handle this condition.

SIMULATION/DEMONSTRATION - STRUCTURES

Analytical Method for Docking and Capture of Elastic Spinning Satellites

Purpose

- Develop Analytical Tools Needed to Represent Behavior of Elastic Bodies During Docking When One Body Is Spinning

Methodology

- Review Existing Docking Programs
- Determine Most Suitable Program or Programs for Modification to Handle Spinning Body
- Generate Necessary Equations and Incorporate Into Program

Need

- Provide Adequate Recovery Time for Higher Risk Concepts
- Support Docking Simulation to Rotating Target

SIMULATION/DEMONSTRATION - STRUCTURES - LIGHTWEIGHT SHELL STRUCTURE

The high mass fraction required for Space Tug makes it necessary to minimize structural weight. This can be done by identifying general types of lightweight structures such as skirt or tank shell sections and engine and equipment support trusses, and by initiating design optimization, fabrication, and test programs early in the overall Space Tug master schedule plan. It is mandatory that materials and structural concepts considered for use in these development programs are prejudged before they are fully evaluated for the specified design requirements.

Advances in the state-of-the-art of advanced fibrous composites in the areas of raw material processing, improved analysis methods, and fabrication techniques make materials such as graphite/epoxy and boron/epoxy leading candidates for incorporation in the design of lightweight shell structures.

A specific space structure, the Space Tug between tanks skirt, will be evaluated to determine the feasibility of using advanced fibrous composites in the design of lightweight space vehicle structure. The desirability of a fibrous composite skirt will be demonstrated by the fabrication and test of a full scale skirt. Successful structural test of the skirt structure will verify design and analysis techniques. Final selection of a fibrous composite material to be used will be made following vacuum effects testing of candidate materials. Successful completion of the proposed program should result in a skirt structure which is approximately 25 percent lighter than a skirt designed using conventional metals.

SIMULATION/DEMONSTRATION - STRUCTURES

Lightweight Shell Structures

Purpose

- Determine Feasibility of Using Lightweight Fibrous Composites

Methodology

- Perform Design Analysis on Several Concepts and Materials
- Fabricate and Test Components
- Fabricate and Test Full-Scale Shell Structure

Need

- Provide Adequate Recovery Time for High Potential Impact Concepts
- Continue Work Already in Progress

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SIMULATION/DEMONSTRATION - STRUCTURES - FRACTURE TOUGHNESS OF THIN GAGE TITANIUM

In order to determine the ability of thin gage Titanium to satisfy the Tug mission life requirements, we must establish analytical procedure for cumulative crack extension under service loading conditions and generate cyclic and sustained load crack growth data suitable for prediction of expected service life capability.

The analysis will consider three growth equations and two overload models.

In determining the best combination of models, the first step will be to curve-fit each of the growth equations to the basic block test data. This will be accomplished by a best-fit scheme, such as least squares, in appropriate plot space, ℓn-ℓn, to the test data. Next, each of the overload models will be used with all three growth equations and the resulting predictions compared with the test data to determine the best combination. The resulting best combination will then be used for parametric evaluation to other crack sizes and stress levels.

SIMULATION/DEMONSTRATION - STRUCTURES

Fracture Toughness of Thin-Gage Titanium

Purpose

Determine Ability of Thin-Gage Titanium (6Al-4V) to Satisfy the Tug Mission Life Requirements

Methodology

Generate Cyclic, Static, and Sustained Crack Growth Data Through Specimen Testing

Refine Existing Computer Programs to Handle Data and Generate Tank Mission Life

Need

Verify Weld Techniques and Life Cycle Characteristics
Minimize Production Risks

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