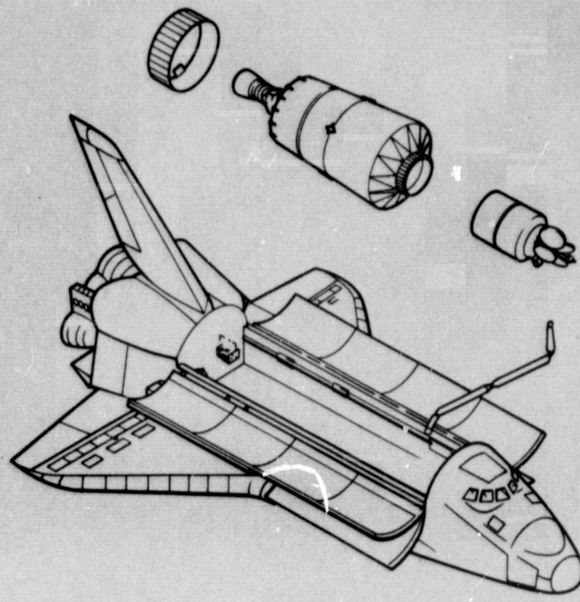
REPORT NO. CASD-NAS 75-017
CONTRACT NAS 8-31012



SPACE TUG/SHUTTLE INTERFACE COMPATIBILITY STUDY

FINAL REPORT

VOLUME II • TUG/PAYLOAD/ORBITER INTERFACE ANALYSES

APPENDICES

(NASA-CR-120652) SPACE TUG/SHUTTLE INTERFACE COMPATIBILITY STUDY. VOLUME 2: TUG/PAYLOAD/ORBITER INTERFACE ANALYSES, APPENDICES Final Report, Jul. 1974 - Mar. 1975 (General Dynamics/Convair) 262 p

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GENERAL DYNAMICS
Convair Division

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SPACE TUG/SHUTTLE INTERFACE COMPATIBILITY STUDY

FINAL REPORT

VOLUME II ♦ TUG/PAYLOAD/ORBITER INTERFACE ANALYSES

June 1975

Prepared for
National Aeronautics and Space Administration
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

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FOREWORD

The study described in this report was conducted by Convair Division of General Dynamics Corporation under NASA Contract NAS8-31012. The work was under the management of the NASA Marshall Space Flight Center, Tug Task Team, in conjunction with four complementary Tug-related study efforts.

The study was conducted between July 1974 and March 1975.

This volume contains the appendices associated with Interface Study Technical Analyses of Volume II.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

APPENDIX A

PAYLOAD ORBITER SERVICES ACCOMMOCATIONS TRADE

The data contained in Appendix A was prepared early in the Interface Study to support analyses of combined Tug and payload interface requirements. It was originally published on 10 September 1974 as Report No. CASD/LVP 74-048-POSAT in brochure form. It is republished in its entirety here.

INTRODUCTION

The purpose of the Space Tug/Shuttle Interface Compatibility Study is to identify Tug related interfaces. This study will also assist in implementing these interfaces into the Space Shuttle Orbiter. The 10 month study, started in July 1974, has six major tasks:

Task 1 - Functional Interface Requirements Definition
Task 2 - Baseline Tug Interface Analysis
Task 3 - Sensitivity Analysis
Task 4 - Tug/Orbiter Interface Requirements
Task 5 - Interface & Baseline Revisions
Task 6 - IUS/Tug Interface Comparison

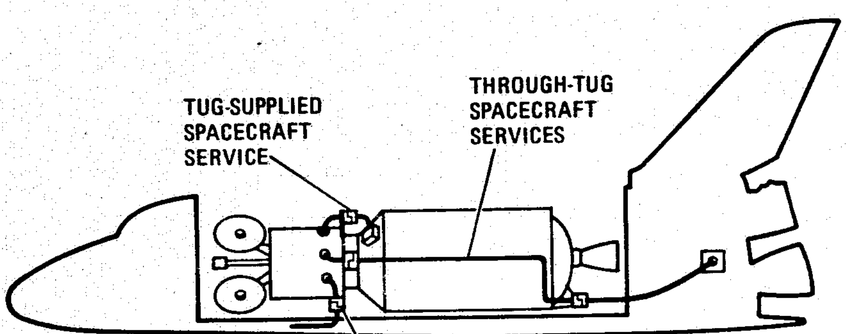
Because Tug payloads compete with the Tug for Orbiter supplied services such as power and data processing, an early initial task during Task 2 is an analysis and identification of the support services required by Tug payloads. This report documents the results.

The study started with an analysis of the requirements of all Tug payloads as specified in current reports by NASA and DOD. Data from the current MSFC/GDC study, Space Shuttle Payload Descriptions (SSPD), was used since it encompassed most of the requirements of all Tug payloads.

The level of support demanded by the payloads was compared with the level of support provided by Orbiter and Tug as given in JSC 07700, Vol. XIV, for Orbiter, and in MSFC 68M00039 for Tug. Trade studies were performed to determine the best way of providing the support services, i.e., through Tug versus direct to Orbiter and baseline versus special mission dedicated kits. Recommendations are shown.

PAYLOAD/ORBITER SERVICES ACCOMMODATIONS

TRADE STUDY TO MAKE PRELIMINARY ASSIGNMENT OF PAYLOAD SERVICES, DIRECT-TO-ORBITER & THRU-TUG, & ASSESS THEIR IMPACT ON TUG / ORBITER INTERFACE REQUIREMENTS



SERVICE ACCOMMODATION TRADE RESULTS WILL BE USED DURING SUBSYSTEM ANALYSES TO DETERMINE EFFECT ON:

- SERVICE PANEL SPACE
- ORBITER RACEWAY SPACE
- MSS/PSS EQUIPMENT ALLOCATION
- MSS/PSS PANEL MOUNTING SPACE & VOLUME
- ORBITER POWER REQUIREMENTS
- RF TRANSMISSION
- CREW EFFECTIVITY

Payload requirements data sources utilized are listed on the facing page. A variety of sources providing data on Tug requirements, DOD spacecraft, and NASA/Commercial spacecraft were utilized. The requirements source numbers are referred to in a tabulation of detail interface requirements on pages 31 through 37 .

Primary source of NASA/Commercial spacecraft interface requirements with Space Tug was the NASA Payload Descriptions document for Automated Payloads. These requirements are defined to two levels. Level A is a summary of the NASA payload descriptions for all automated payloads to be flown with the Shuttle only and Shuttle and Space Tug/IUS.

Detail definition of automated payloads are contained in Level B Data Book. Payloads which will be launched during the IUS operational period from 1980 through 1984 are contained in the Level B Data Book in more detail than Tug payloads which are in an earlier conceptual phase. Level B data, in many cases preliminary or incomplete, is available for 28 of the 50 IUS/Tug payloads identified.

Primary source of DOD spacecraft interface requirements was the DOD Space Transportation System Payload Interface study performed by MDC. In this study the contractor analyzed in depth three existing DOD satellites; Defense Satellite Communication System II (DSCS II), Defense Support Programs (DSP) and Fleet Satellite Communication (FLTSATCOM). These satellites are similar to the majority of the satellites which will be advanced into Shuttle era. Objective of this study was to define the interface concepts required to achieve compatibility with Shuttle and Tug vehicles.

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SOURCE DOCUMENTS

PAYLOAD INTERFACE REQUIREMENTS

TUG REQUIREMENTS	DOD SPACECRAFT	NASA/COMMERCIAL
1) BASELINE SPACE TUG SYSTEM RQMTS & GUIDELINES MSFC68M00039-1	3) DOD MISSION MODEL FOR STS, REV. 3	8) SUMMARIZED NASA PL DESCRIPTIONS, AUTOMATED PLs, LEVELS A & B DATA (SSPD DATA)
2) BASELINE SPACE TUG FLIGHT OPERATIONS MSFC68M00039-3	4) PAYLOAD INTERFACE STUDY MDC G 4801	9) A STUDY OF PAYLOAD UTILIZATION OF TUG MDC G 5356
	5) INTERIM UPPER STAGE SYSTEM RQMTS SR-IUS-100	7) PAYLOAD-SHUTTLE INTERFACE DATA BOOK MSFC-PD-73-1
	6) AFSCF SPACE/GRD INTERFACE TOR-005(6110-OD)-3, REV. 1	

Available data on DOD payloads does not include detailed descriptive information similar to that in the Level A or B NASA payload data due to the classified nature of DOD payloads. A total of 17 payloads were identified for post 1984 missions with one requiring use of the IUS due to a payload length in excess of Tug capabilities. From a review of the documents available, few requirements unique to DOD payloads were identified. As a result, payloads listed in the July 1974 "Summarized NASA Payload Descriptions," Levels A and B, are assumed to be representative of DOD payloads and were used as guidelines for the Payload Interface Study.

DOD TUG PAYLOADS

- REVIEW MADE OF:
  1) DOD STS PAYLOAD INTERFACE STUDY, MDC
  2) DOD REQMT'S FROM PAYLOAD-SHUTTLE INTERFACE DATA BOOK, MSFC-PD-73-1
  3) SR-IUS-100, INTERIM UPPER STAGE SYST. REQMT'S, 7/74
  4) AFSCF SPACE/GROUND INTERFACE, REV. 1
- FEW DOD UNIQUE PAYLOAD INTERFACE REQUIREMENTS IDENTIFIED
  1) VERTICAL GROUND PROCESSING REQUIRED - STRUCTURE, PROPULSION, PL ACCESS
  2) PRELAUNCH COMMAND DATA VIA RF LINK
  3) SPACECRAFT STRUCTURAL SUPPORT FOR TUG MATING
- CONSEQUENTLY, PAYLOADS LISTED IN JULY '74 SUMMARIZED NASA PAYLOAD DESCRIPTIONS (SPD) ARE ASSUMED TO BE REPRESENTATIVE OF ALL PAYLOADS
- SPD REQUIREMENTS WILL BE USED AS GUIDELINES FOR ALL PAYLOADS, INCLUDING DOD

The two following pages list IUS/Tug payloads contained in the Summarized Payload Descriptions data. Shuttle + Tug/IUS payloads constitute 50 of the 81 payloads defined in Level A. Existing planning calls for IUS to be operational for the period from 1980 through 1984 and continuing for the remainder of the Space Transportation System Program. Therefore, in 1984 both upper stages will be in the inventory, IUS phasing out and Tug phasing in. Those SC which are planned to be carried into orbit during 1984 have been shown to be payloads for both IUS and Tug. Under this rationale the total number of NASA/Commerical payloads applicable to Tug is 43, and 29 applicable to IUS. Twenty-three of the fifty payloads are common to both Tug and IUS.

Payloads for which Level B data is available are designated by an asterisk under the SPD code designation.

SPACE TUG & IUS NASA/NON-NASA PAYLOADS
SUMMARIZED NASA PAYLOAD DESCRIPTIONS - JULY '74

Tug Code Number	SSPD PL Code	Payload Name	Tug PL	IUS PL
PHY-1A	AP-01-A	Upper Atmosphere Explorer	x	x
PHY-1B	AP-02-A	Medium Altitude Explorer	x	x
PHY-1C	AP-03-A	High Altitude Explorer	x	x
PHY-3A	AP-05-A	Environmental Perturbation Satellite - Mission A	x	x
PHY-2B	AP-06-A	Gravity and Relativity Satellite - Solar	x	
PHY-3B	AP-07-A	Environmental Perturbation Satellite - Mission B	x	
PHY-4	AP-08-A	Heliocentric and Interstellar Spacecraft	x	
	AS-02-A	Extra Coronal Lyman Alpha Explorer	x	x
AST-1	AS-05-A	Advanced Radio Explorer	x	x
AST-8	AS-16-A	Large Radio Observatory Array	x	
NN/D-1	CN-51-A	INTELSAT	x	x
NN/D-2A	CN-52-A	US DOMSAT "A"		x
NN/D-2B	CN-53-A	US DOMSAT "B"	x	
NN/D-3	CN-54-A	Disaster Warning Satellite	x	x
NN/D-4	CN-55-A	Traffic Management Satellite	x	x
NN/D-5	CN-56A	Foreign Communications Satellite A	x	x
NN/D-2	CN-58-A	US DOMSAT "C"	x	x
NN/D-6	CN-59-A	Communications R&D/Prototype Satellite	x	
NN/D-9	CN-60-A	Foreign Communications Satellite B	x	
EO-7	EO-07-A	Advanced Synchronous Meteorological Satellite	x	
EO-4A/4B	EO-09-A	Synchronous Earth Observatory Satellite	x	x
EO-6	EO-12-A	TIROS "O"	x	x
NN/D-8	EO-56-A	Environmental Monitoring Satellite	x	x
NN/D-9	EO-57-A	Foreign Synchronous Meteorological Satellite	x	x
NN/D-10	EO-58-A	Geosynchronous Operational Meteorological Satellite	x	x
NN/D-12	EO-59-A	Geosynchronous Earth Resources Satellite	x	
NN/D-13	EO-62-A	Foreign Synchronous Earth Observatory Satellite	x	

SPACE TUG & IUS NASA/NON NASA PAYLOADS
SUMMARIZED NASA PAYLOAD DESCRIPTIONS - JULY '74

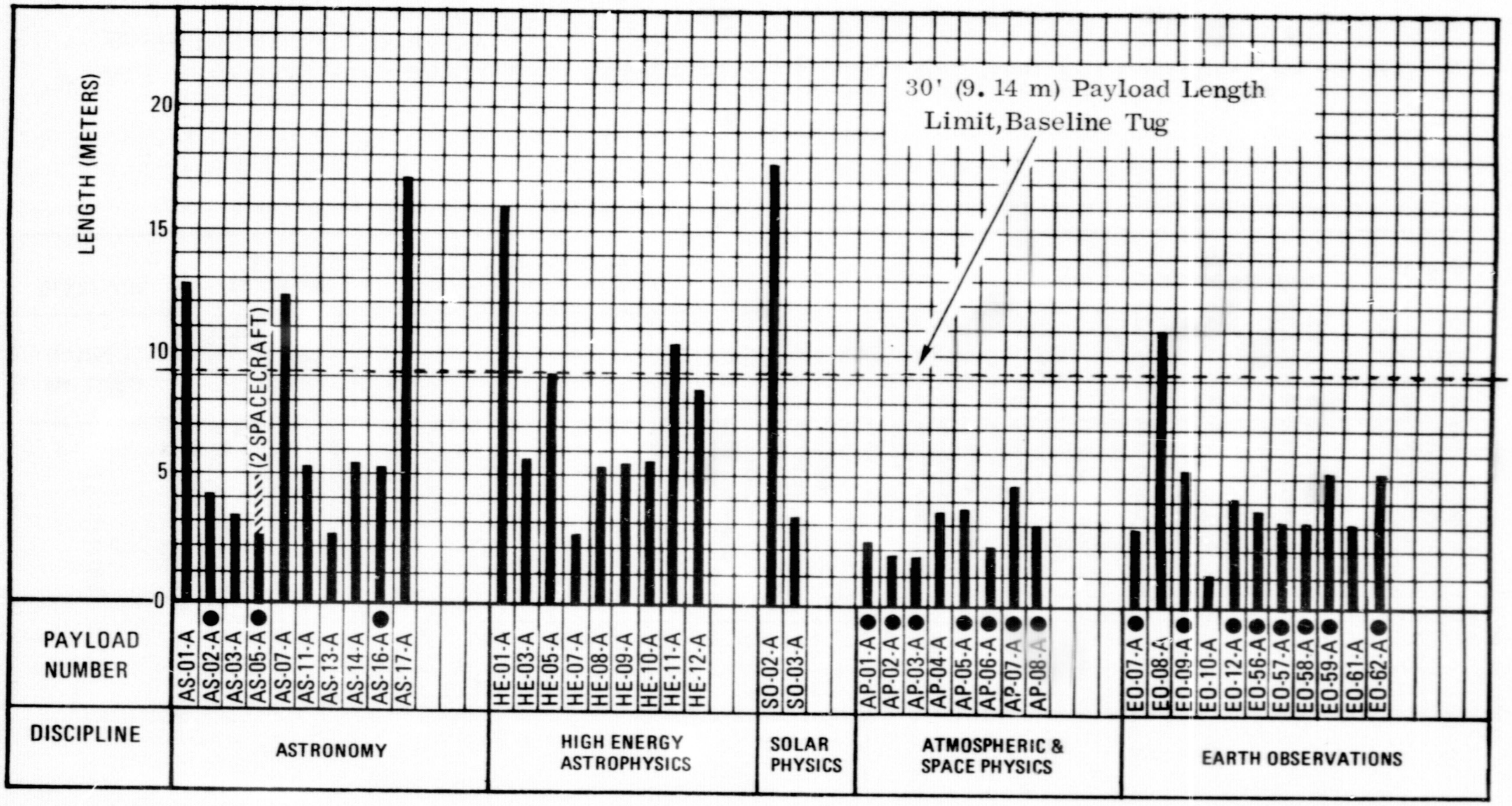
Tug Code Number	SSPD PL Code	Payload Name	Tug PL	IUS PL
LUN-2	LU-01-A	Lunar Orbiter	x	
LUN-3	LU-02-A	Lunar Rover	x	
LUN-4	LU-03-A	Lunar Halo Satellite	x	
LUN-5	LU-04-A	Lunar Sample Return	x	
EOP-4	OP-01-A	GEOPAUSE		x
EOP-9	OP-06-A	Magnetic Field Monitor Satellite	x	x
PL-7	PL-01-A	Mars Surface Sample Return	x	
PL-8	PL-02-A	Mars Satellite Sample Return	x	
PL-10	PL-03-A	Pioneer Venus Multiprobe	x	x
PL-11	PL-07-A	Venus Orbital Imaging Radar		x
PL-12	PL-08-A	Venus Bouyancy Probe	x	
PL-13	PL-09-A	Mercury Orbiter	x	
PL-14	PL-10-A	Venus Large Lander	x	
PL-18	PL-11-A	Pioneer Saturn/Uranus Blyby		x
PL-19	PL-12-A	Mariner Jupiter Orbiter		x
PL-20	PL-13-A	Pioneer Jupiter Probe	x	
PL-21	PL-14-A	Saturn Orbiter	x	
PL-22	PL-15-A	Uranus Probe/Neptune Flyby	x	
PL-23	PL-16-A	Ganymede Orbiter Lander	x	
PL-26	PL-18-A	Encke Rendezvous		x
PL-27	PL-19-A	Halley Comet Flyby	x	
PL-28	PL-20-A	Astoroid Rendezvous	x	
PL-17	PL-22-A	Pioneer Saturn Probe		x
			Total = 43	

The two following charts present payload lengths from SPD data. Tug payloads are designated by a dot adjacent to the payload number.

The 30 ft. payload limit for baseline Tug will accommodate all Tug payloads in the SPD with the longest being 25 ft. One DOD payload exceeds the 30 ft. limit and would have to be flown on the IUS.

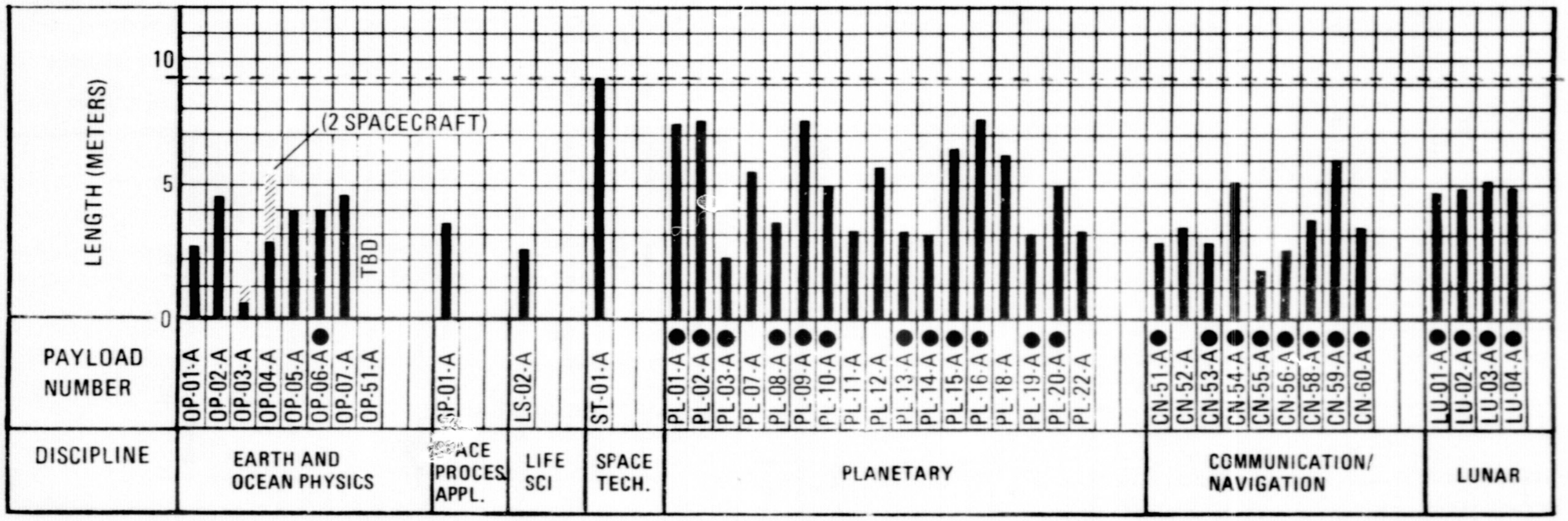
PAYLOAD LENGTH SUMMARY DATA

SUMMARIZED NASA PAYLOAD DESCRIPTIONS



NOTE ● Designates Tug Payload

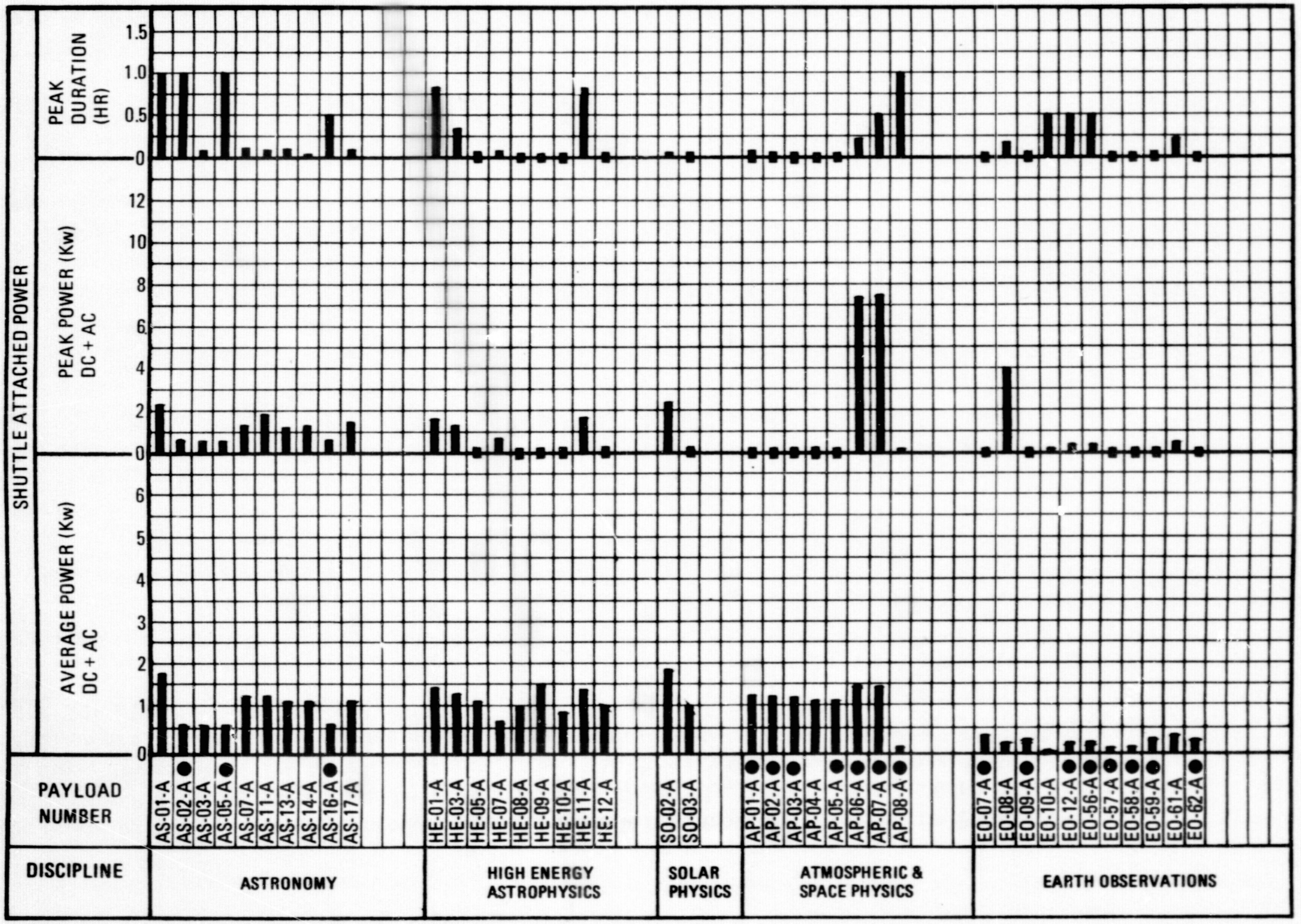
PAYLOAD LENGTH SUMMARY DATA
SUMMARIZED NASA PAYLOAD DESCRIPTIONS



- ALL NASA/NON NASA PAYLOADS DESIGNATED FOR TUG, POST 1984, FALL WITHIN THE 30' (9.14 m) BASELINE TUG CAPABILITY
- ONE DOD PAYLOAD EXCEEDS BASELINE TUG CAPABILITY BUT CAN BE FLOWN ON IUS.
- DATA FROM "SUMMARIZED NASA PAYLOAD DESCRIPTIONS", JULY 1974, IS ASSUMED TO SUPERCEDE BASELINE TUG MISSION MODEL IN MSFC M6800039-3.

The following eight charts are reproductions of applicable data from the Space Shuttle Payload Description Activity for Automated Spacecraft, Level A document. Generally, Level A data includes both Tug spacecraft and those flown without Tug for all mission phases. The data presented here has been limited to payload requirements only for those mission phases while Shuttle is attached. Tug spacecraft are identified by a bullet following the payload number.

ELECTRICAL POWER SUMMARY DATA (WHILE ATTACHED TO SHUTTLE)



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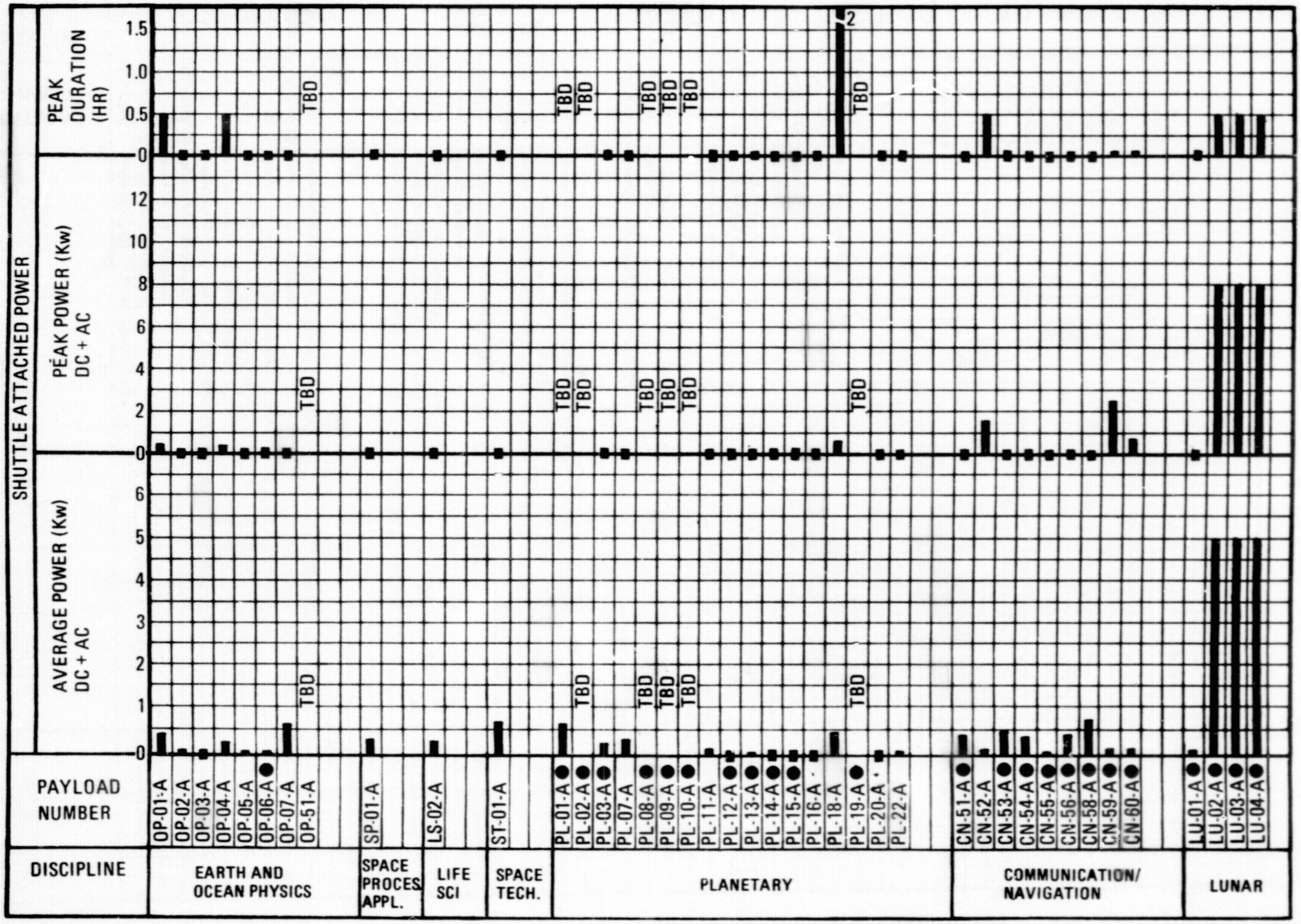
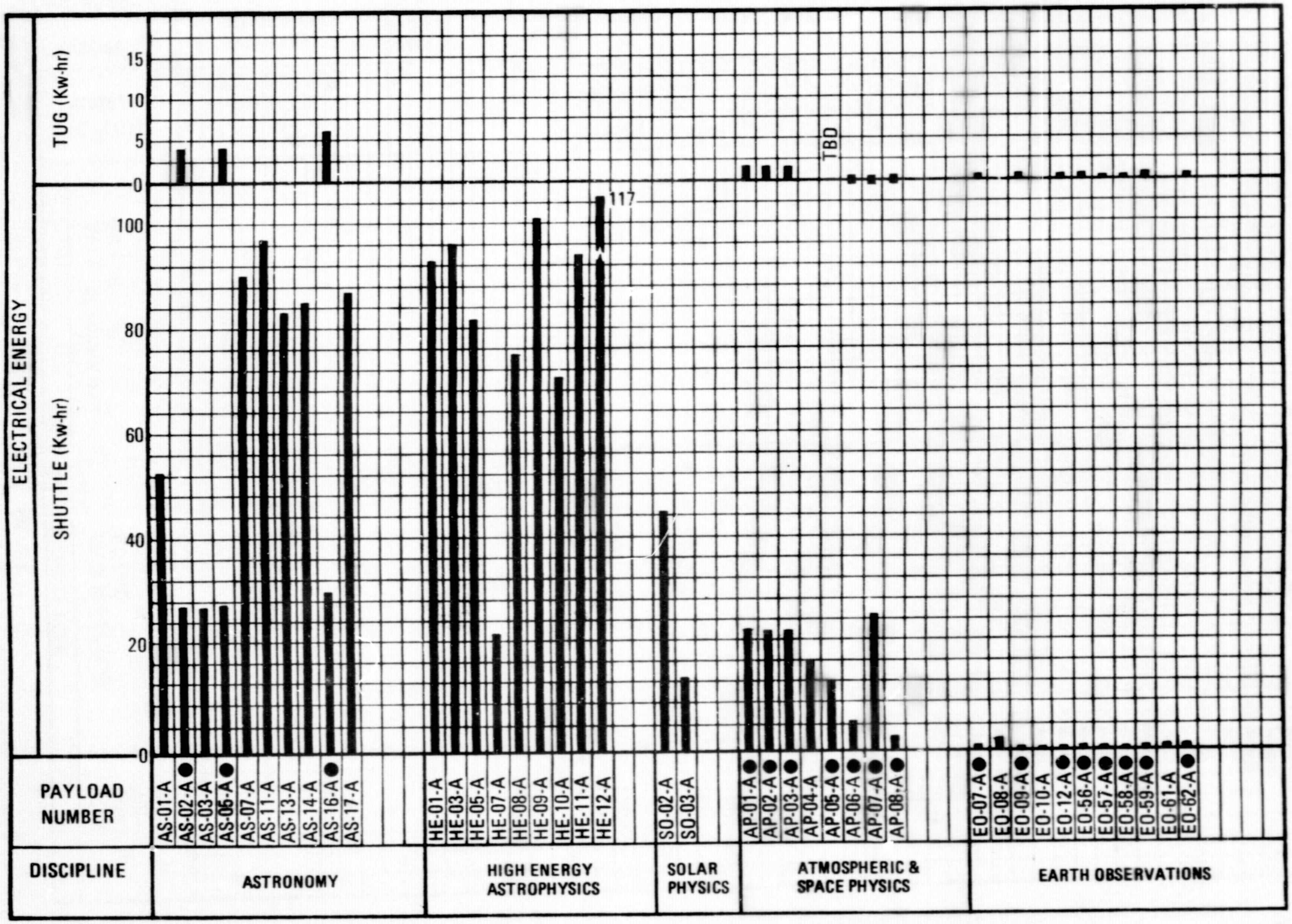


ELECTRICAL ENERGY SUMMARY DATA



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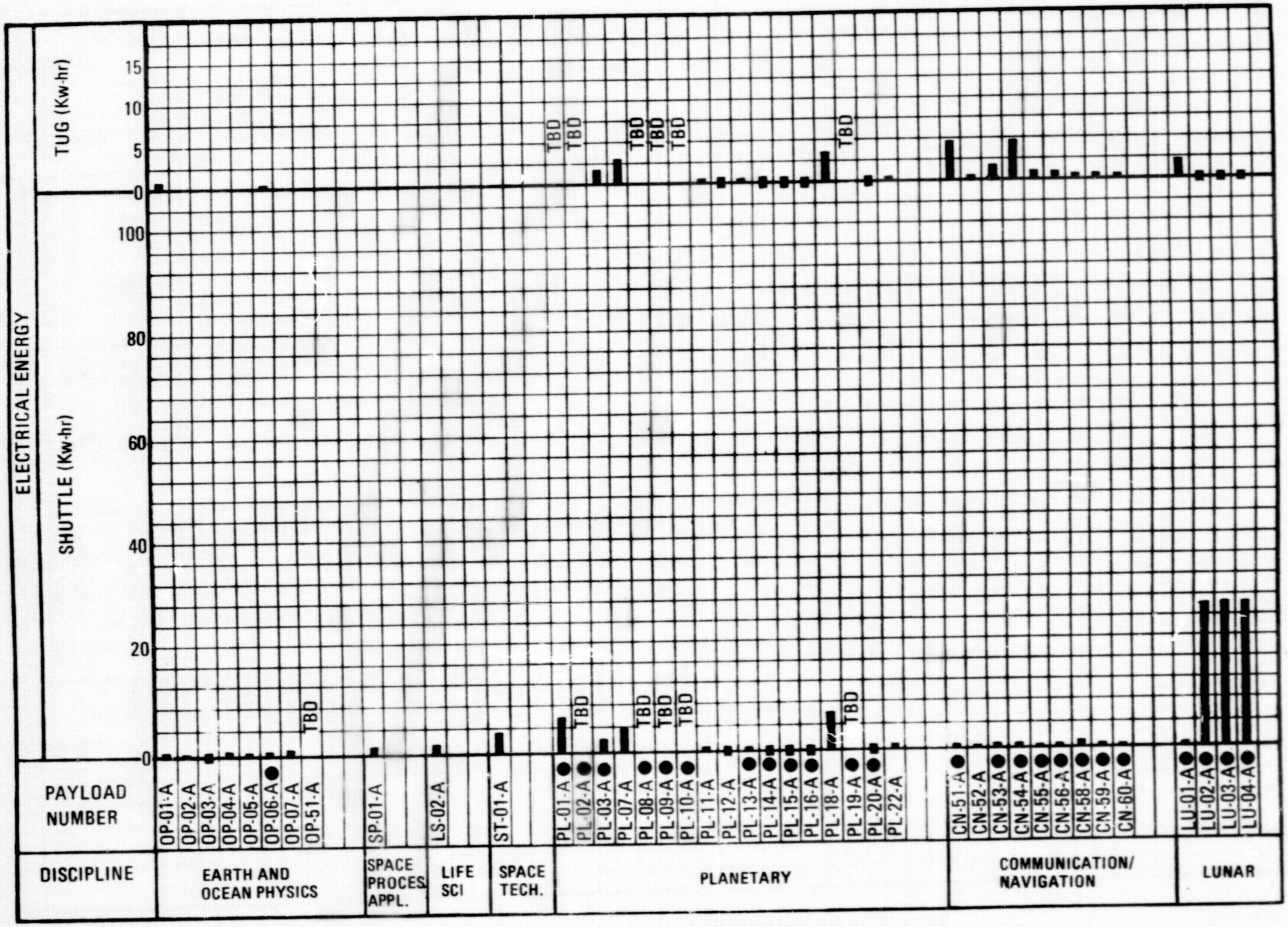

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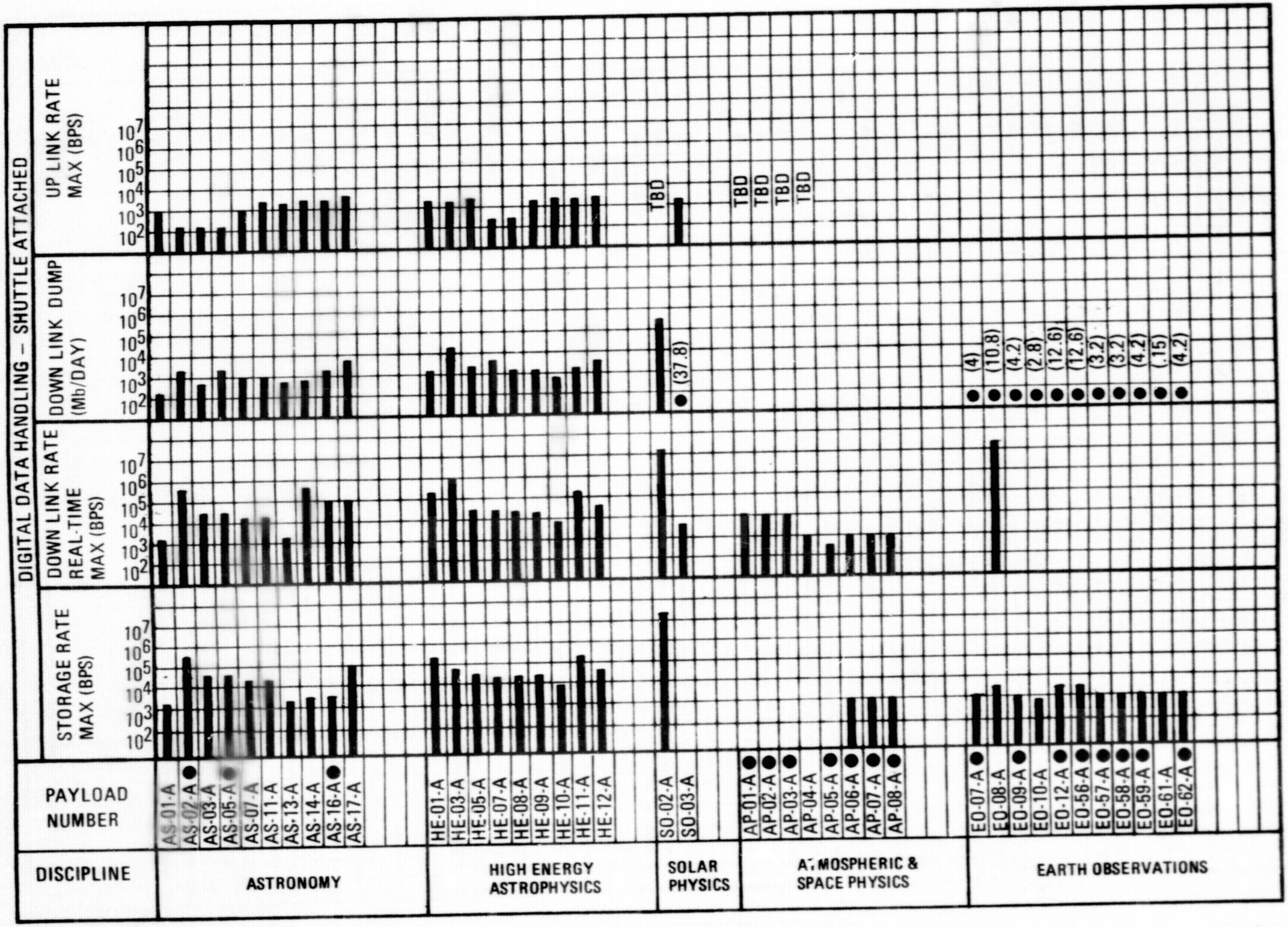

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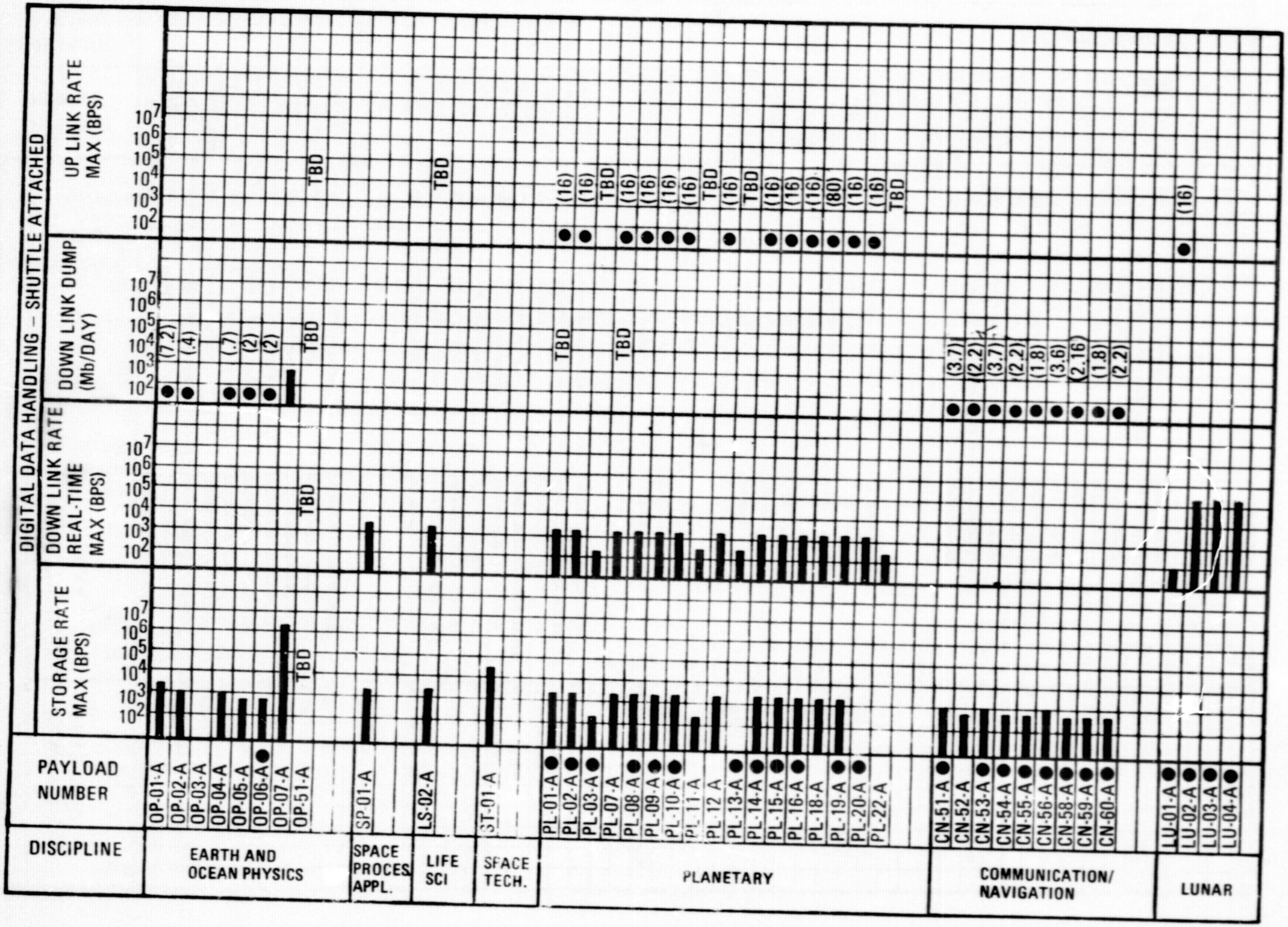
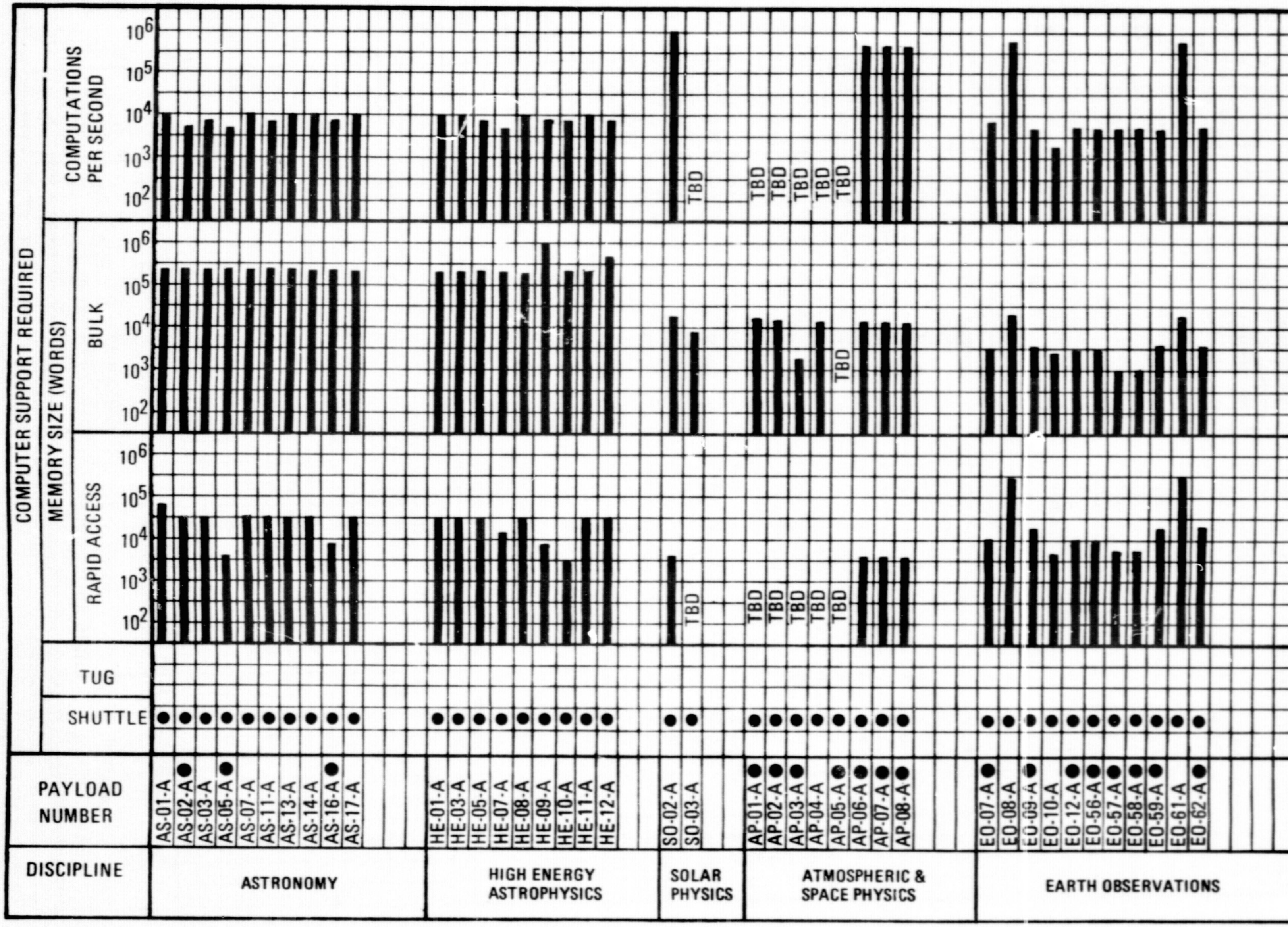
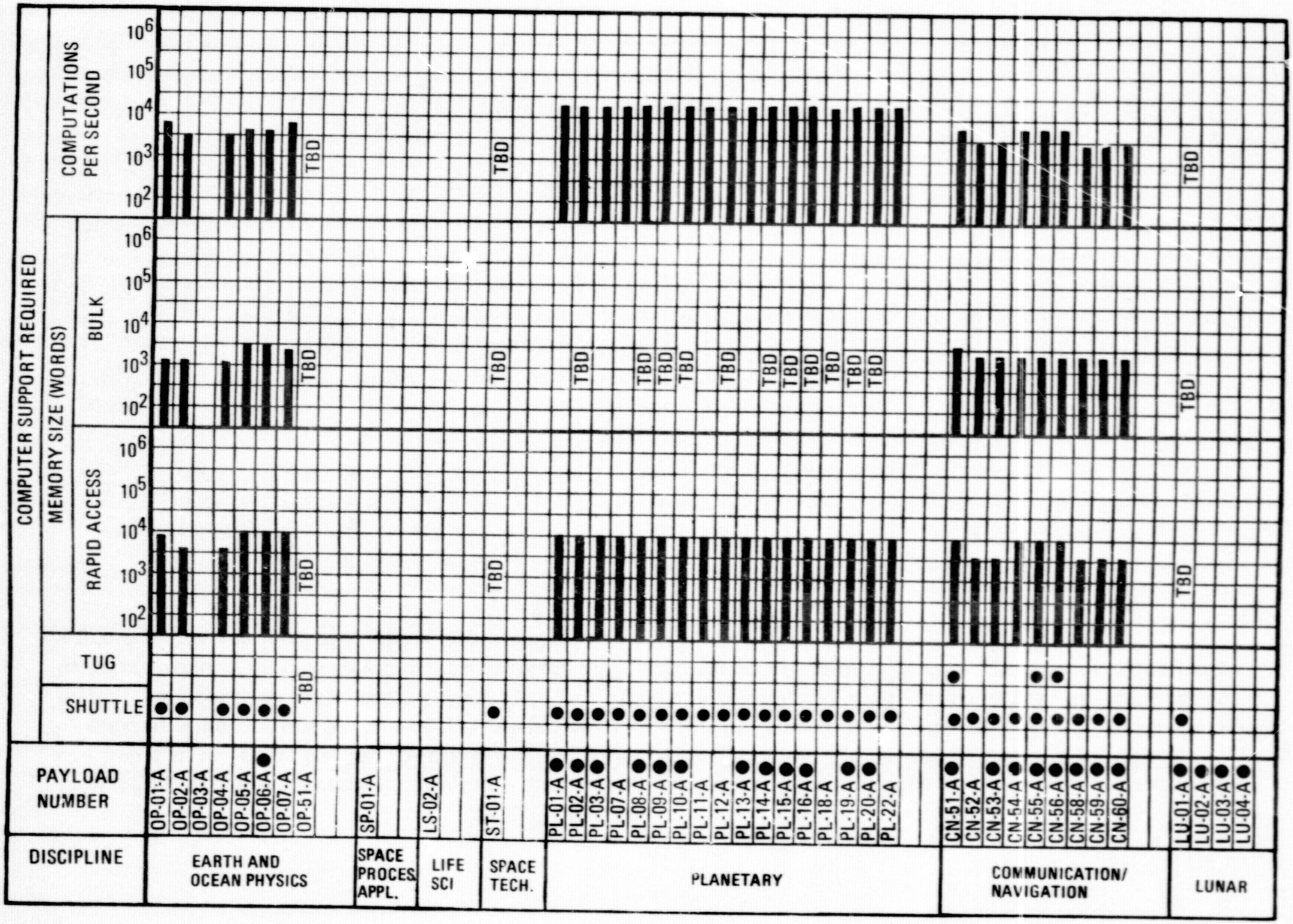


COMPUTER SUMMARY DATA



COMPUTER SUMMARY DATA



Payload interface requirements to satisfy a specific fluid system function, such as propellant fill and drain, are listed in tables on the two following pages. The source document for the requirement is identified by number which refers back to page 3 where all requirements source documents were listed. Optional requirements, not specified in the source documents but which are considered viable alternatives, are also shown. Interface routing options to satisfy the function and requirement are indicated with a recommendation from a previous source identified where applicable.

PAYLOAD INTERFACE REQUIREMENTS

PROPULSION & FLUIDS

FUNCTION	REQUIREMENT	REQUIREMENT SOURCE			INTERFACE ROUTING		
		Baseline Tug	DOD	NASA	Thru Tug	Orbiter Direct	Payload Direct
1) Propellant Fill & Drain	• Provide Interconnects Via Orbiter Service Panels	1)	7)	7)	Option	1),7)	
	• Accomplish Fill & Drain with Payload Vertical		4)		4)	Option	
	• Accomplish Fill Prior to Payload Mate to Tug & Drain After Demate	N/S	N/S	N/S			Option
2) Pressurant Fill & Drain	• Accomplish at Launch Pad		4)		4)	Option	
	• Accomplish Fill Prior to PL Mate to Tug & Drain After Demate	N/S	N/S	N/S			Option
3) Propellant & Pressurant Abort Dump	• Provide Capability to Dump Hazardous Fluids During Abort	1)				1),7)	
	• Expel Payload Consumables in any Abort Mode		7)	7)	7)		
4) Propellant Venting	• Provide Interconnects for Payload Propellant Vent	1)	7)	7)	Option	1),7)	
5) Battery Vent	• PL Battery Case Shall be Vented into Orbiter Overboard Venting System	1)			Option	Option	
6) Cryogen Fill & Drain	Provide Cryogenic (LHe) Fluid Loading Interface (AP-06-A, PL-03-A)			8)	Option	Option	

PAYLOAD INTERFACE REQUIREMENTS

FUNCTION	REQUIREMENT	REQUIREMENT SOURCE			INTERFACE ROUTING		
		Baseline Tug	DOD	NASA	Thru Tug	Orbiter Direct	Payload Direct
1) Inflight Coolant Interface	Provide a Thermal Interface for Payload Waste Heat Dissipation (RTG Cooling) During all Flight Phases.	1)	7)	7), 8)	Option	1)	
2) Ground Coolant Interface	Provide Ground-Supplied Coolant flow to the Payload During Ground Operations		7)		7)	Option	
3) Payload Shroud* Purge	Provide Conditioned Gas to a Payload Shroud to Maintain Specified Temperature and Cleanliness Levels - Prelaunch & Post Landing			9)	Option	9)	

*PL Shroud Assumed as Worst Case Orbiter Physical Interface Configuration

A variety of payload interface requirements have been identified by the various government agencies associated with the Space Shuttle, Space Tug, and spacecraft. A compilation of the range of general payload avionic support provisions and the techniques by which these needs are to be accommodated is included in the following two charts. The listing of reference documents 1) through 8) referred to on these charts is provided on Page 3 of this brochure.

PAYLOAD INTERFACE REQUIREMENTS

AVIONICS

FUNCTION	REQUIREMENT	REQUIREMENT SOURCE			INTERFACE ROUTING		
		Baseline Tug	DOD	NASA	Thru Tug	Orbiter Direct	Payload Direct
1) Communication	• Transmit Command to Payload	1)	4), 7)	8)	1), 4)	Option	
	• $\leq$2048 BPS in Bay			8)			
	• RF & Hardwire During Prelaunch		4)				
	• Thru Orbiter RF During Ascent/ Descent		4)				
	• Secure Communication		7)				
	• Receive/Relay Payload TM Data	1)	4), 7)	8)	1), 4)	Option	
	• $\leq 2.5\times10^6$ RPS thru Orbiter			8)			
	• $\leq 2.56\times10^5$ RPS thry Orbiter		7)				
	• Receive/Store Payload TM Data						
	• $\leq 1.024\times10^5$ BPS						
	• $\leq 1.168\times10^{10}$ Bits/Mission						
	• Receive Analog Data				Option	Option	
	• Relay $\leq$ 3.2 MH_2			8)			
	• Store 0.22 MH_2			8)			
	• Receive Data Dump 1947 MB/Day			8)	Option	Option	
	• Store & Transmit TV Data			8)	Option	Option	

PAYLOAD INTERFACE REQUIREMENTS

AVIONICS

FUNCTION	REQUIREMENT	REQUIREMENT SOURCE: Baseline Tug	DOD	NASA	INTERFACE ROUTING: Thru Tug	Orbiter Direct	Payload Direct
2) Electrical Power	• Provide DC Power to Payload	1)	4)	8)	1), 4)	Option	
	o ≤ 600 Watts	1)					
	o ≤ 400 Watts		4)				
	o ≤ 8000 W Peak, 5000 w Avg			8)			
	o ≤ 30 K W H			8)			
	• Provide Secondary Power Sources for Safety Critical Functions	1)			1)	Option	
3) Status & Control	• Provide Status or Condition of Payload Systems				1), 4)	Option	
	• Provide for Orbiter Override of Safety Critical Functions				1)	Option	
	• Provide Confirmation of Connection of Safety Critical Interfaces				1)	Option	
4) Caution & Warning (C&W)	• Provide C&W Data to Orbiter While Aboard or in Vicinity of Orbiter	1)	4)		1), 4)	Option	
5) Bonding	• Provide a Positive Ground Between Payload and Orbiter Structure	1)			1)	Option	

Based on data from JSC 07700, Space Shuttle System Payload Accommodations, Vol. XIV, Rev C, interface panel locations for Tug and payloads are as shown on the adjacent figure.

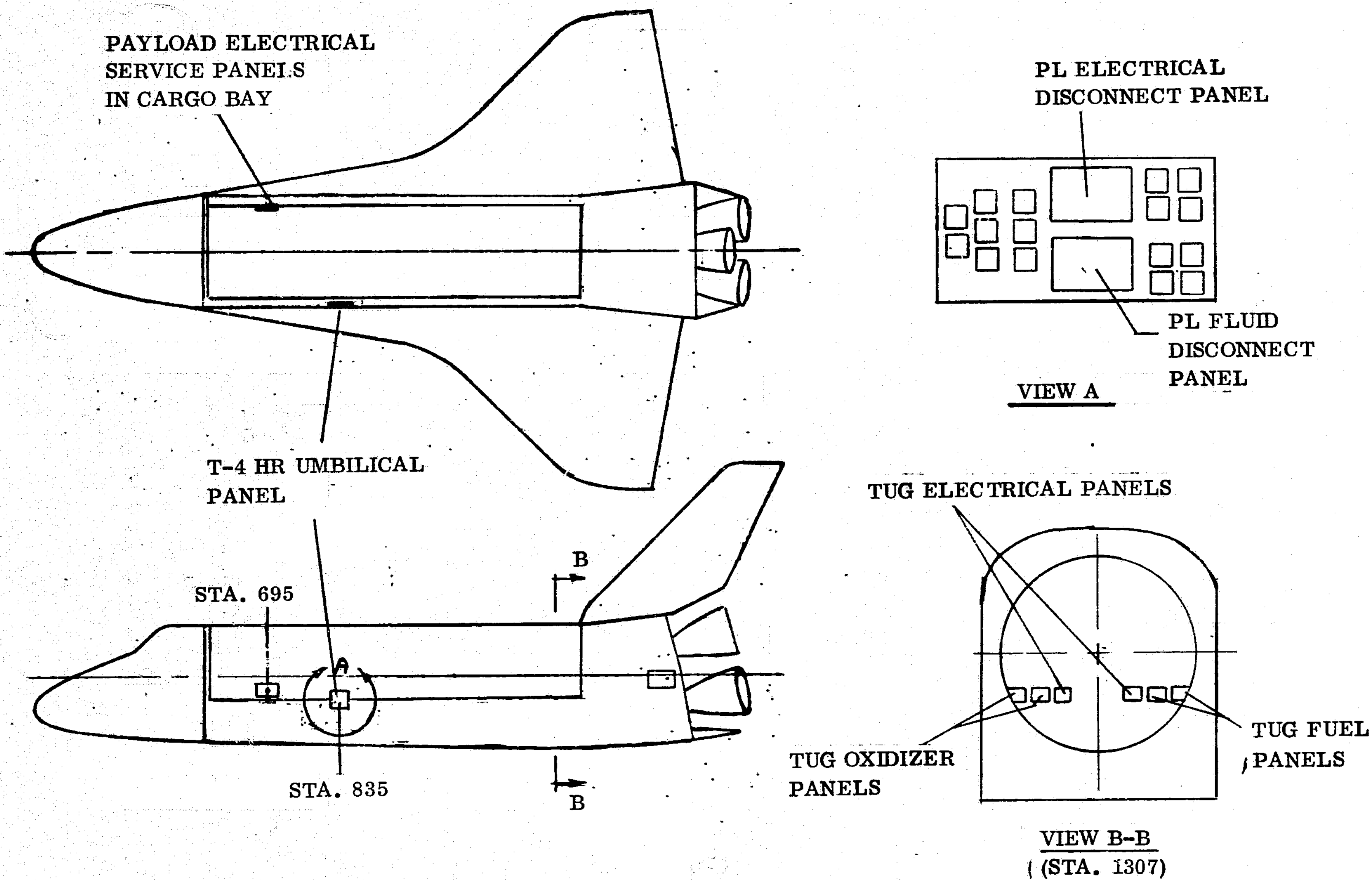
The primary panel for direct payload interfaces which can be terminated at T-4 hours is located at Sta 835. Both fluid and electrical services are available at this location. Subsequent to T-4 hours, the panel is covered by a door which remains closed during flight. An inflight disconnect within the payload bay will be required between the payload and service lines to it from T-4 panel.

Internal to the cargo bay is a payload electrical service panel on the right sidewall at Sta 695. This panel is primarily for direct connection to the Orbiter fuel cell power supply.

Aft panels are located at Sta 1307 on the cargo bay aft bulkhead. Included are Tug fuel, oxidizer and electrical panels on the lower half of the bulkhead and OMS/storable propellant fluid and electrical panels near the top of the bulkhead.

RTG coolant interfaces are located at Sta 1307 for ground cooling and near the cargo bay forward bulkhead for inflight cooling.

TUG & PAYLOAD/ORBITER INTERFACE PANEL LOCATIONS



Review of Level B summarized NASA Payload Descriptions provided quantitative data on propellant requirements for 46% of the payloads designated for Tug. No data is available for the remaining 54%.

Most payloads utilize only one propellant with only one payload out of the 43 utilizing storable bipropellant and two payloads utilizing both GN_2 and N_2H_4 monopropellant for propulsive purposes.

N_2H_4 is the only earth storable monopropellant used with a maximum quantity on a single payload of 390 lb. GN_2 is also used as an RCS propellant on five payloads.

Cesium is used for ion propulsion units on three payloads and is assumed to be loaded aboard the spacecraft prior to delivery to the Tug mating facility. It is also assumed that no drain, vent, or dump requirements exist for Cesium.

The bipropellant payload, PL-01-A, is a Mars Surface Sample Return Vehicle with seven propulsive stages, four of which contain liquid propellants and pressurant. The propellant quantities shown are total liquids aboard the vehicle and are more than five times the quantity required by any other payloads.

PAYLOAD PROPELLANT REQUIREMENTS
REACTION CONTROL & ΔV

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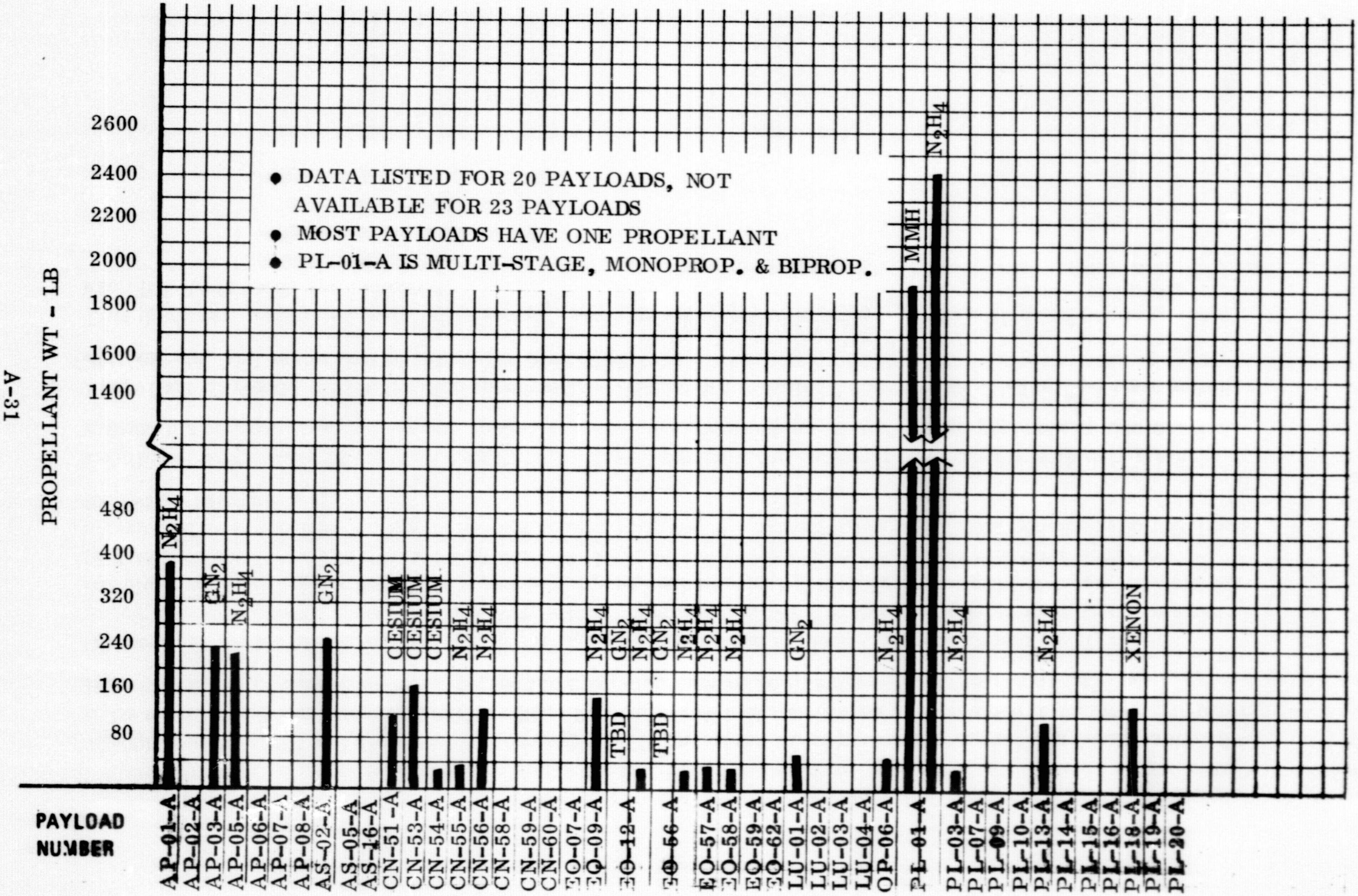


Liquid propellant fill and drain can be accomplished in any of the three modes shown, with payloads assumed to be vertical and one hour available for fill. Payloads with multiple stages are assumed to manifold fill/drain lines within the payload adapter or payload to minimize number of interfaces with the Tug or Orbiter.

Of the three modes identified, fill and drain of propellants in the Payload Changeout Room (PCR) is the recommended method. Evaluation of safety aspects indicate that the storable propellants identified are stable in nature and will not create a safety problem due to loading ahead of installation into the Orbiter. Experience to date with satellites and manned vehicles has shown no instances where propellant reactions occurred subsequent to propellant loading which would have resulted in a hazard under equivalent conditions for payloads loaded on Tug/Orbiter.

Loading of propellants in the PCR results in minimum payload/Tug weight and complexity with only a single manual dis connect required for each propellant source. Manifolding on multi-stage payloads is also avoided.

Propellant fill/drain via the Orbiter requires the addition of 2-3 inflight disconnects, T-0 or T-4 hour umbilical disconnects, and associated plumbing for each fluid.

Line diameter, estimated installation weight, and number of added interfaces, both active and passive, for each fill/drain mode are indicated.

PAYLOAD PROPELLANT FILL/DRAIN (LIQUIDS)

FILL & DRAIN MODE	LINE DIA F/D	INSTL WT F/D	ADDED ACTIVE INTERFACES GSE	ADDED ACTIVE INTERFACES INFLIGHT	ADDED PASSIVE INTERFACES GSE	ADDED PASSIVE INTERFACES AIRBORNE
1) VIA T-4 PANEL DIRECT TO P/L ADAPTER	0.375"	6#/LINE	1	2		
2) VIA TUG INTERFACE THRU ORBITER AFT UMBILICALS	0.5"	21#/LINE	1	3		1
3) IN PAYLOAD CHANGEOUT ROOM (PCR)	0.375"	2#/LINE			1	

ASSUMPTIONS

- MULTI-STAGE PAYLOADS MANIFOLD FILL & DRAIN LINES WITHIN PAYLOAD
- ONE HOUR FOR FILL & DRAIN
- PAYLOADS IN VERTICAL POSITION

EVALUATION/RECOMMENDATIONS

- FILL & DRAIN IN PCR WITH INTERFACE DIRECTLY TO PAYLOAD IS DESIRABLE
  - MINIMUM WEIGHT & COMPLEXITY
  - NO ACTIVE INFLIGHT DISCONNECTS - 4 MIN REQUIRED FOR BIPROP. IF T-4 PANEL USED
  - NO PROPELLANT STORABILITY OR SAFETY PROBLEMS IDENTIFIED
  - NO TUG OR ORBITER INTERFACES

Pressure relief venting of payload propellants has been assumed a safety requirement for storable propellant tanks. Multi-stage payloads are assumed to manifold venting within the payload or payload adapter.

The three vent modes shown are all through Orbiter Sta 1307 interfaces, two via the Tug and one direct to the Orbiter via an inflight disconnect with the payload adapter or payload. The T-4 hour disconnect is not available for inflight venting. All modes shown require 2-3 additional inflight disconnects.

Approximately 60% of the payloads utilize N_2H_4, only 5% utilize other storable liquids, and the remaining 35% either can be vented into the cargo bay or do not require venting.

Since the Tug utilizes an N_2H_4 RCS which requires a vent line through Sta 1307, it is recommended that payloads utilizing N_2H_4 route a vent line into the Tug RCS vent line with no added Orbiter interfaces. For the one payload which utilizes storable bipropellant, a mission peculiar kit is recommended which interfaces with the Orbiter at the payload or payload adapter inflight disconnect and is routed aft to the Sta 1307 storable payload propellant panels near the top of the cargo bay aft bulkhead.

PAYLOAD PROPELLANT VENT

VENT MODE	LINE DIA	INST WT.	ADDED ACTIVE INTERFACES		ADDED PASSIVE INTERFACES	
			GSE	INFLIGHT	GSE	INFLIGHT
1) VIA TUG INTERFACE THRU ORBITER AFT UMBILICAL	0.5'	21#/LINE	1	3		1
2) VIA TUG RCS N_2H_4 VENT LINES (N_2H_4 ONLY)	0.5"	10#		2		
3) DIRECT TO ORBITER & THEN AFT UMBILICALS WITH LINE KIT	0.5"	19#/LINE	1	2		1

ASSUMPTIONS

- VENT CAPABILITY REQ'D FOR STORABLE & HIGH PRESSURE PROPELLANT TANKS
- MULTI-STAGE PAYLOADS MANIFOLD VENT LINES WITHIN PAYLOAD
- PAYLOADS IN VERTICAL POSITION
- VENT VIA T-4 PANEL NOT POSSIBLE IN FLIGHT

EVALUATION/RECOMMENDATIONS

- ~60% OF PAYLOADS UTILIZE N_2H_4
- <5% OF PAYLOADS ARE BIPROPELLANT
- ~20% OF PAYLOADS UTILIZE INERT GAS - VENT INTO CARGO BAY
- ~15% OF PAYLOADS DO NOT REQUIRE VENTING
- VENT PAYLOAD N_2H_4 INTO TUG RCS N_2H_4 VENT LINE
  - MINIMUM INTERFACES
  - MINIMUM WEIGHT
- PROVIDE ORBITER KIT FOR BIPROP. OXIDIZER & FUELS, OTHER THAN N_2H_4
  - ACCOMMODATES <5% OF PAYLOADS
  - NO PENALTY TO MAJORITY OF PAYLOADS
  - UTILIZES STA. 1307 STORABLE PROPULSION PANELS

In sizing lines for payload propellant dump, it was assumed that dump would be aft to minimize Orbiter contamination potential. Monopropellants were assumed to dump in 30 seconds and bipropellants in 150 seconds sequentially. GN_2 can be dumped into the cargo bay with no hazard to the Orbiter.

The maximum propellant load for PL-01-A can be dumped in the required time with a 1" line while the majority of payloads, utilizing N_2H_4, require only a 0.5" line.

Evaluation of the safety aspects, which are the controlling criteria for whether dump is required at all, disclosed no safety hazards other than propellant tank/supports structural failure under crash load conditions. The mere presence of storable propellants in an abort situation does not present an identifiable hazard and the quantities do not appreciably affect the Orbiter abort C.G. Location.

It is recommended that Tug payloads, which in most cases carry less than 500 lbs of propellant, be designed to sustain crash loading conditions. It is possible that a relatively small percentage of payloads such as PL-0-A will incur unacceptable weight penalties by designing for crash loads. For those payloads, it is recommended that a kit be provided to route dump lines from the payload, through an inflight disconnect at the payload or adapter, and aft through the cargo bay to Sta 1307 propulsive payload panels.

PAYLOAD PROPELLANT DUMP

	LINE DIA	INSTL WT	ADDED ACTIVE INTERFACES		ADDED PASSIVE INTERFACES	
			GSE	INFLIGHT	GSE	INFLIGHT
PL-01-A (BIPROP)	1"	75#	2	6		2
95% OF PL's (MONOPROP)	0.5"	21#	1	3		1

ASSUMPTIONS

- LIQUID DUMP VIA AFT UMBILICALS TO AVOID ORBITER CONTAMINATION
- GN_2 DUMP INTO CARGO BAY - NO INTERFACES REQUIRED
- SEQUENTIAL DUMP OF BIPROPELLANTS IN 150 SEC EACH
- MONOPROPELLANT DUMP IN 300 SEC
- DUMP LINES MANIFOLDED WITHIN PAYLOAD FOR MULTI-STAGE PAYLOADS

EVALUATION

- PL-01-A HAS MAX PROPELLANT LOAD - 4 STAGE BIPROP & MONOPROP
- 8 ACTIVE DISCONNECTS AND 75# WEIGHT PENALTY TO DUMP MAXIMUM IDENTIFIED PROPELLANT LOAD (NOT INCLUDING PAYLOAD PENALTIES FOR MANIFOLDING)
- ABORT DUMP NOT REQUIRED FOR SAFETY IF TANKAGE/STRUCTURE DESIGNED FOR CRASH LOADS
  - ~95% OF PL's HAVE LESS THAN 400# PROPELLANT
  - NO SAFETY PROBLEM OTHER THAN STRUCTURE FAILURE IDENTIFIED

RECOMMENDATION

- NO PROPELLANT ABORT DUMP
- DESIGN PAYLOADS TO SUSTAIN CRASH LOADS
- IF DESIGN TO CRASH LOADS IS NOT FEASIBLE FOR SMALL PERCENTAGE OF PAYLOADS WITH LARGE PROPELLANT QUANTITIES (SUCH AS PL-01-A) :
  - DUMP VIA STORABLE PROPULSIVE PAYLOAD PANELS - STA. 1307
  - PROVIDE KIT TO ROUTE DUMP LINES FROM PAYLOAD DIRECT TO PANELS

Options for pressurant fill include, via the T-4 panel, via aft umbilicals thru the Tug or direct to Orbiter, and in the payload Changeout Room (PCR). Vent options include the above plus venting or dumping directly into the cargo bay.

Line sizes are assumed since no data on pressurant quantities was available.

The presence of pressurant under abort conditions does not appear to be a safety hazard. The pressurant tank/supports will be designed for crash loads. Since the pressurant, assumed to be helium, is a small percentage of the storage vessel weight, retention of the gas will impose little added payload weight penalty and adds no Orbiter interfaces or inflight disconnects. Venting or dumping outside the cargo bay would involve lines through the Sta 1307 panels and 2-3 added inflight disconnects. The T-4 panel is not available for vent or dump, consequently, for minimum complexity and weight, it is recommended that pressurant fill be accomplished in the PCR and vent, or dump if required, be directly into the cargo bay.

PAYLOAD PRESSURANT FILL, VENT OR ABORT DUMP

FILL, VENT OR DUMP MODE	ASSUMED LINE DIA.*	INSTL WT	ADDED ACTIVE INTERFACES GSE	ADDED ACTIVE INTERFACES AIRBORNE	ADDED PASSIVE INTERFACES GSE	ADDED PASSIVE INTERFACES AIRBORNE
1) VIA T-4 PANEL DIRECT TO PAYLOAD (FILL)	~0.25"	~7#	1	2		
2) VIA TUG INTERFACE THRU ORBITER AFT UMBILICALS	~0.375"	~20#	1	3		1
3) IN PCR (FILL & VENT)	~0.25"	~3#			1	
4) INTO CARGO BAY (VENT & DUMP)	~0.25"	~3#			1	
5) DIRECT TO ORBITER & VIA AFT UMBILICALS	~0.375"	~18#	1	2		1

ASSUMPTIONS

- NO ORBITER CONTAMINATION PROBLEM WITH VENTED GASES
- VENT/DUMP OF INERT GAS INTO CARGO BAY IS ALLOWABLE

EVALUATION/RECOMMENDATIONS

- FILL PRESSURANT IN PCR
- VENT/DUMP INTO CARGO BAY

*PRESSURANT QUANTITIES NOT DEFINED IN AVAILABLE PAYLOAD DATA

Two of the 43 Tug payloads contain liquid helium, for infrared sensor conditioning, stored in a low heat leak dewar. No data was available on quantity so 100 lbs was assumed. Abort dump of LHe is not felt to be a safety requirement.

Fill, drain and topping capability until T-4 was assumed with vacuum jacketed lines and disconnects required. With Dewar storage and low boiloff rates, venting directly into the cargo bay was assumed allowable.

Of the fill modes identified the T-4 panel mode is recommended. Not only does this routing minimize number of interfaces, but it also satisfies the needs of a number of non-Tug payloads, carried by the Orbiter, which require the use of liquid helium. Weight penalties for vacuum jacketed lines are also minimized with this routing.

PAYLOAD CRYOGEN FILL, DRAIN, & VENT

FILL & DRAIN OR VENT MODE	LINE O.D. (VAC. JACK)		INSTL WT		ADDED ACTIVE INTERFACES		ADDED PASSIVE INTERFACES	
	F/D	VENT	F/D	VENT	GSE	AIRBORNE	GSE	AIRBORNE
1) VIA T-4 PANEL DIRECT TO PAYLOAD (FILL)	0.75"	1"	8#	10#	1	2		
2) VIA TUG INTERFACE THRU ORBITER AFT UMBILICALS	1"	1.25"	50#	60#	1	3		1
3) VENT INTO CARGO BAY		1"		2#				
4) VIA AFT UMBIL. WITH ORBITER LINE KIT		1.25"		48#				

ASSUMPTIONS

- ON PAD FILL & DRAIN OF CRYOGENICS (LHe)
- ABORT DUMP OF LHe NOT REQUIRED
- VACUUM JACKETED LINES AND DISCONNECTS
- NO ORBITER CONTAMINATION PROBLEM WITH LHe
- COLD He GAS VENTING INTO CARGO BAY AT LOW RATES ALLOWED
- 100 LBS LHe (PAYLOAD DATA NOT AVAILABLE ON QUANTITY REQUIRED)

EVALUATION/RECOMMENDATION

- CRYOGEN TOPPING REQUIRED UNTIL 4 HR BEFORE LAUNCH
- T-4 PANEL DESIRED LOCATION FOR FILL & DRAIN
  - SAVES ~42 LB WEIGHT
  - MINIMUM NUMBER OF DISCONNECTS
- VENT INTO CARGO BAY
  - NO DISCONNECTS
  - SAVES ~58 LB WEIGHT

BATTERY VENT (PRESSURE RELIEF)

	ASSUMED LINE DIA	INSTL WT	ADDED ACTIVE INTERFACES		ADDED PASSIVE INTERFACES	
			GSE	INFLIGHT	GSE	INFLIGHT
1) VIA TUG INTERFACE THRU AFT UMBILICALS	0.5"	21#	1	3		1
2) INTERFACE WITH TUG BATTERY CASE VENT LINE	0.5"	8#	NO ADDT'L	2		

ASSUMPTIONS

- CORROSIVE BATTERY FLUIDS/GASES DUMP THRU AFT UMBILICALS
- BATTERY CASE PRESSURE RELIEF REQUIRED FOR SAFETY

EVALUATION/RECOMMENDATIONS

- VENT INTO TUG BATTERY CASE VENT LINE
  - MINIMUM WEIGHT
  - MINIMUM NUMBER OF DISCONNECTS
  - NO ADDED ORBITER INTERFACES

Pressure relief venting of payload battery cells is required to avoid rupture of the cell in the event of rapid pressure rise. The battery fluids, such as potassium hydroxide, are corrosive and must be dumped aft to minimize potential contamination.

The Tug itself also carries an emergency battery which requires a pressure relief vent. Consequently, it is recommended that payload battery case vents be routed into the Tug battery case vent line to minimize weight and number of added disconnects.

NASA planetary payloads, 11 out of 43 in SSPD data, contain Radioisotope Thermoelectric Generators (RTGs) which require ground and inflight active cooling. The ground coolant source is demineralized water with an interface at the Sta 1307 panels. The coolant is required continuously until T-0. A heat rejection rate of 34,000 BTU per hr with a 50° coolant delta T was assumed. Some DoD payloads also require a similar coolant supply. Coolant inlet and return lines were assumed.

To minimize number of active interfaces, routing direct to the Orbiter through a mission peculiar line kit is recommended. The kit would interface with the payload inflight umbilical disconnect near Sta 835 and route lines aft through the cargo bay to the Sta 1307 panel coolant source.

PAYLOAD GROUND COOLING (RTG)

	LINE DIA	INSTL WT	ADDED ACTIVE INTERFACES		ADDED PASSIVE INTERFACES	
			GSE	INFLIGHT	GSE	INFLIGHT
1) VIA STA 835 INFLIGHT DISCONNECT DIRECT FROM ORBITER STA 1307 SOURCE	0.5"	38# (2 LINES)	2	4		2
2) VIA TUG INTERFACE TO ORBITER STA 1307 SOURCE	0.5"	42#	2	6		2

ASSUMPTIONS

- COOLANT SUPPLY & RETURN LINES REQUIRED
- HEAT REJECTION RATE = 34,000 BTU/HR
- COOLANT IS DEMINERALIZED WATER
- 50° COOLANT ΔT
- COOLANT SOURCE IS AT STA 1307
- COOLANT REQUIRED UNTIL T-0

EVALUATION/RECOMMENDATIONS

- 11 PAYLOADS OUT OF 43 NASA/COMMERCIAL REQUIRE COOLANT (ALL PLANETARY)
- DOD PAYLOADS ALSO REQUIRE COOLANT
- ROUTE VIA STA 835 INFLIGHT DISCONNECT DIRECT TO ORBITER SOURCE
  - MINIMUM NUMBER OF ACTIVE INTERFACES
  - CAN BE ORBITER KIT FOR PAYLOADS REQUIRING COOLANTS

PAYLOAD INFLIGHT COOLING (RTG)

The RTG inflight coolant source is located near the cargo bay forward bulkhead per JSC 07700. Consequently the two coolant lines are assumed to be routed through a payload inflight disconnect panel near Sta 835 and forward in the cargo bay.

LINE DIA	INSTL WT	ADDED ACTIVE INTERFACES		ADDED PASSIVE INTERFACES	
		GSE	INFLIGHT	GSE	INFLIGHT
0.5	15 LB (2 Lines)		2		1

ASSUMPTIONS

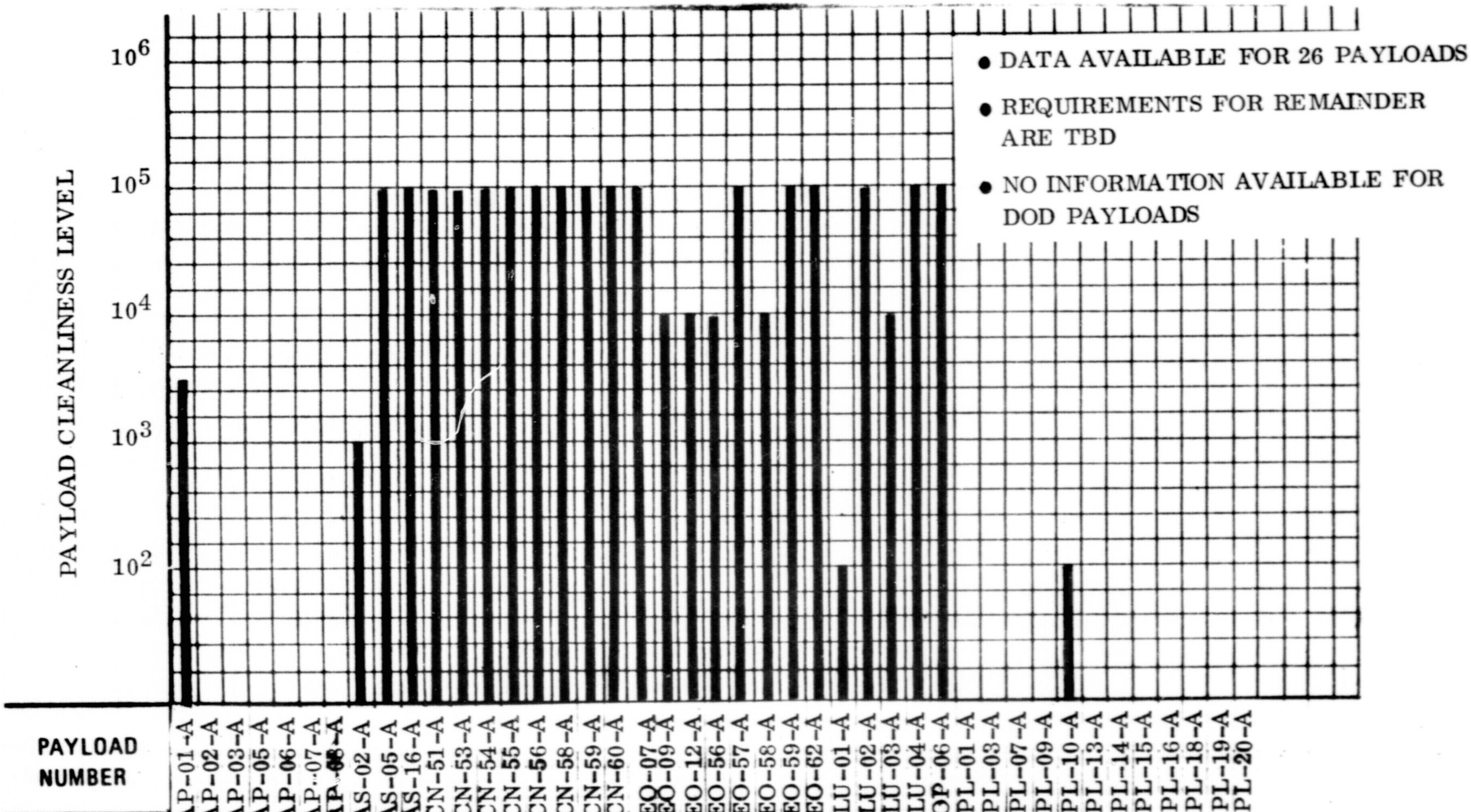
- COOLANT SUPPLY & RETURN LINES REQUIRED
- COOLANT SOURCE IS NEAR CARGO BAY FORWARD BULKHEAD

EVALUATION/RECOMMENDATION

- ROUTE FROM FORWARD BULKHEAD SOURCE TO PAYLOAD VIA STA 835 INFLIGHT DISCONNECT PANEL

PAYLOAD CLEANLINESS REQUIREMENTS

Payload cleanliness levels specified in summarized NASA Payload Descriptions are level 100,000 for the majority of payloads. Four have a level 10,000 requirement, one each at level 5,000 and 1000, and two at level 500. No data is available on the remaining 17 payloads.



For payloads with relatively stringent cleanliness criteria, levels of 5,000 or lower, a payload shroud is assumed to be installed. Approximately 10% of the payloads fall within this category. It is assumed that the shroud will be purged with GN_2 at 500 CFM and 550°R. The shroud purge gas will exit from the shroud into the cargo bay. The venting line diameter is 3" with an installed weight of approximately 70-75 lbs.

Shroud purge is required until T-0 so the T-4 panel cannot be utilized.

Since less than 10% of the Tug payloads and some non-Tug payloads will require a shroud, it is recommended that a mission peculiar kit be provided to route purge gas from the Sta 1307 panels forward in the cargo bay, connecting with a payload inflight disconnect panel near Sta 835.

PAYLOAD SHROUD PURGE

PURGE MODE	LINE DIA.	INSTL. WT.	ADDED ACTIVE INTERFACES		ADDED PASSIVE INTERFACES	
			GSE	INFLIGHT	GSE	INFLIGHT
1) VIA TUG INTERFACE THRU AFT UMBILICALS	3"	74 LB	1	3		1
2) VIA ORBITER INTERFACE THRU STA 1307 UMBILICALS	3"	69 LB	1	2		1

ASSUMPTIONS

- PAYLOAD SHROUD REQUIRED ON PAYLOADS WITH CLEANLINESS LEVELS ≤ 5000
- PURGE REQUIRED UNTIL LAUNCH
- PURGE VENTED INTO CARGO BAY
- 500 CFM GN_2 PURGE RATE

EVALUATION/RECOMMENDATION

- < 10% OF TUG PAYLOADS SPECIFY CLEANLINESS LEVELS POTENTIALLY REQUIRING USE OF SHROUD
- PAYLOAD DESCRIPTION DATA INDICATES SOME NON-TUG PAYLOADS WILL ALSO REQUIRE SHROUD
- MAJORITY OF PAYLOADS DO NOT REQUIRE SHROUD
- PROVIDE ORBITER MISSION PECULIAR KIT FOR SHROUD PURGING AS REQUIRED.

PAYLOAD INTERFACE RECOMMENDATIONS

A listing of payload interface recommendations for fluids and gases is included in the two following charts for each identified functional requirement. The charts summarize recommendations and rationale from the previous detailed charts.

FUNCTION	INTERFACE RECOMMENDATIONS	RATIONALE
1) PROPELLANT FILL & DRAIN	ACCOMPLISH IN PAYLOAD CHANGEOUT ROOM – INTERFACE DIRECTLY WITH PAYLOAD	• NO TUG OR ORBITER INTERFACES • ELIMINATES 4–6 INFLIGHT DISCONNECTS • NO SAFETY CONCERN IDENTIFIED • MINIMUM WEIGHT
2) PROPELLANT VENT	VIA STA 1307 UMBILICAL PANELS • INTERFACE WITH TUG RCS N_2H_4 VENT • PROVIDE ORBITER LINE KIT FOR BIPROP PAYLOADS	• RELIEF TYPE VENT REQ'D. FOR SAFETY • MINIMUM INTERFACES FOR MOST PLs • KIT FOR < 5% OF PLs
3) PROPELLANT ABORT DUMP	NO ABORT DUMP (MAJORITY OF PAYLOADS NOTE – ADD ORBITER KIT IF SOME PLs CANNOT BE DESIGNED FOR CRASH LOADS	• DESIGN TANKAGE/SUPPORTS TO SUSTAIN CRASH LOADS • MOST PAYLOADS CONTAIN < 500# PROP. • ELIMINATES 8 INFLIGHT DISCONNECTS
4) PRESSURANT FILL	ACCOMPLISH IN PAYLOAD CHANGEOUT ROOM – INTERFACE DIRECTLY WITH PAYLOAD	• SAME AS 1) EXCEPT 2 INFLIGHT DISCONNECTS ELIMINATED
5) PRESSURANT VENT/RELIEF OR ABORT DUMP	NO INTERFACE REQUIRED	• VENT/DUMP DIRECTLY INTO CARGO BAY
6) BATTERY VENT (PRESSURE RELIEF)	INTERFACE WITH TUG BATTERY CASE VENT LINE	• MINIMUM INTERFACES

PAYLOAD INTERFACE RECOMMENDATIONS

FUNCTION	INTERFACE RECOMMENDATION	RATIONALE
7) CRYOGEN FILL & DRAIN	VIA T-4 PANEL	• CRYOGEN TOPPING REQ'D. UNTIL SHORTLY BEFORE LAUNCH • ~40# WEIGHT SAVINGS • MINIMUM NUMBER OF DISCONNECTS
8) CRYOGEN VENT	NO INTERFACE REQ'D	• VENT DIRECTLY INTO CARGO BAY • ~58# WT SAVINGS • NO DISCONNECTS REQ'D.
9) GROUND COOLING (RTG)	VIA STA 835 INFLIGHT DISCONNECT PANEL DIRECT FROM ORBITER (STA 1307 SOURCE)	• MINIMUM NUMBER OF DISCONNECTS
10) INFLIGHT COOLING (RTG)	VIA STA 835 INFLIGHT DISCONNECT PANEL DIRECT FROM ORBITER (STA 576 SOURCE)	• ORBITER COOLANT SOURCE LOCATED AT STA 576
11) PAYLOAD SHROUD PURGE	VIA STA 835 INFLIGHT DISCONNECT PANEL DIRECT FROM ORBITER (STA 1307)	• SATISFIES BOTH TUG & NON-TUG PAYLOAD REQUIREMENTS

PAYLOAD INTERFACE SUMMARY
(PROPELLANTS & FLUIDS)

INTERFACE TYPE	LOCATION	FUNCTION	NUMBER & SIZE
PAYLOAD DIRECT TO ORBITER	T-4 PANEL	CRYOGEN FILL & DRAIN	1 @ 0.75"
	STA 835 INFLIGHT DISCONNECT	• INFLIGHT COOLING	2 @ 0.5"
	STA 835 INFLIGHT DISCONNECT AFT TO STA 1307 UMBILICAL PANELS	• PROPELLANT VENT KIT (BIPROP) • GROUND COOLING • PAYLOAD SHROUD PURGE KIT	2 @ 1.5" 2 @ 0.5" 1 @ 3"
PAYLOAD TO ORBITER THRU TUG	CONNECT INTO EXISTING TUG LINES	BATTERY VENT	1 @ .5"
		N_2H_4 VENT	1 @ .5"

A total of 8 added interfaces, direct from payload to orbiter, without routing through the Tug, have been identified. One from the T-4 panel, 2 via a sta 835 inflight disconnect panel forward in the cargo bay, and five from the sta 835 inflight disconnect aft to sta 1307 panels.

No added Tug to orbiter interfaces are recommended. Two added payload to Tug interfaces were identified however.

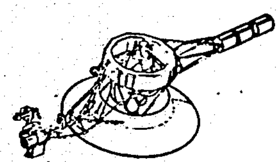
Three data sources were used for performing the avionics services trade. Space Shuttle payload description activity (SSPDA) information was used to determine overall payload functional requirements. Payload utilization with Tug (PUT) data was used to obtain detail information on wire quantities and routing options, and a typical complex NASA payload, Viking, was used to evaluate the actual implementation requirement and functional use (i.e., critical safety, comm, health assessment, etc.) of each umbilical connection.

Once the service requirements were defined, analyses were conducted to determine the best method of accommodating these services. Important considerations used during this evaluation were:

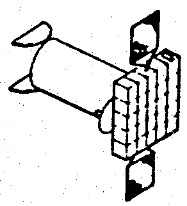
Who does it?	Is the service satisfied by the Tug or the Orbiter? If the Orbiter potentially provides the service, the Tug must be considered only for its service transmission acceptability.
How is it transmitted?	Do all functions have to be individually hardwired, or may some data be interleaved and multiplexed?
Where are wires routed?	Should they go completely through the Tug, partially through Tug, or direct from payload to Orbiter?

PAYLOAD AVIONICS SERVICES ACCOMMODATIONS

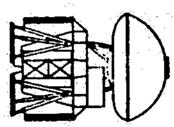
SSPDA DATA



MDAC PUT STUDY



TYPICAL NASA PAYLOAD



GOALS

- STANDARD INTERFACE
- LOW WEIGHT
- COST EFFECTIVE
- SAFE

INTERFACE IMPLEMENTATION

- WHO DOES IT
  - ORBITER
  - TUG
- HOW
  - DIRECT HARDWIRE
  - MULTIPLEX
- WHERE DO THE WIRES GO
  - VIA TUG
  - DIRECT

SPECIAL CONSIDERATIONS

- RTG (WHO SUPPLIES ORBITER INTERFACE UNIT)
- RFI, EMC
- RF ORBITER PAYLOAD BAY RECEIVER
- KICK STAGES REQUIREMENTS
- FORWARD UMBILICAL MECHANISM (MECHANISM WEIGHT VS WIRE WEIGHT)

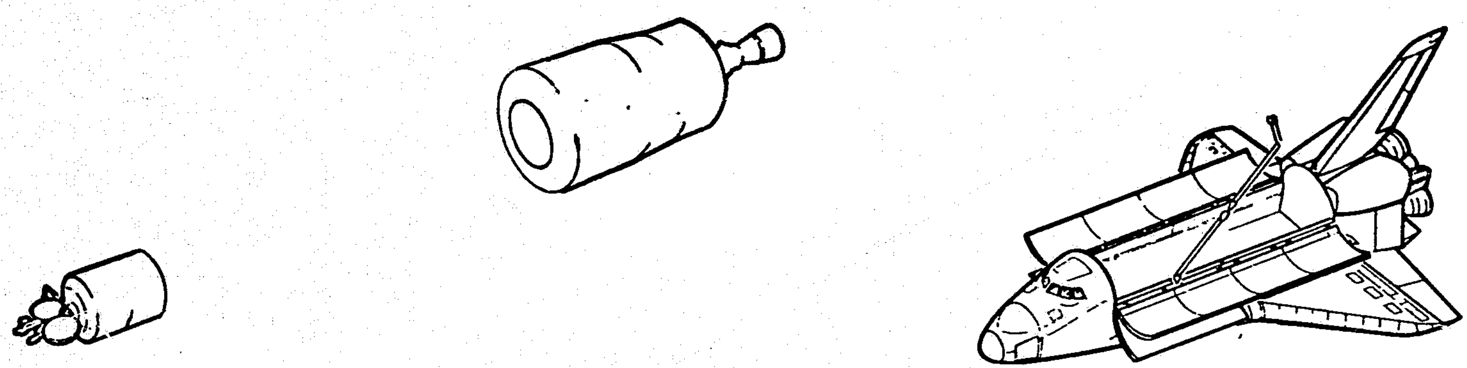
Because of the limited scope of this trade study all areas affecting the determination of payload interface requirements have not been addressed in detail. The chart on the facing page lists several of these areas which should be considered in determining the final payload electrical interface requirements.

Space Shuttle payload description activity (SSPDA) information for Tug payloads was used to identify spacecraft functional requirements for the 1984 and on time period.

The applicable SSPDA data includes 43 different spacecraft types flown during 139 Tug-Shuttle missions. Requirements were included for multiple payload combinations as well as individual payloads for all operational phases conducted in conjunction with the Orbiter. These operations include prelaunch, ascent, on-orbit prior to deployment, and deployment while still within the Orbiter's influence. Although many requirements for individual payloads are TBD, the SSPDA data is the best compilation of overall requirements available for the 1984 and on activity.

SSPDA information was used to evaluate payload avionics requirements for the three areas identified on the facing page. Data was compiled for Tug payloads in each area, compared with tentatively planned Tug and/or Orbiter support capability, and a reasonable cut-off point recommended for each particular service. The following 12 charts present this data.

SSPDA PAYLOADS REQUIREMENTS



DETERMINATION OF PAYLOAD REQUIREMENTS VS % OF TOTAL P/L ACCOMMODATED, FOR:

- POWER
  - AVE POWER REQUIRED BY S/C
  - PEAK POWER REQUIRED BY S/C
  - SPACECRAFT ASCENT POWER REQUIRED (AVE)
  - SPACECRAFT TOTAL ENERGY REQUIREMENTS
- DATA TRANSFER
  - S/C UPLINK DATA RATE VIA SHUTTLE
  - S/C DOWNLINK DATA RATE VIA SHUTTLE
  - S/C DATA RATE FOR STORAGE
  - S/C TOTAL DIGITAL DATA TO BE STORED
- DATA MANAGEMENT
  - PROCESSOR WORD LENGTH
  - RAPID ACCESS MEMORY SIZE
  - MASS MEMORY SIZE

Total average power required by the spacecraft plus its monitor and control equipment while located within the Orbiter is shown in kilowatts.

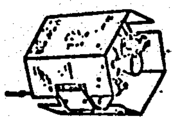
Some information concerning the split between spacecraft and monitor and control power is contained in the level B SSPDA data for a limited number of the 43 payloads. For those identified, more power is generally required for the control equipment than for the spacecraft vehicle.

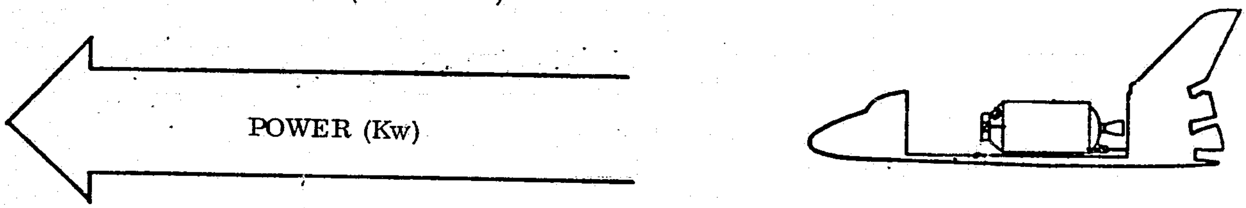
A 600 watt accommodation line is referenced which corresponds with 85% of the missions. The 600 watt number was identified in the MSFC baseline Tug documentation as a general Tug requirement for Tug power delivery from its fuel cell after deployment rather than for thru Tug orbiter to spacecraft power trans mission during operations.

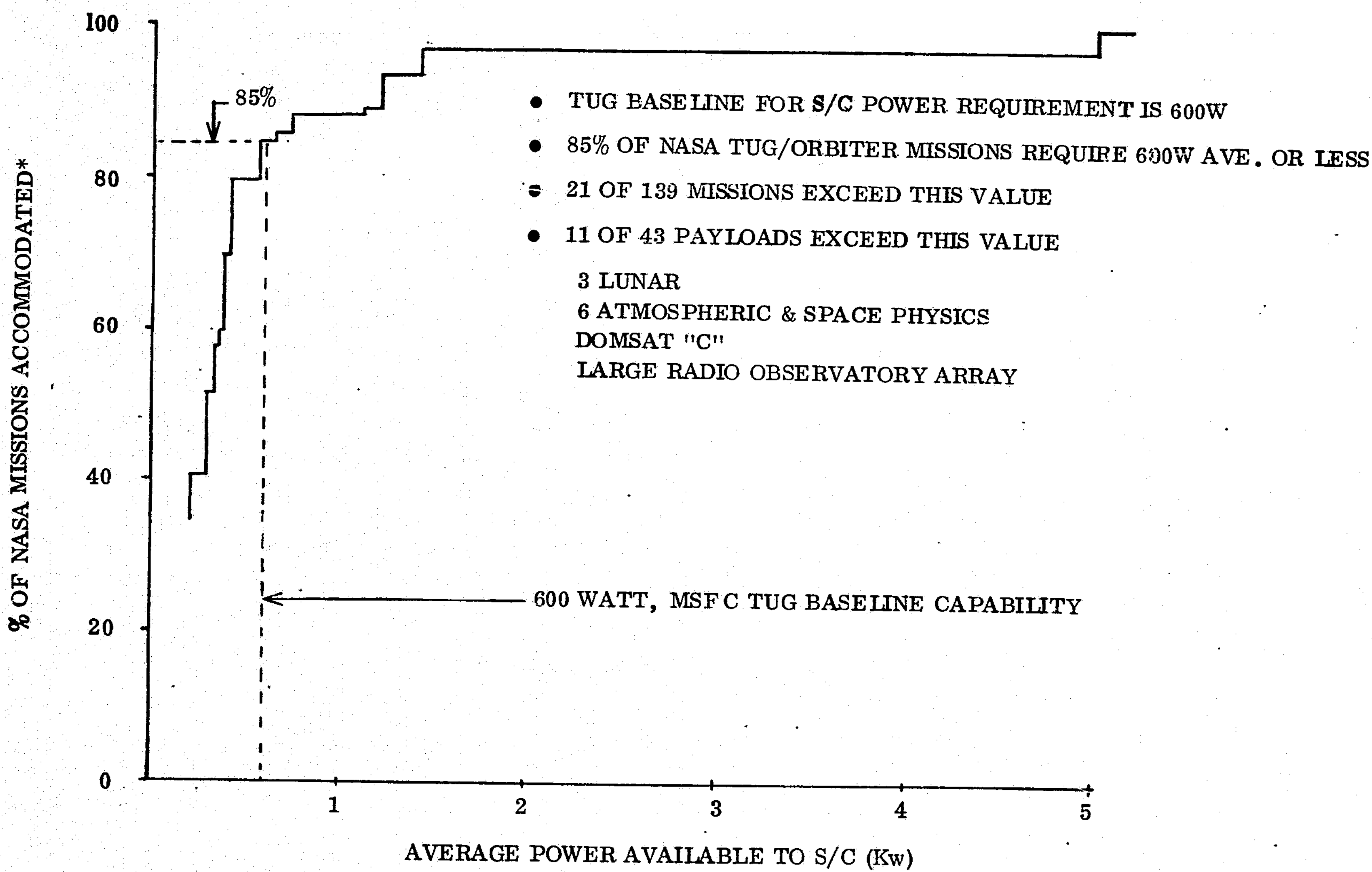
The payloads (plus their orbiter on-board support equipment) which would not be satisfied by the 600 watt reference capability are identified on the chart.

AVERAGE POWER REQUIRED BY SPACECRAFT
(ON ORBIT)

GENERAL DYNAMICS
Convair Division



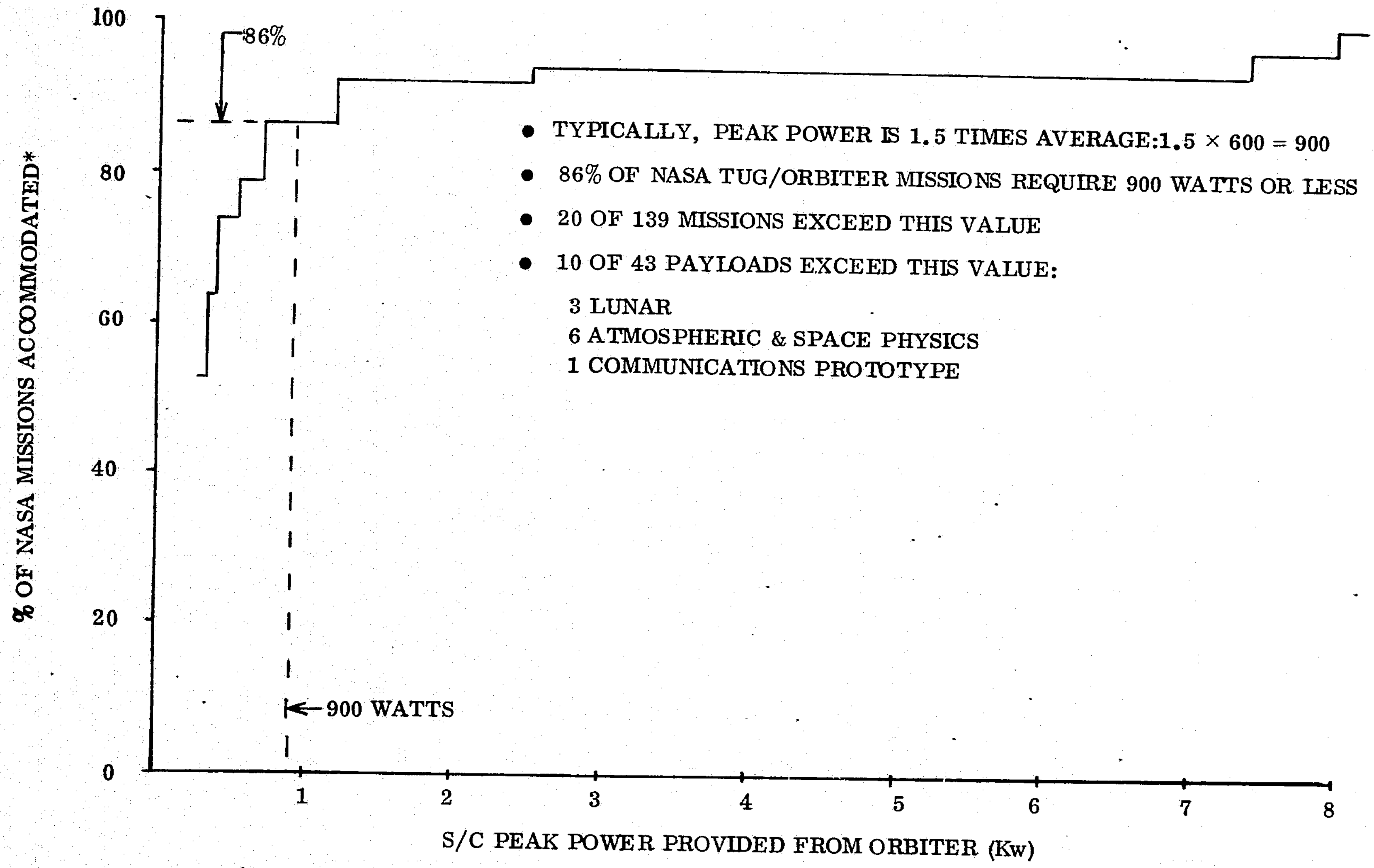




*FROM MSFC'S PRELIMINARY 'SUMMARIZED NASA PAYLOAD DESCRIPTIONS-AUTOMATED PAYLOADS, LEVEL A DATA," JULY 1974

PEAK POWER REQUIRED BY S/C

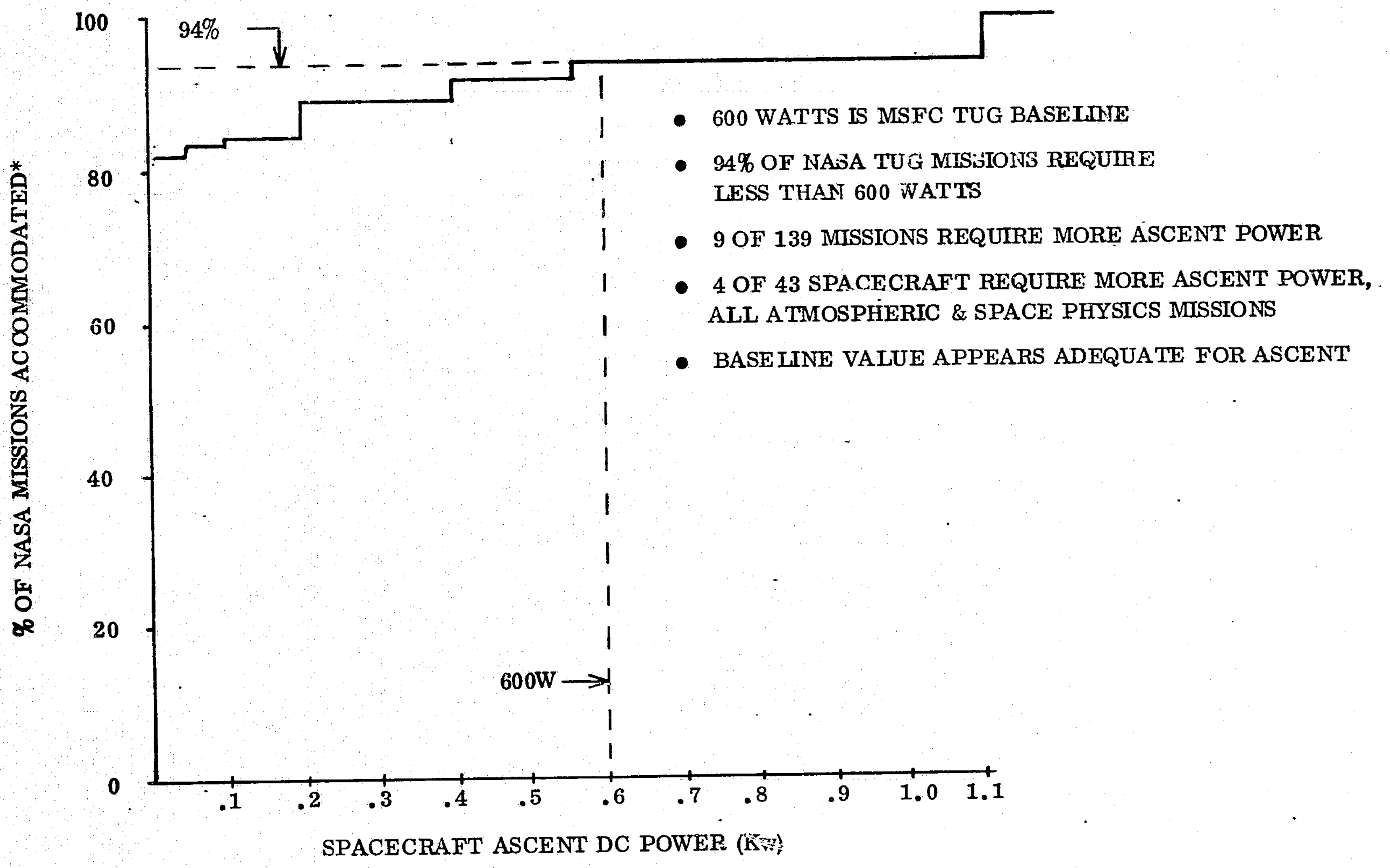
Peak power requirements are not specifically included in the Tug baseline data. Typically, however, peak power is assumed to be 1.5 times the average power. The 900 watt reference shown results in a similar percentage of acceptable payload accommodations, with generally the same group of spacecraft as in on orbit average power exceeding the reference capability.



*FROM MSFC'S PRELIMINARY 'SUMMARIZED NASA PAYLOAD DESCRIPTIONS-AUTOMATED PAYLOADS, LEVEL A DATA," JULY 1974

POWER REQUIRED BY S/C DURING ASCENT

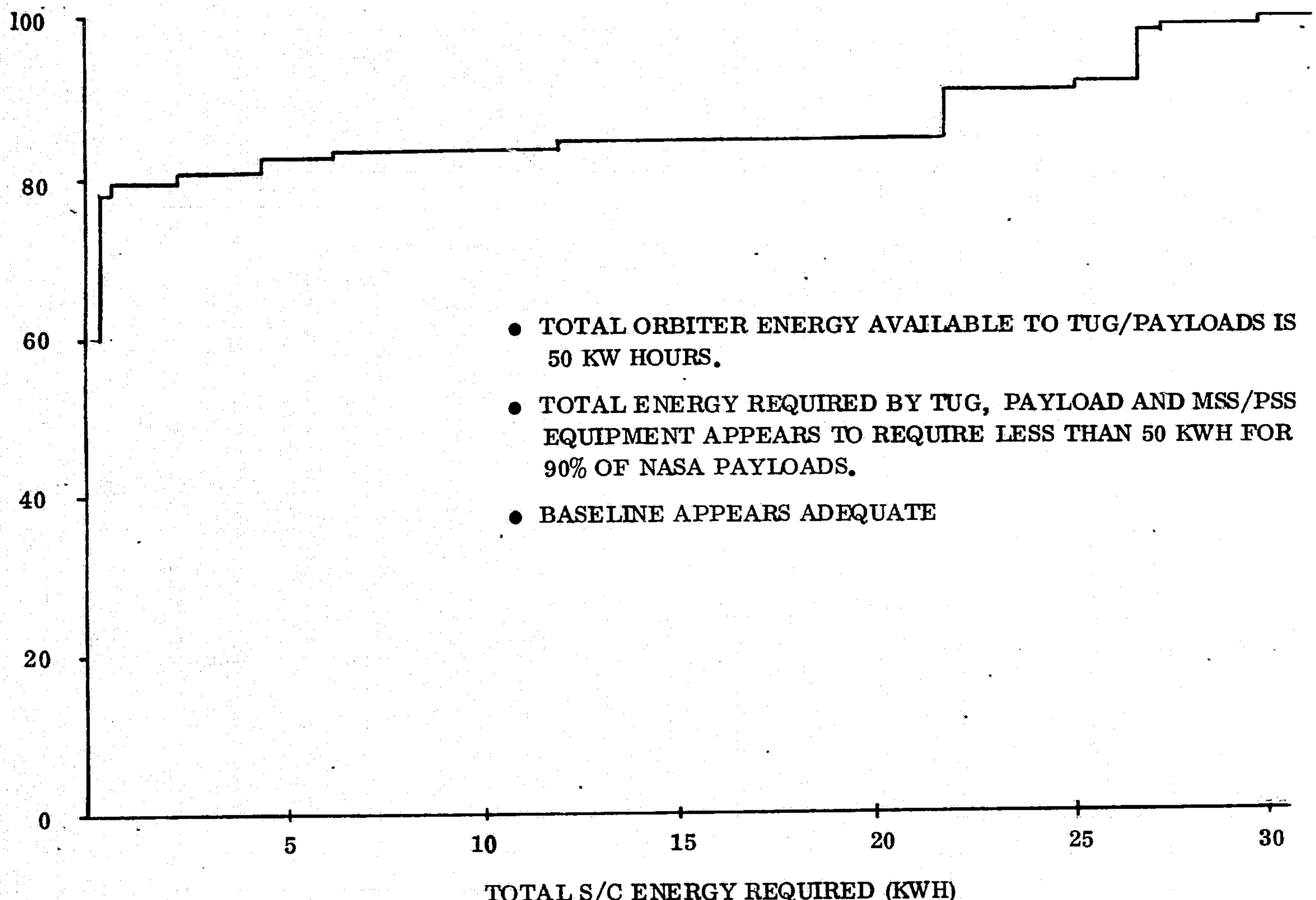
During ascent, the payload plus its orbiter mounted monitor and control equipment generally require less power than during on orbit pre-deployment operations. This enables the 600 watt reference capability to satisfy 94% of the missions. Since 1100 watts (almost double the reference value) is needed to pick up the four remaining payloads, the 600 watt power requirement appears reasonable.



*FROM MSFC'S PRELIMINARY "SUMMARIZED NASA PAYLOAD DESCRIPTIONS–AUTOMATED PAYLOADS, LEVEL A DATA," JULY 1974

TOTAL ENERGY REQUIRED BY S/C

Total energy required by the spacecraft plus its orbiter mounted support equipment is shown. Total orbiter energy available for total payload use (Tug, Tug deployment adapter, Tug monitor and control equipment, spacecraft, and spacecraft monitor and control equipment) is 50 KW hours. Using preliminary estimates of the energy needs of Tug and its peripheral equipment, the 50 KWH available should satisfy at least 90% of the Tug/spacecraft missions.



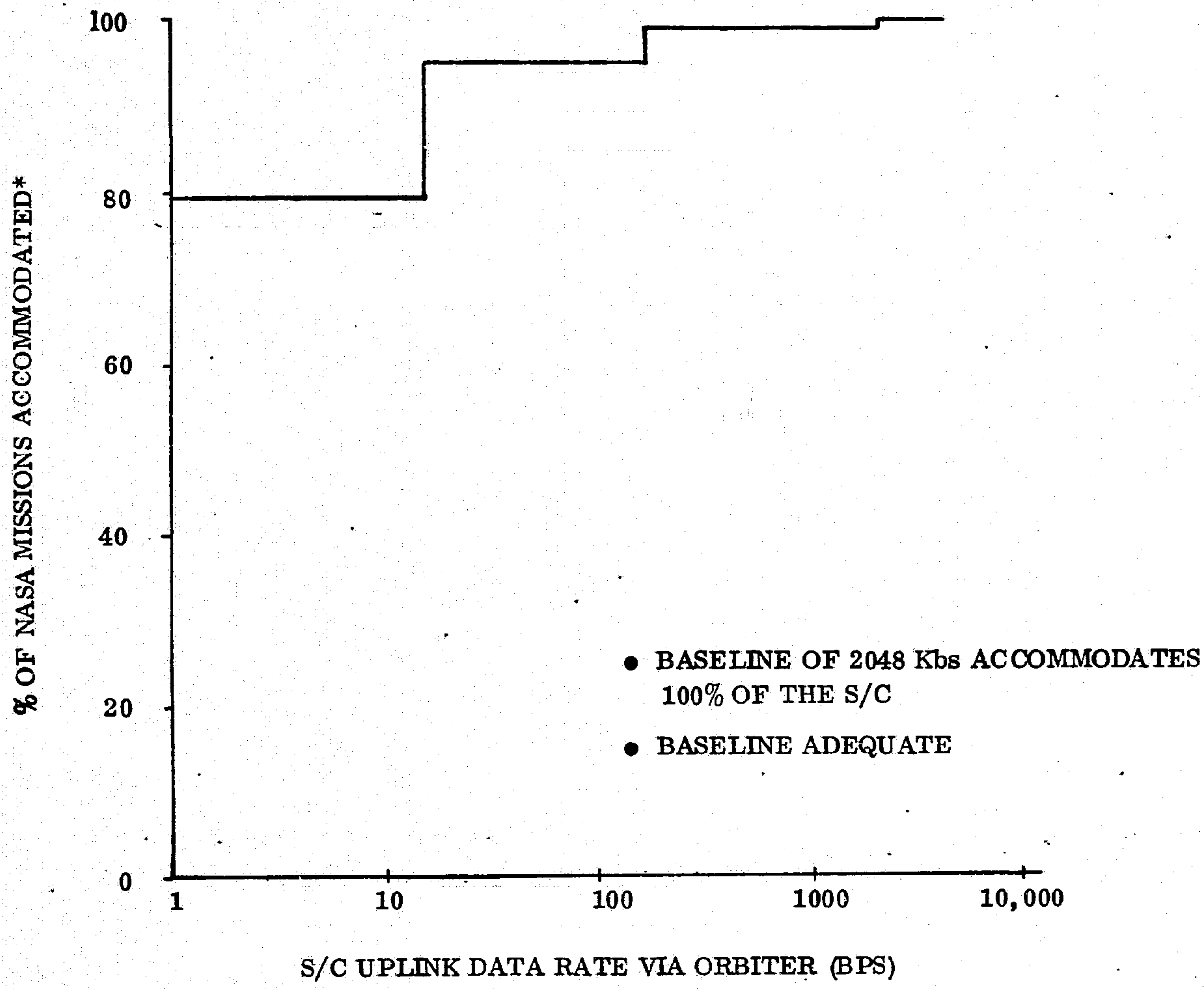
- TOTAL ORBITER ENERGY AVAILABLE TO TUG/PAYLOADS IS 50 KW HOURS.
- TOTAL ENERGY REQUIRED BY TUG, PAYLOAD AND MSS/PSS EQUIPMENT APPEARS TO REQUIRE LESS THAN 50 KWH FOR 90% OF NASA PAYLOADS.
- BASELINE APPEARS ADEQUATE

*FROM MSFC'S PRELIMINARY 'SUMMARIZED NASA PAYLOAD DESCRIPTIONS–AUTOMATED PAYLOADS, LEVEL A DATA," JULY 1974

S/C UPLINK BIT RATE (VIA ORBITER)

GENERAL DYNAMICS
Convair Division

The Orbiter uplink capability of receiving and relaying 2048 thousand bits per second to spacecraft satisfies 100% of the identified payload requirements and is therefore adequate.

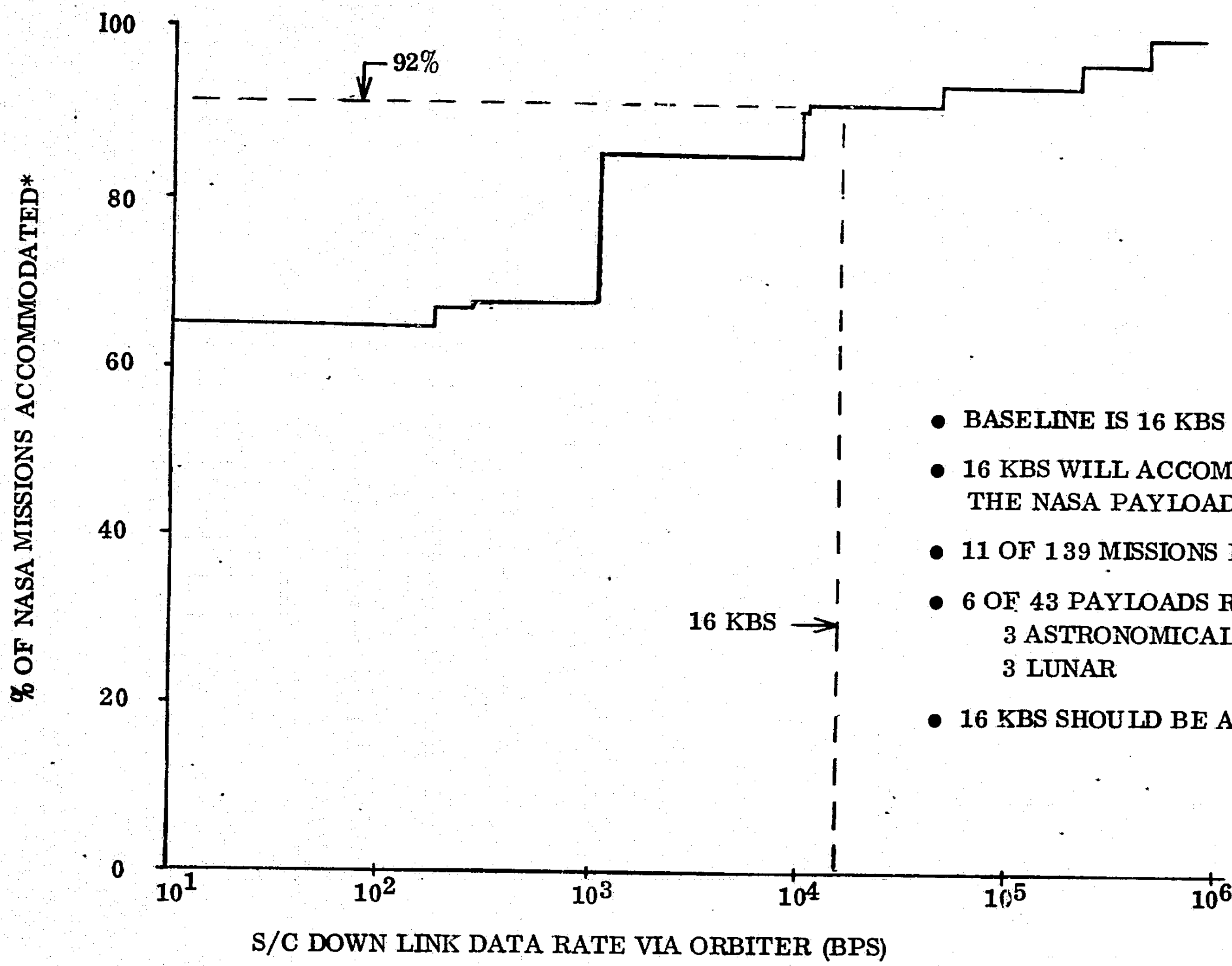


*FROM MSFC'S PRELIMINARY 'SUMMARIZED NASA PAYLOAD DESCRIPTIONS-AUTOMATED PAYLOADS, LEVEL A DATA," JULY 1974

S/C DOWN LINK BIT RATE (VIA ORBITER)

GENERAL DYNAMICS
Convair Division

The Orbiter baseline provides for transmission of 16 thousand bits per second of spacecraft to ground data. Ninety two percent of the mission model is satisfied by this capability, therefore the Orbiter baseline appears to be reasonable.

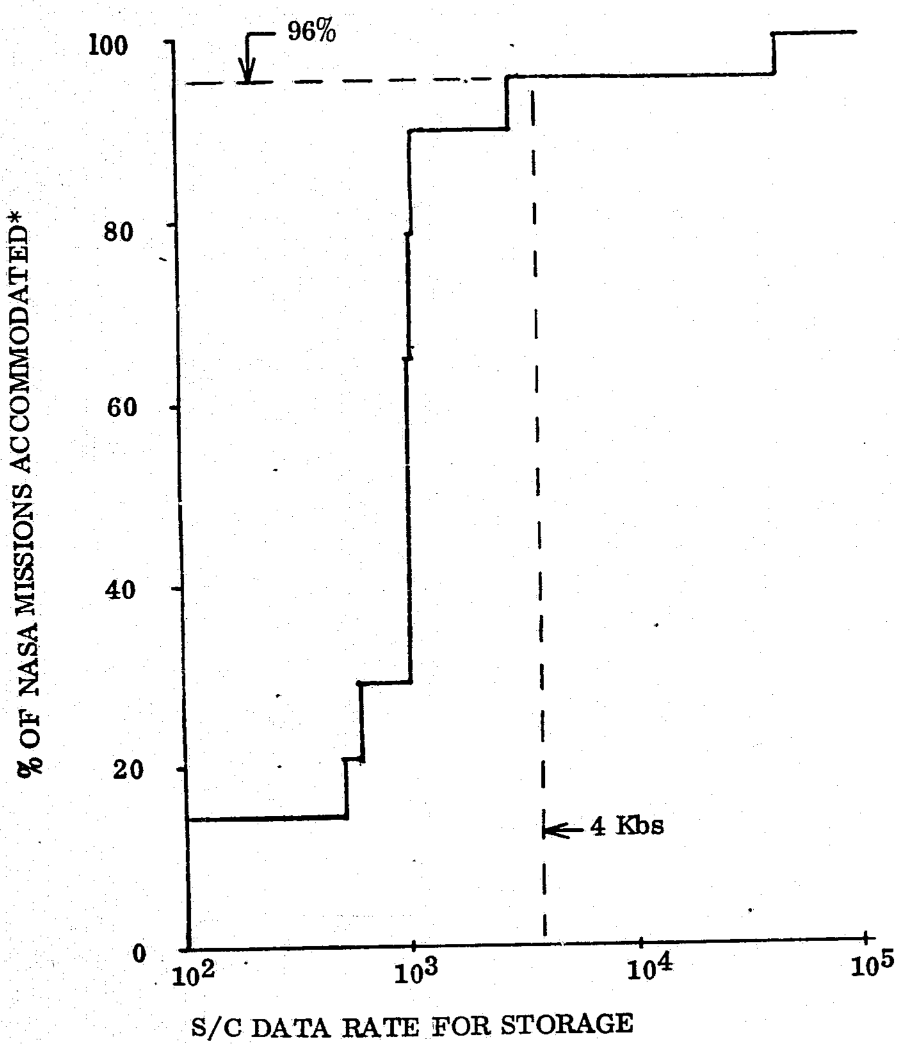


- BASELINE IS 16 KBS
- 16 KBS WILL ACCOMMODATE 92% OF THE NASA PAYLOADS
- 11 OF 139 MISSIONS REQUIRE HIGHER BIT RATES
- 6 OF 43 PAYLOADS REQUIRE HIGHER BIT RATES:
  3 ASTRONOMICAL
  3 LUNAR
- 16 KBS SHOULD BE AN ADEQUATE BASELINE

*FROM MSFC'S PRELIMINARY 'SUMMARIZED NASA PAYLOAD DESCRIPTIONS–AUTOMATED PAYLOADS, LEVEL A DATA," JULY 1974

BIT RATE FOR S/C DATA TO BE STORED

Although no specific Tug or Orbiter provisions have been identified for storage of spacecraft data, data storage would probably be accommodated by the Orbiter for spacecraft attached mission modes. As indicated by the facing chart, a four thousand bit per second data stream for storage purposes would satisfy 96% of the identified spacecraft requirements. Since an order of magnitude increase would be necessary to include the six excluded missions, the 4 Kbps storage data bit rate should be acceptable.

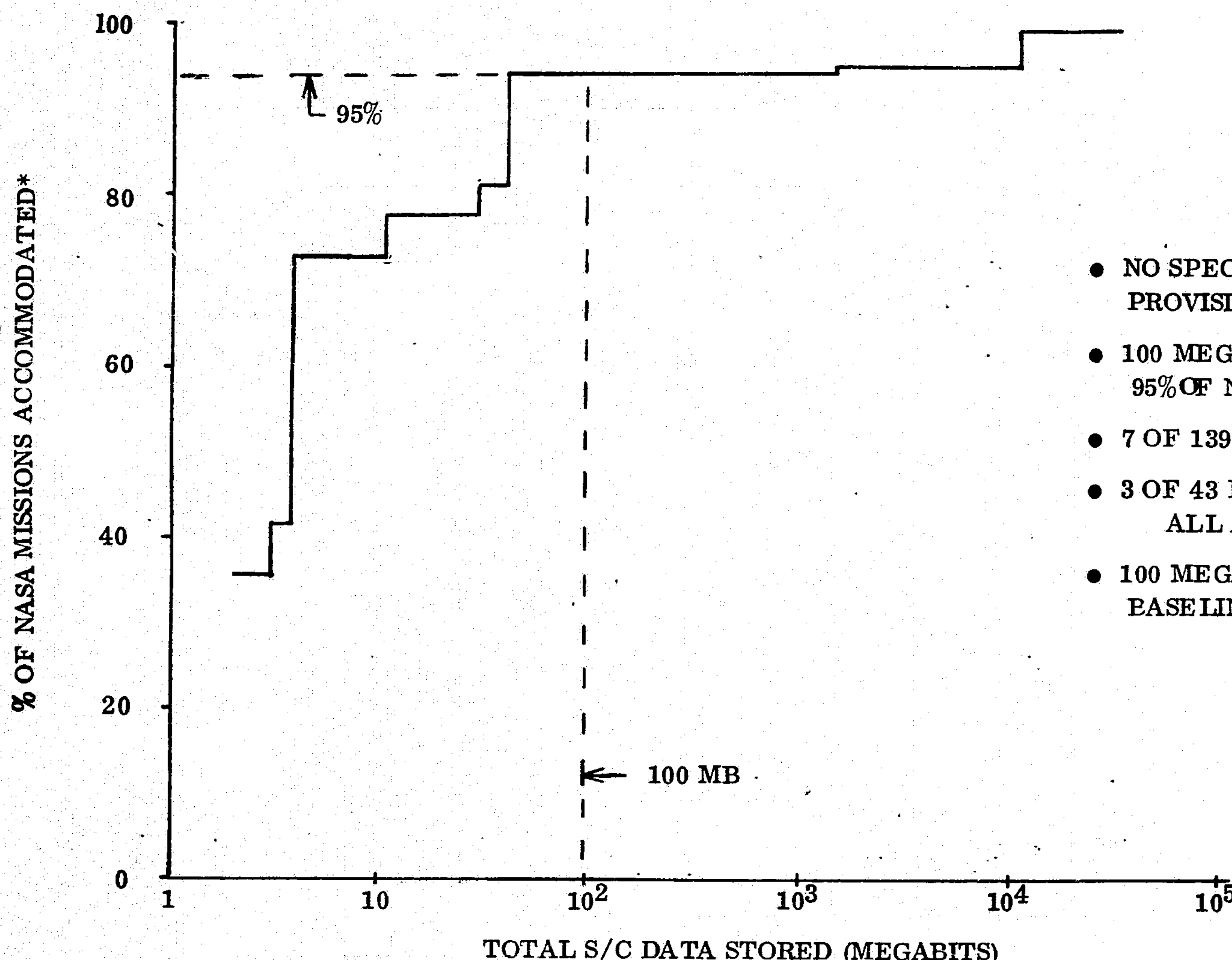


- NO SPECIFIC ORBITER OR TUG PROVISIONS.
- 4 Kbs ACCOMMODATES 96% OF NASA TUG PAYLOADS.
- 6 OF 139 MISSIONS REQUIRE HIGHER RATES.
- 2 OF 43 PAYLOADS REQUIRE HIGHER RATES:
  2 ASTRONOMICAL
- 4 Kbs SHOULD BE AN ADEQUATE BASE LINE

*FROM MSFC'S PRELIMINARY 'SUMMARIZED NASA PAYLOAD DESCRIPTIONS-AUTOMATED PAYLOADS, LEVEL A DATA," JULY 1974

TOTAL S/C DATA STORED

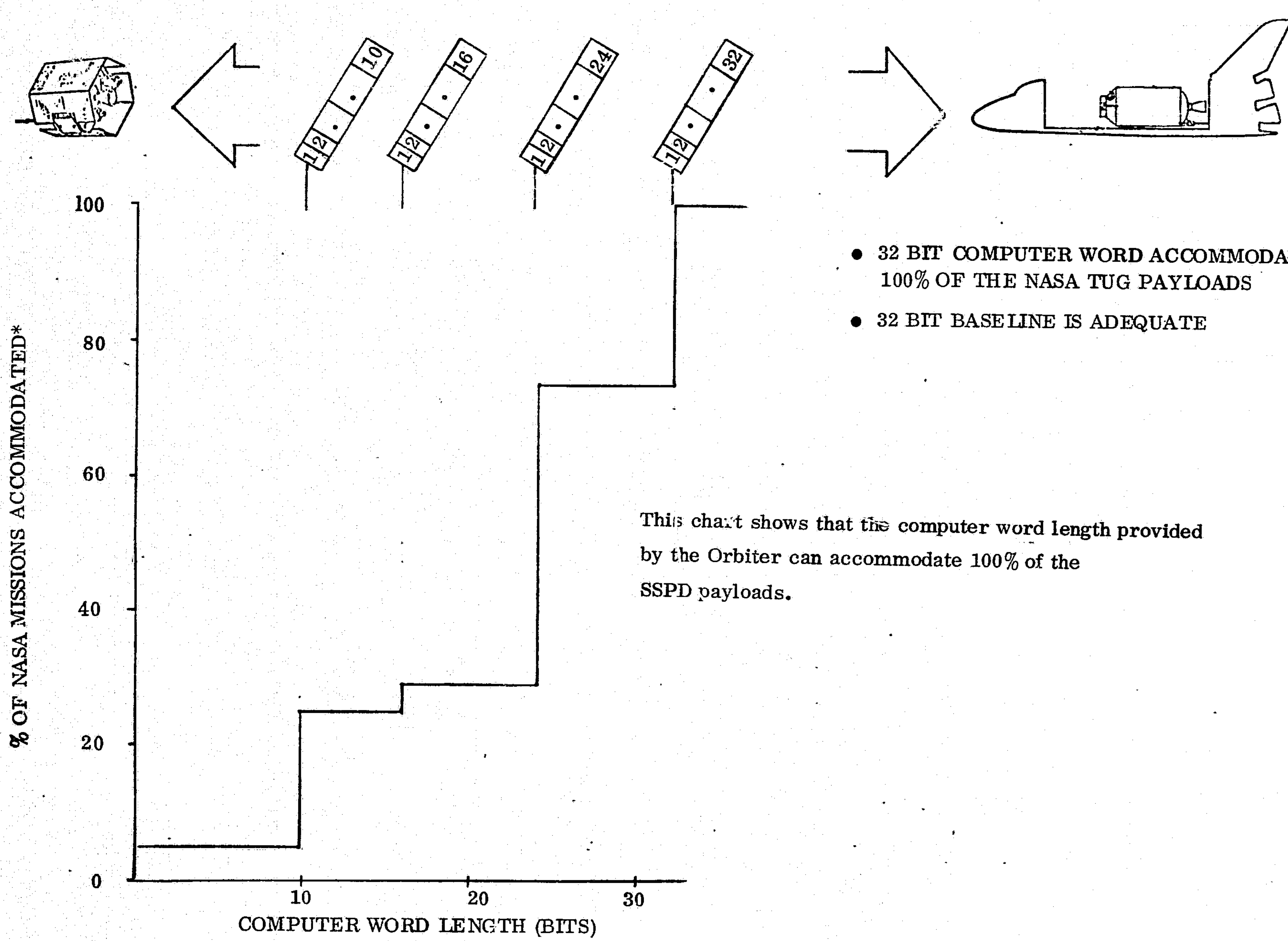
As previously stated, storage capacity for Shuttle attached spacecraft is assumed to be an Orbiter supplied accommodation. A capability to store 100 megabits of data would satisfy 95% of the spacecraft requirements currently identified. One hundred percent accommodation requires a storage capacity two orders of magnitude greater. One hundred megabits appears to be a realistic baseline accommodation.



- NO SPECIFIC ORBITER OR TUG PROVISIONS
- 100 MEGABITS WOULD ACCOMMODATE 95% OF NASA TUG PAYLOADS.
- 7 OF 139 MISSIONS REQUIRE MORE
- 3 OF 43 PAYLOADS REQUIRE MORE: ALL ARE ASTRONOMICAL
- 100 MEGABITS SHOULD BE AN ADEQUATE BASELINE

*FROM MSFC'S PRELIMINARY 'SUMMARIZED NASA PAYLOAD DESCRIPTIONS-AUTOMATED PAYLOADS, LEVEL A DATA," JULY 1974

COMPUTER WORD LENGTH FOR COMPUTATIONAL SUPPORT OF S/C



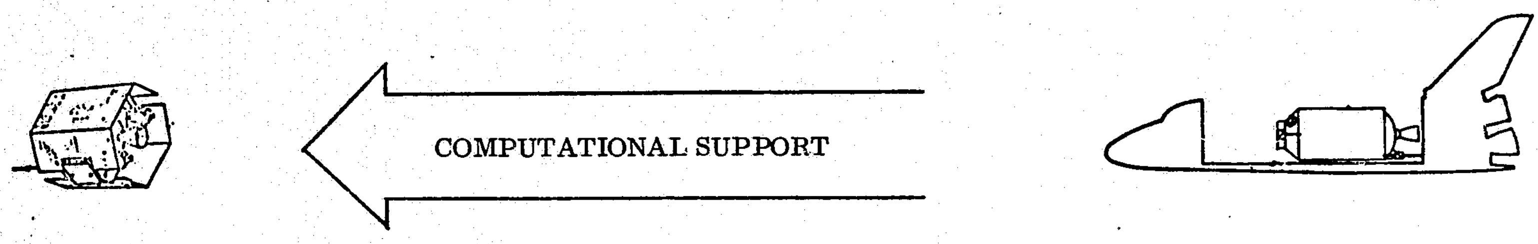
- 32 BIT COMPUTER WORD ACCOMMODATES 100% OF THE NASA TUG PAYLOADS
- 32 BIT BASELINE IS ADEQUATE

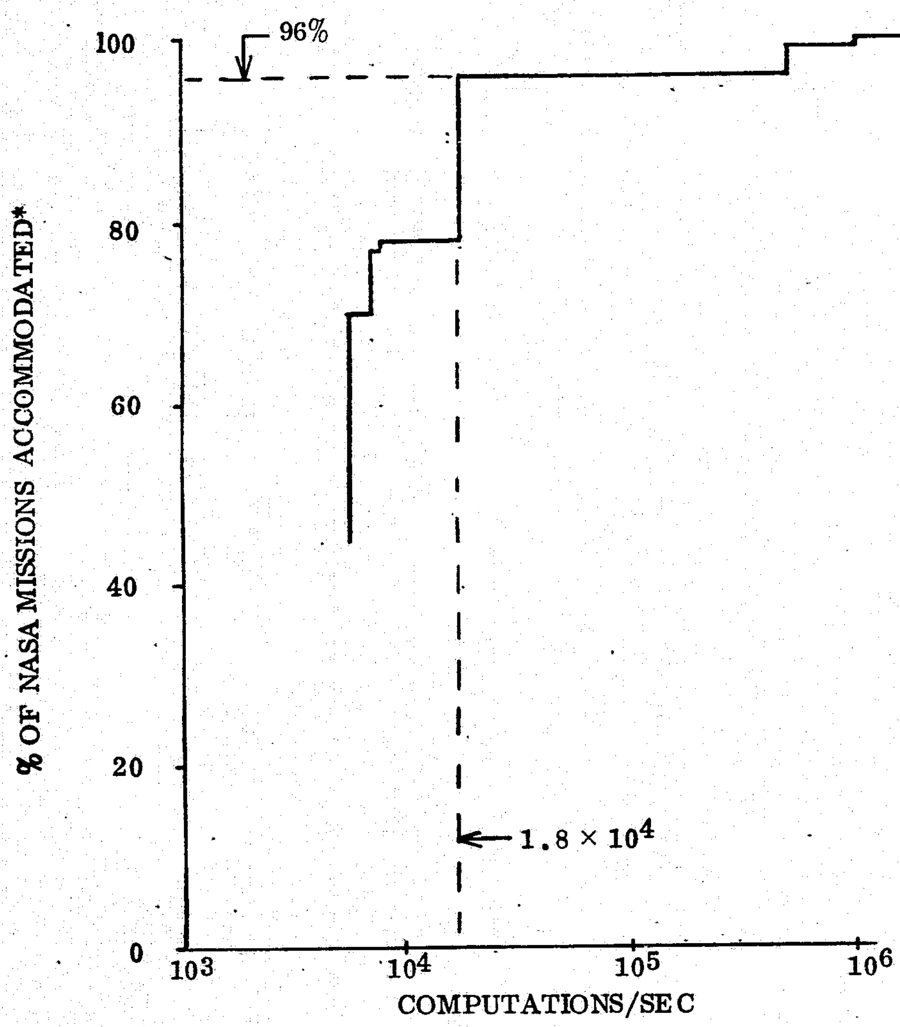
This chart shows that the computer word length provided by the Orbiter can accommodate 100% of the SSPD payloads.

*FROM MSFC'S PRELIMINARY 'SUMMARIZED NASA PAYLOAD DESCRIPTIONS-AUTOMATED PAYLOADS, LEVEL A DATA," JULY 1974

Computational speed requirements for SSPDA payloads have been identified. The chart shows the percentage of total mission payloads that can be accommodated by a given level of computational speed. The Orbiter baseline of 18,000 computations/second will accommodate 96% of the payloads. Payloads AP-06 and AP-07 require 1,000,000 computations/second and payload AP-08 requires 500,000 computations/second. There are 5 total missions with these high computer speed requirements. The Orbiter capability of 18K appears to be reasonable for the Tug payloads, although that is the total Orbiter capability to satisfy both Tug and Payload requirements. The distribution of the 18K between Tug and payload will be done later as part of the avionic subsystem analysis portion of Task 2.

COMPUTER SPEED REQUIRED FOR COMPUTATIONAL SUPPORT OF S/C



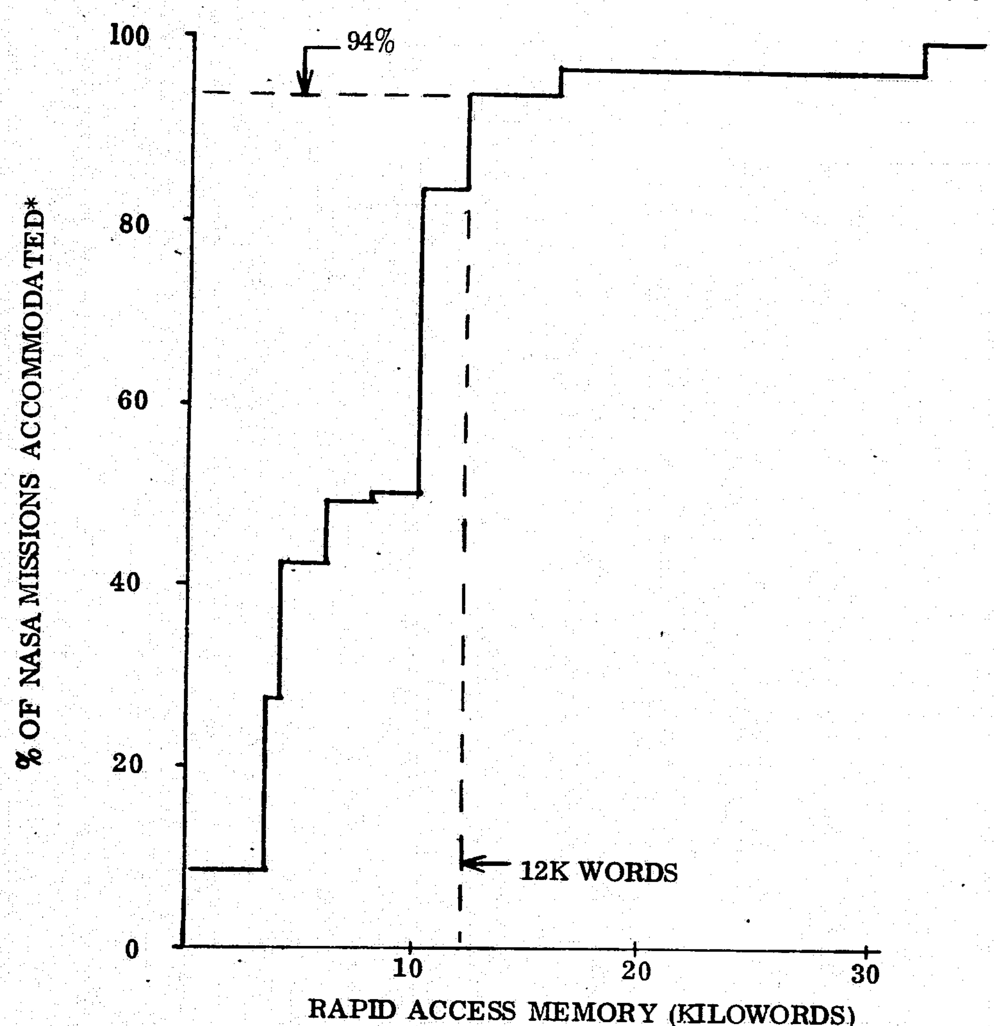


- BASELINE IS 18K EQUIVALENT ADDS/SEC
- THIS SPEED ACCOMMODATES 96% OF NASA TUG PAYLOADS
- 5 OF 139 MISSIONS REQUIRE GREATER SPEED
- 3 OF 43 S/C REQUIRE GREATER SPEED. ALL ARE ATMOSPHERIC AND SPACE PHYSICS PAYLOADS.
- BASELINE APPEARS ADEQUATE.

*FROM MSFC'S PRELIMINARY 'SUMMARIZED NASA PAYLOAD DESCRIPTIONS-AUTOMATED PAYLOADS, LEVEL A DATA," JULY 1974

RAPID ACCESS MEMORY REQUIRED FOR COMPUTATIONAL SUPPORT OF S/C

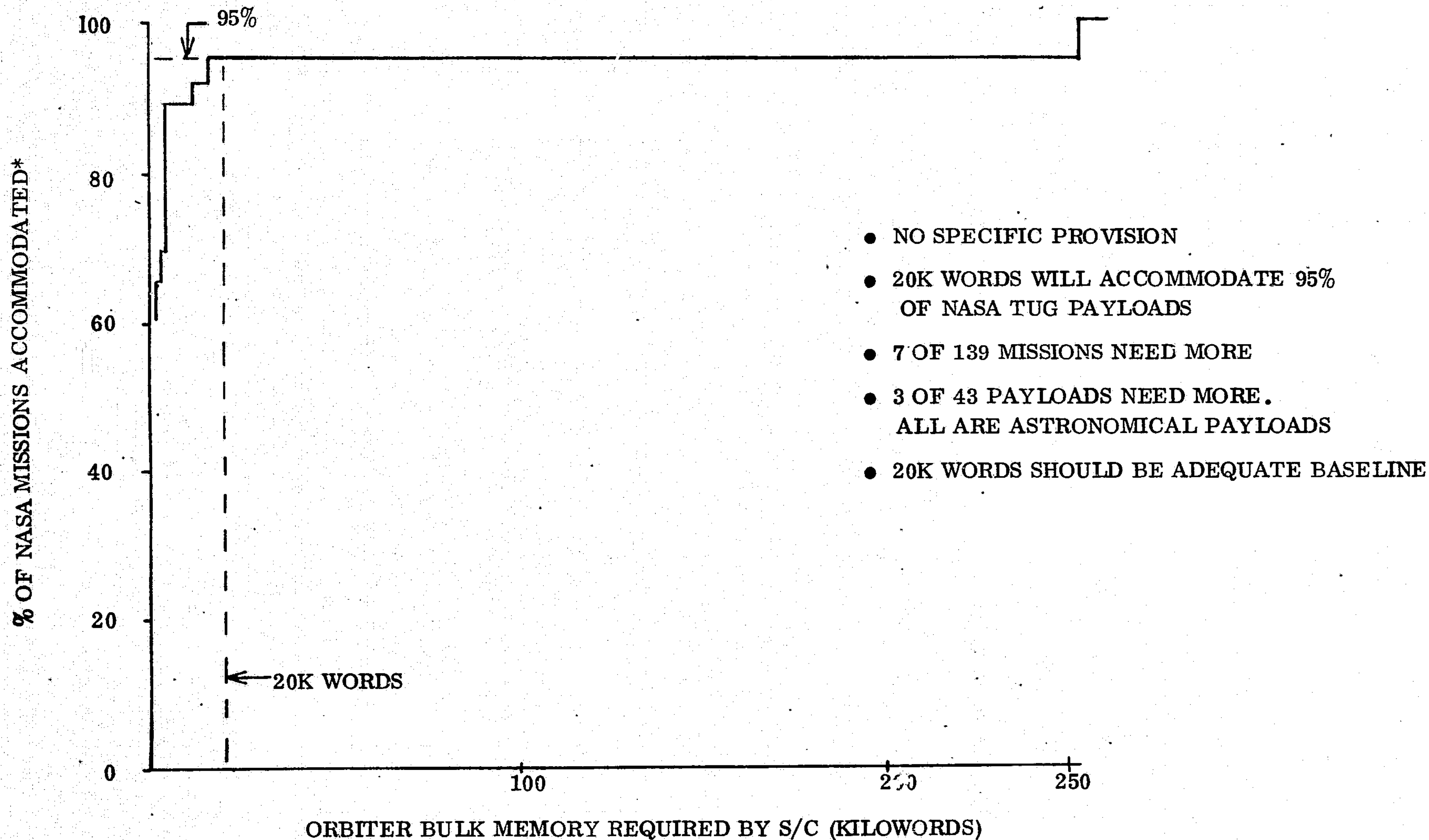
Rapid access memory requirements for SSPDA payloads have been compiled. The chart shows the percentage of total mission payloads that can be accommodated by a given memory size. The Orbiter baseline is currently sized for 10K words. It is recommended that this be increased to 12K words because there are 15 payloads (EO-09, EO-59, and EO-62) that require 12K words, which if included in the Orbiter capability increase mission accomplishment from 83% to 94%. Distribution of the 12K words memory allocation between Tug and payload will be done later in the Interface Compatibility Study.



- BASELINE CAPABILITY IS 10K WORDS
- 10K WORDS ACCOMMODATES 83% OF NASA TUG PAYLOADS
- 23 OF 139 MISSIONS REQUIRE MORE STORAGE
- 5 OF 43 PAYLOADS REQUIRE MORE STORAGE:
  1 ATMOSPHERIC & SPACE PHYSICS
  1 ASTRONOMICAL
  3 EARTH OBSERVATORIES
- THE EARTH ORSERVATORIES REQUIRE ONLY 2K WORD INCREASE
- RECOMMEND BASELINE CHANGE TO 12K WORDS.

*FROM MSFC'S PRELIMINARY 'SUMMARIZED NASA PAYLOAD DESCRIPTIONS-AUTOMATED PAYLOADS, LEVEL A DATA," JULY 1974

Mass storage requirements for SSPDA payloads have been compiled. The chart shows the percentage of payloads that can be accommodated with a given Orbiter bulk memory. The Orbiter baseline currently identified 20K words allocated for payload use which will accommodate 95% of the payloads. Seven payloads (AS-02, AS-05, and AS-16) require 250K words. A baseline capability of 20K words appears to be reasonable.



*FROM MSFC'S PRELIMINARY 'SUMMARIZED NASA PAYLOAD DESCRIPTIONS-AUTOMATED PAYLOADS, LEVEL A DATA," JULY 1974

Specific requirements of the SSPD payloads that cannot be attained with the recommended levels of Orbiter/Tug support are identified. SSPD payload designations are shown in the left hand column and recommended support levels that should be Orbiter/Tug provided are shown across the top of the chart. The level of support desired by the payload is shown in the table. In most cases a single payload is deficient in more than one parameter. The footnotes show that most of the deficiencies are either due to limitations in the basic capability of the Orbiter, or to payload requirements that appear to be suspect.

Spacecraft requirements associated with downlink and stored data bit rates can easily be satisfied by Tug since these are Orbiter services which only require Tug transmission.

Four service categories, total data stored, rapid access storage, mass storage, and computer speed are assumed to be Orbiter peculiar services provided to payloads while in the attached mode which have no effect on Tug interface requirements.

Some average and ascent power requirements (Footnote 4) are assumed to lie within the 600W baseline Tug capability since Level B SSPD data indicates that over 50% of this power is required by Orbiter mounted monitor and control equipment rather than the spacecraft vehicle.

The remaining deficiencies were used to obtain the 92% accommodation listed on the previous chart. If Orbiter capability is increased to satisfy these requirements, accommodation should probably be achieved by direct spacecraft to Orbiter mission peculiar kits.

UNACCOMMODATED PAYLOAD REQUIREMENTS VS BASELINE

SSPD PL CODE	MISSIONS PLANNED	AVERAGE POWER 600W	PEAK POWER 900W	ASCENT POWER 600W	DOWN LINK BIT RATE (1) 16 KBS	STORED DATA BIT RATE (1) 4 KBS	TOTAL STORED ORBITER 100MB	RAPID ACCESS STORAGE ORBITER 12K WORDS	MASS STORAGE ORBITER 20K WORDS	COMPUTER SPEED ORBITER 18K ADDS/SEC
AP-01	2	1200[2]		1100[2]						
AP-02	2	1200[2]		1100[2]						
AP-03	4	1200[2]		1100[2]						
AP-05	1	1116[2]		1100[2]						
AP-06	2	1400	7400							500
AP-07	2	1400	7400							1000
AP-08	1									500
AS-02	4				430	430	11682	32	250	
AS-05	2				43	43	11682		250	
AS-16	1				102		1592		250	
CN-58	3	716								
CN-59	3		2520							
EO-09	7							12[3]		
EO-59	4							12[3]		
EO-62	4							12[3]		
LU-02	2	5000[4]	8000[4]		200					
LU-03	1	5000[4]	8000[4]		200					
LU-04	1	5000[4]	8000[4]		200					

(1) TUG DESIGN CAN ACCOMMODATE S/C REQUIREMENTS SHOWN SINCE AT MOST, THE TUG WILL PROVIDE HARNESSING ONLY.
(2) 600 WATTS IS THE BASELINE FOR POWER DELIVERED BY TUG TO S/C. THESE PAYLOAD LEVELS INCLUDE 1000 WATTS FOR USE BY ORBITER LOCATED C/O EQUIPMENT. ALLOCATIONS FOR C/O EQUIPMENT FOR OTHER PAYLOADS ARE NOT AVAILABLE.
(3) SHOWN TO JUSTIFY RECOMMENDATION TO INCREASE BASELINE FROM 10K TO 12K, PICKING UP 15 MISSIONS.
(4) S/C REQUIREMENTS APPEAR QUESTIONABLE SINCE THEY MATCH SHUTTLE CAPABILITY PER JSC 07700.

The results of the previous 12 charts have been combined to show recommended level of support that should be provided to Tug payloads. The first two columns show the parameters and the selected level of support obtained by reviewing the capabilities of Tug and Orbiter and eliminating the "tall poles" from the SSPD data. The third and fourth columns show the source documents that specify support levels available from Tug or Orbiter. The data contained in the fifth column shows the percentage of payloads that are accommodated by the recommended Tug/Orbiter baseline assuming a total of 139 missions as identified by the SSPD data. Percentage accommodations listed include 92% for Tug and 78% for Orbiter. The Orbiter percentage was obtained directly from the 12 baseline parameters with the exception of rapid access storage capability which was increased from 10 to 12K words. The greater Tug accommodation percentage was obtained by not precluding transmittal of Orbiter to payload services, even though payload demands exceed planned Orbiter capabilities. The next chart describes the rationale used to obtain 92% Tug mission accomplishment.

NASA TUG PAYLOAD AVIONICS INTERFACE REQUIREMENTS SUMMARY

PARAMETER	BASELINE	SOURCE: BASELINE TUG	SOURCE: JSC 07700	% ACCOMMODATED BY BASELINE PARAMETER	TOTAL % MISSIONS ACCOMMODATED: BY TUG	TOTAL % MISSIONS ACCOMMODATED: BY ORBITER
AVERAGE POWER	600W	X		85		
PEAK POWER	900W (1)			86		
ASCENT POWER	600W	X		94		
TOTAL ENERGY	50KWH (2)		X	91		
UP LINK RATE	2Kbs		X	100		
DOWN LINK RATE	16Kbs		X	92	92% (4)	78%
STORED DATA RATE	4Kbs (1)			96		
TOTAL STORED	100Mb (1)			95		
COMPUTER WORD	32 BITS		X	100		
RAPID ACCESS STG	12K WORDS (3)		X	94		
MASS STORAGE	20K WORDS (1)			94		
COMPUTER SPEED	18 K ADDS/SEC		X	96		

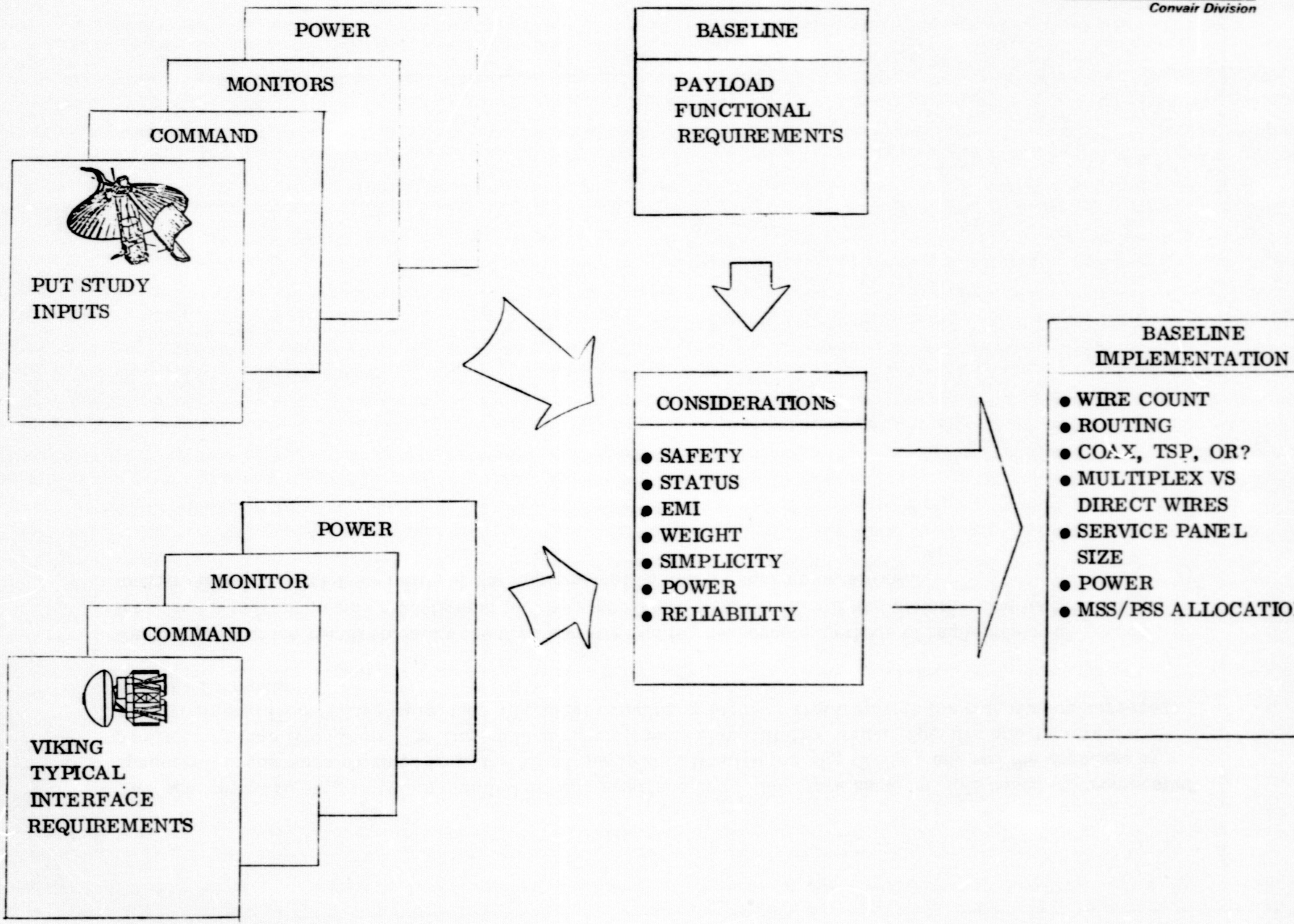
(1) SUGGESTED. PRESENT BASELINES DO NOT SPECIFY
(2) INCLUDES TUG ALLOCATION
(3) ASSUMES RECOMMENDED BASELINE
(4) ORBITER PROVISIONS FOR PAYLOAD SUPPORT MUST BE INCREASED TO ACCOMMODATE THIS PERCENTAGE

Two sources were used to obtain detailed avionic interface data. Interface requirements based on "composite" spacecraft needs were obtained from the MDAC payload utilization for Tug (PUT) study and the exchange of preliminary data from their IUS/Tug payload requirements compatibility study. Specific interface requirements obtained from Viking were used as typical complex spacecraft requirements for comparison purposes with the PUT data.

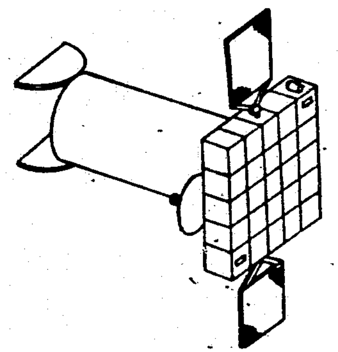
Resulting interface requirements were then investigated for reasonable methods of implementation. Each interface requirement was investigated for the appropriate consideration listed to determine its best implementation option, and description of the implementation detail requirements shown.

PAYLOAD INTERFACE IMPLEMENTATION CONSIDERATIONS

GENERAL DYNAMICS
Convair Division



MDAC DATA EXCHANGE PRELIMINARY INPUTS



TUG PAYLOAD INTERFACE REQUIREMENTS

FUNCTION	TO TUG	TO ORBITER	TO GSE
COMMANDS	86		
MONITORS	343	318	316
POWER & EXCITATION	40	16	20
COMMUNICATION LINKS			
UPLINK	4	4	4
DOWNLINK	2	2	2
VIDEO	2	2	2
TOTAL INTERFACE PINS REQUIRED	497	342	344

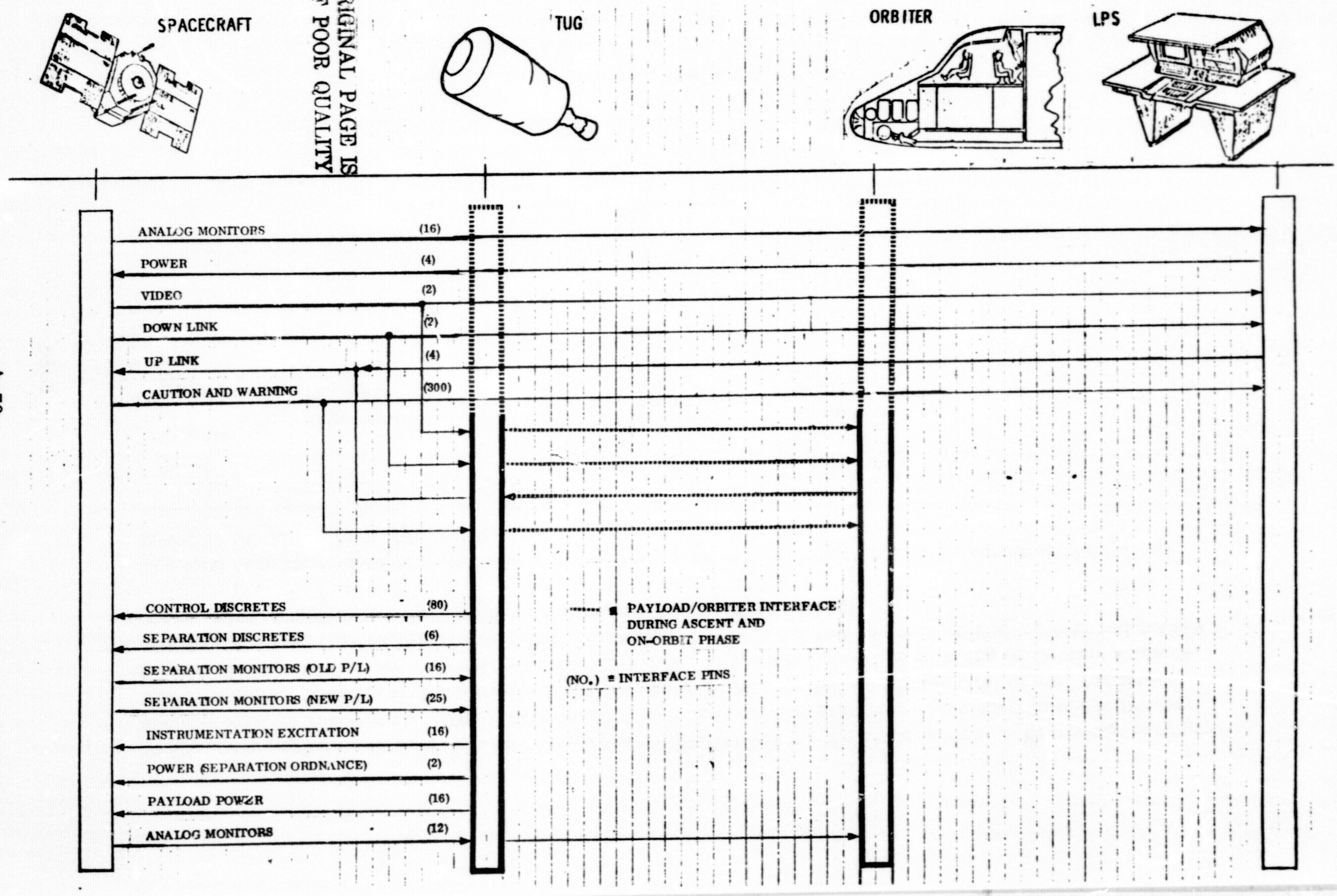
- BASED ON PUT STUDY DATA
- DIRECT WIRED (MULTIPLEXING TECHNIQUES NOT EMPLOYED)
- NO DISTINCTION BETWEEN SAFETY FUNCTIONS & MISSION STATUS FUNCTIONS WITHIN C&W CATEGORY
- SHIELD WIRES NOT ACCOUNTED FOR

A review of the results of the PUT study plus an update by MDAC personnel at a data exchange meeting between MDAC and GDC resulted in the data shown in the table. This shows that approximately 400 pins are required across the Tug/payload interface if direct wire techniques are used.

Based on preliminary agreements between MDAC and GDC, this chart shows the spacecraft interfaces to Tug, Orbiter and GSE. Approximately 330 interface pins are required to throughput analog, power, video, downlink, uplink and caution and warning data to GSE via Tug/Orbiter/GSE interfaces. During ascent video, downlink, uplink and caution and warning data are transmitted via 310 Tug and Orbiter interfaces. During Tug/spacecraft flight outside of the Orbiter approximately 170 pins are required across the Tug/spacecraft interface.

SPACECRAFT, TUG, ORBITER, GSE INTERFACES

(MDAC PRELIMINARY DATA)



Preliminary payload interface data was exchanged with MDAC during the performance of the payload services accommodations trade study. The requirements listed on the facing page were developed from preliminary MDAC results. Specific payload avionic functions are identified for the associated Orbiter and Tug interfaces including the Orbiter T-4 and T-0 prelaunch umbilicals, interconnection with Tug or Orbiter avionics, and thru Tug interface requirements. Signal quantities for each function are indicated along with redundancy needs, wire quantities per function and an allowance for multiple payloads.

The total quantity of interface pins required for each class of signal function may be conservatively determined by the following multiplication

$$\text{Total Quantity of Interface Pins} = \frac{\text{Number}}{\text{Payload}} \times (\text{Redundancy}) \times \frac{\text{Wires}}{\text{Function}} \times \text{Number of Payloads}$$

GENERAL DYNAMICS
Convair Division

PAYLOAD INTERFACE REQUIREMENTS
(Based on MDAC Data Exchange Preliminary Results)

Signal Function	Prelaunch GSE	Orbiter Avionics	Tug		Number/ Payload	Redundancy	Wires per Function	Number of Payloads	Interface PINS
			IF	Avionics					
Control Discretes			x	x	10	2	2	2	80
Uplink	T-0	x	x	x	1	Dual	1	2	4
Downlink	T-0	x	x	x	1	No	1	2	2
Analog Monitor		x	x	x	9	No	2	1	18
Separation Monitor (New P/L)			x	x	25	No	1	2	25
Video	T-4		x		2	No	1	1	2
Separation Monitor (Old P/L)					4	Dual	1	1	16
Instrumentation Excitation		x	x	x	2	Dual	2	2	16
Separation Discretes			x	x	6	No	1	1	6
Caution & Warning	T-0	x	x		30	Dual	2.5	2	300
Battery Charge	T-4		x		1	No	2	2	4
Analog Monitors	T-4		x		4	No	2	2	16
Payload Power	T-4		x	x	1	Dual	2	2	8
Separation Ordnance Power			x	x	8	No	1	1	8

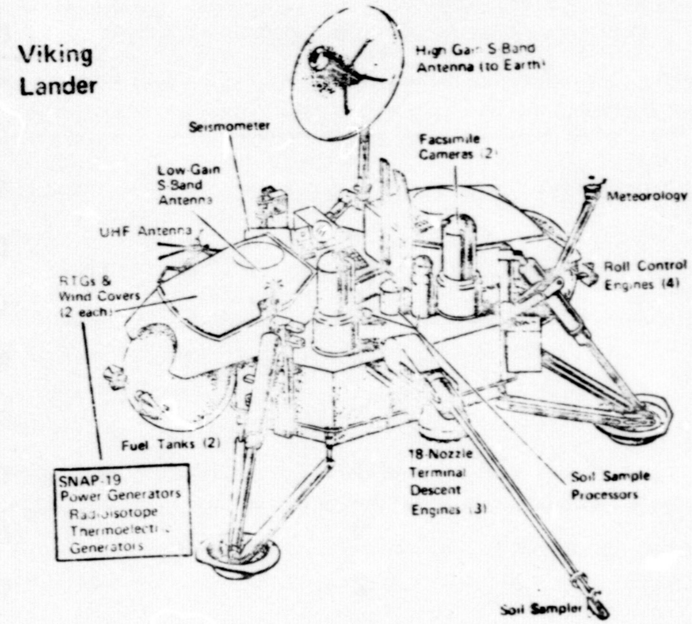
To confirm the type of data that must be transmitted across the payload interface and so provide a valid data point for comparison with the PUT data, several current payloads were investigated. These included Viking, MVM, Intelsat, Helios and MJO. The number of pins and functions being performed were determined from interface drawing of the payloads. The data were modified to reflect the difference between operating these payloads on an expendable launch vehicle and in the payload bay of the Shuttle. The following table shows the discretes from payload to Tug/Shuttle but without the redundancy that the Shuttle system will demand:

Payload:	Viking	MVM	Intelsat	Helios	MJO
No. of Pins:	102	59	20	16	76

From these data the Viking was selected as the worst case since it has the most complex interface.

The 102 pins for the Viking payload have various functions and destinations as shown in the table, i.e., 35 to Tug, 48 to Orbiter and 86 to GSE. Some of the wires go to more than one destination. These data showed good agreement with the (non-redundant) number of pins given in the PUT study for Shuttle payloads. It was concluded that the number of pins and interface functions assumed for this interface study were realistic.

VIKING - A TYPICAL COMPLEX PAYLOAD



ESTIMATED TUB/PAYLOAD INTERFACE REQUIREMENTS

FUNCTION	TO TUG	TO ORBITER	TO GSE
COMMANDS	6	7	15
MONITORS	6	30	45
POWER & EXCITATION	21	9	24
COMMUNICATION LINKS			
UPLINK			
DOWNLINK	2	2	2
VIDEO			
TOTAL INTERFACE PINS REQUIRED	35	48	86

- MISSION MARS LANDER
- LAUNCHED SEPT. 1975
- COMPLEXITY:
  - 2 STAGES
  - RTG
  - TV
  - UHF, S-BAND

VIKING UMBILICAL MONITORS

FUNCTION	CIRCUITS	PINS
TANK PRESSURES	4	4
TANK TEMPS	4	8
RTG TEMP	2	4
BIOSHIELD PRESSURE	1	1
ION PUMP CURRENT	1	2
ION PUMP VOLTAGE	1	2
TELEMETRY	1	2
BATTERY TEMPERATURES	2	4
BATTERY VOLTAGES	2	4
GYRO OUTPUTS	6	7
DC POWER	1	2
SAFE/ARM	1	1
VLC PYRO SAFE	1	2
CONNECTOR	1	2
S BAND	2	2
	30	47

This supporting data shows the Viking payload information being monitored and the number of pins required to transmit data across the payload/launch vehicle/GSE interfaces.

VIKING UMBILICAL COMMANDS

FUNCTION	CIRCUITS	PINS
PYRO POWER ON	2	2
ARM LAUNCH PYRO	1	2
FIRE LAUNCH PYRO	1	2
SAFE LAUNCH PYRO	1	1
FUNCTIONAL C/O	1	1
POWER SYSTEM RESET	1	1
PYRO SAFE	1	1
TAPE RECORDER ON	1	1
MAIN POWER CHAIN SELECT	1	2
EXTERNAL POWER SELECT	1	1
INTERNAL POWER SELECT	1	1
	12	15

This supporting data shows the payload commands being transmitted across the payload/launch vehicle/GSE interface. The number of pins required to transmit the data is also shown.

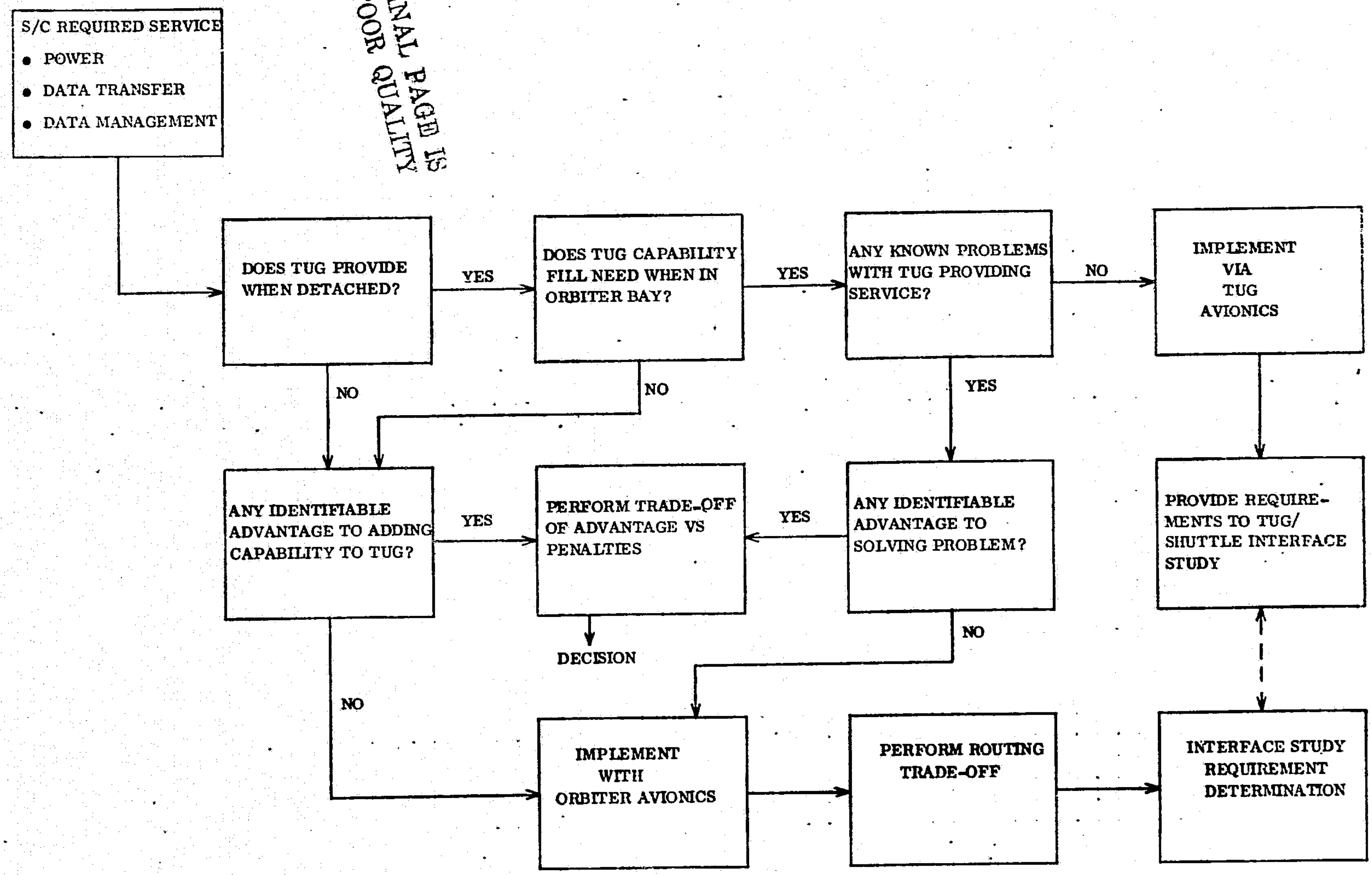
VIKING UMBILICAL POWER

FUNCTION	CIRCUIT	PINS
HAZARD MONITOR EXCITATION	1	2
C/O POWER	3	6
PYRO & B/S PRESS MON EXC	1	3
ION PUMP GROUND POWER	1	1
EXTERNAL POWER	3	6
VIS STIMULUS POWER	1	2
BATTERY CHARGE	2	2
IRTM STIMULUS ON/OFF EXC	1	2
	14	24

This supporting data shows the power functions being transmitted across the payload/launch vehicle/GSE interface. The number of pins required to transmit power is also shown.

Payload service functions may be allocated either to the Orbiter or to the Tug for implementation. The decision logic used to determine this allocation for this trade study is shown on the facing page. If the Tug is required to provide a service to the space craft during both: 1) Orbiter ascent thru deployment, and 2) after Tug/spacecraft deployment from the Orbiter, then this service was allocated to the Tug. If this service is only required during Orbiter ascent thru the Tug/spacecraft deployment phase it is allocated to the Orbiter for implementation.

PAYLOAD SERVICE ALLOCATION LOGIC FLOW



PAYLOAD SERVICE ALLOCATIONS
(ATTACHED TO ORBITER)

SERVICE	VIA ORBITER AVIONICS	VIA TUG AVIONICS
POWER		X
UPLINK		X
DOWNLINK		X
DATA STORAGE	X	
COMPUTER SUPPORT	X	
C&W	X	X

Application of the payload service allocation logic flow to the Tug class of payloads indicates that:

1) Spacecraft requirements involving data storage and computer support (data management) are best satisfied by orbiter capabilities, and

2) Spacecraft requirements involving power and data transfer may be implemented via Tug capability. During tug/spacecraft pre-deployment from the orbiter phases, for example, the Tug would receive power from the orbiter and would transfer part of this power on to the spacecraft using the same Tug/spacecraft interface employed during Tug Flight Operation.

1. TUG AVIONICS STUDY INTERFACES

   INCLUDES POWER AND ALL S/C INTERFACE REQUIREMENTS FOR DEPLOYED OPERATIONS

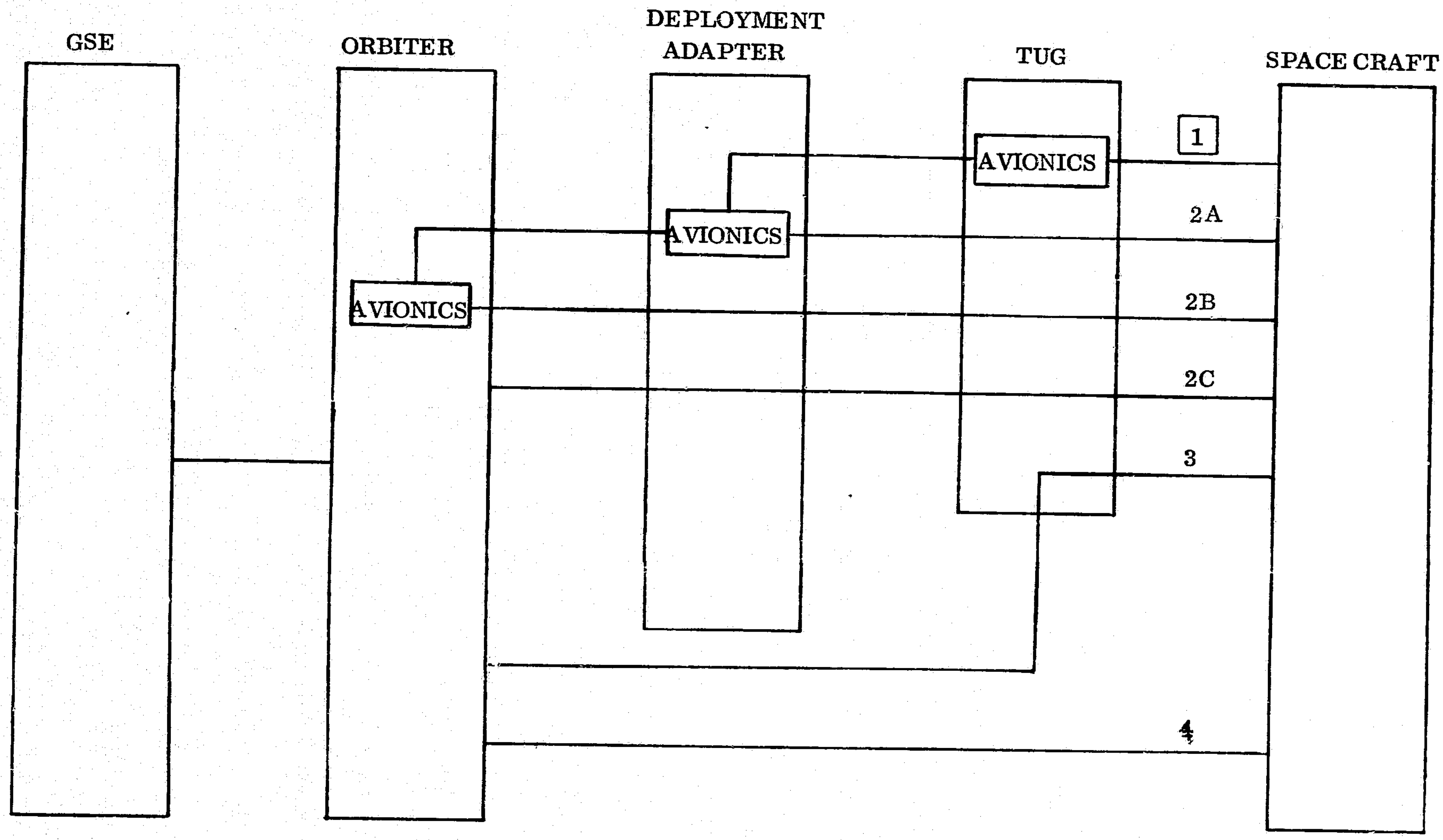
2. A GROUP OF ROUTINGS WHICH ALL RUN THE LENGTH OF THE TUG. FOR THE PURPOSES OF THIS TRADE-OFF, THEY WILL BE LUMPED TOGETHER.

3. INTERFACES WHICH WOULD UTILIZE A FORWARD DISCONNECT ON THE TUG.

4. INTERFACES WHICH WOULD UTILIZE A DISCONNECT DIRECTLY BETWEEN THE SPACECRAFT AND ORBITER.

NUMBER 4 WOULD REQUIRE THAT ALL SPACECRAFT HAVE THE IDENTICAL DISCONNECT CONFIGURATION OR THAT THE ORBITER CHANGE ON A MISSION PECULIAR BASIS. SINCE NUMBER 3 AVOIDS THESE COMPLEXITIES BY EMPLOYING A STANDARD DISCONNECT BETWEEN TUG & ORBITER, NUMBER 4 HAS BEEN DISCARDED.

SPACECRAFT/TUG/ORBITER INTERFACE ROUTING CANDIDATES



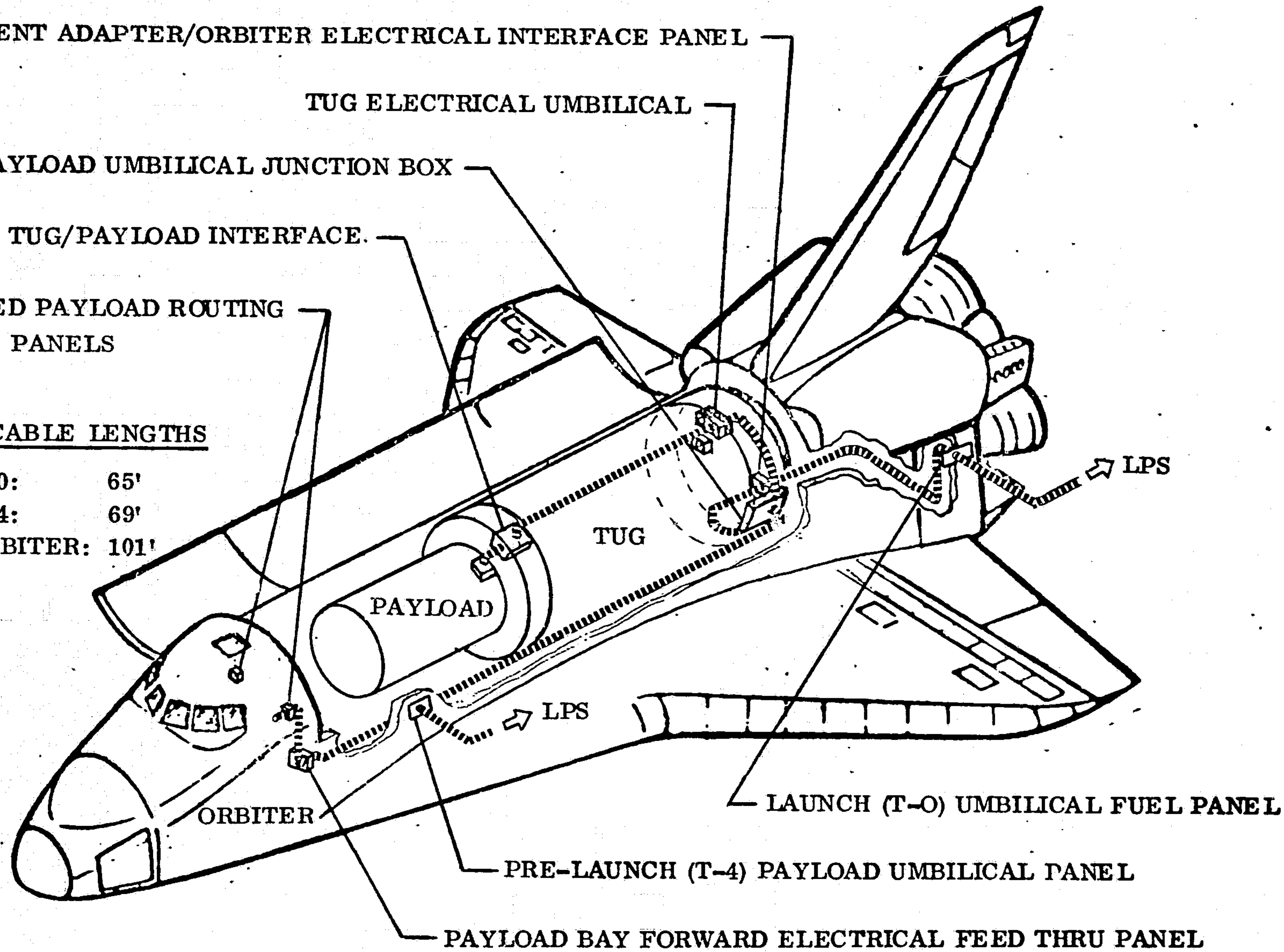
1 = AVIONICS STUDY INTERFACE

The diagram on the facing page shows a candidate payload umbilical routing route and the associated cable lengths. In this configuration payload umbilical wiring is routed from the payload/Tug interface (at the forwared end of Tug) to the Tug Deployment Adapter, where the umbilical functions split and are routed to the Orbiter avionics, the Orbiter T-4 umbilical panel, versus the Orbiter T-0 umbilical panel. Cable lengths shown indicate total length in feet from the Tug/spacecraft interface to the Orbiter panel or destination.

The diagram on the facing page shows a candidate payload umbilical routing route and the associated cable lengths. In this configuration payload umbilical wiring is routed from the payload/Tug interface (at the forwared end of Tug) to the Tug Deployment Adapter, where the umbilical functions split and are routed to the Orbiter avionics, the Orbiter T-4 umbilical panel, versus the Orbiter T-0 umbilical panel. Cable lengths shown indicate total length in feet from the Tug/spacecraft interface to the Orbiter panel or destination.

C-2

PAYLOAD ELECTRICAL UMBILICAL ROUTING
THRU TUG AFT UMBILICAL PANEL



ASSUMED CABLE LENGTHS

TUG TO T-0:	65'
TUG TO T-4:	69'
TUG TO ORBITER:	101'

The Orbiter service panel requirements in terms of payload signal functions, wire type, wire size, and number of connector pins is shown on the facing page for the Orbiter T-4 umbilical, T-0 umbilical and the payload to Orbiter MSS/PSS interface. Connector numbers and sizes (inches - diameter). Required to accommodate these signals are indicated in terms of circular connector dimensions as shown. Assuming that cross hatched areas shown in JSC 07700 No. XIV are allocated for payload use (Tug and spacecraft), then the allocated areas appear to be adequate.

ORBITER SERVICE PANEL REQUIREMENTS FOR TUG PAYLOADS (DIRECT WIRED)

GENERAL DYNAMICS
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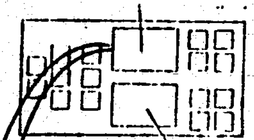
PAYLOAD ELECTRICAL DISCONNECT PANEL

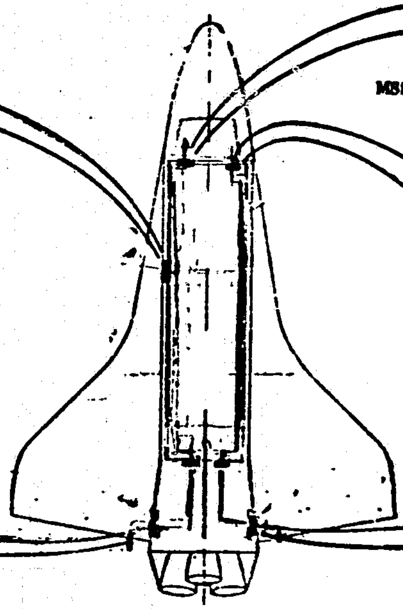


PAYLOAD FLUID DISCONNECT PANEL

FUNCTION	WITE TYPE	WIRE SIZE	PINS
DATA LINKS	COAX		2
DISCRETES			
ANALOG	TSP	22	16
POWER	TP TSP	6 22	8 4

11/2"

3"



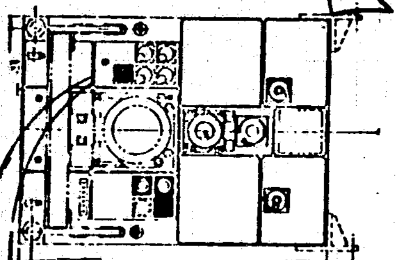
MSS/PSS INTERFACE PANELS

4" 3"

FUNCTION	WIRE TYPE	WIRE SIZE	PINS
DATA LINKS	COAX		6
DISCRETES	TSP	22	300
ANALOG	TSP	22	18
POWER	TP TSP	6 22	8 32

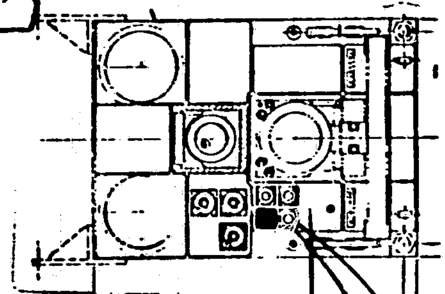
FUNCTION	WIRE SIZE	WIRE SIZE	PINS
DATA LINKS			
DISCRETES			
ANALOG			
POWER			

T-0 LAUNCH UMBILICAL FUEL PANEL



LAUNCH UMBILICAL FUEL PANEL	
LOCATING NO.	FUNCTIONAL OPERATION
521-3	P/L LH_2 FILL & DRAIN
521-4	P/L LH_2 TANK VENT
521-5	GH_2 FILL ACCUM
521-23	P/L COLD He FILL
521-25	T0-ELECT

T-0 LAUNCH UMBILICAL OXIDIZER PAYLOAD PANEL



LAUNCH UMBILICAL OXIDIZER PAYLOAD PANEL	
LOCATING NO.	FUNCTIONAL OPERATION
531-6	P/L LO_2 FILL, DRAIN & DUMP
531-7	P/L GO_2
531-9	P/L AMBIENT He FILL
531-16	T-0 ELECT

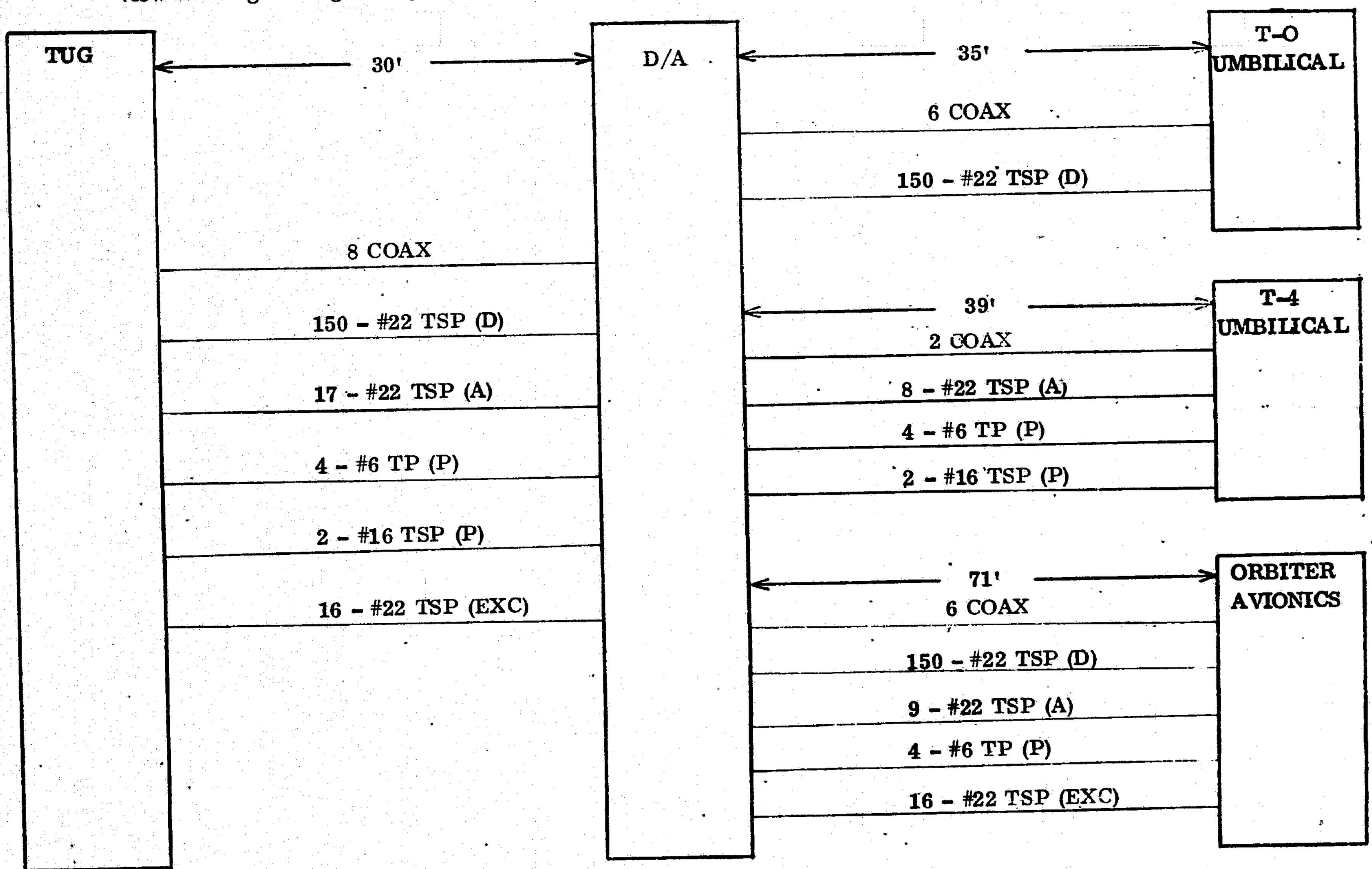
4"

FUNCTION	WIRE TYPE	WIRE SIZE	PINS
DATA LINKS	COAX		6
DISCRETES	TSP	22	300
ANALOG			
POWER			

FUNCTION	WIRE TYPE	WIRE SIZE	PINS
DATA LINKS			
DISCRETES			
ANALOG			
POWER			

CABLING METHOD 1 D: DIRECT WIRING THROUGH TUG, INTERFACING VIA THE DEPLOYMENT ADAPTER

The model shown will be used for trade-off calculations. The dimensions shown are from the isometric view showing routing through a Tug aft disconnect. The wire counts are based on MDAC preliminary data.

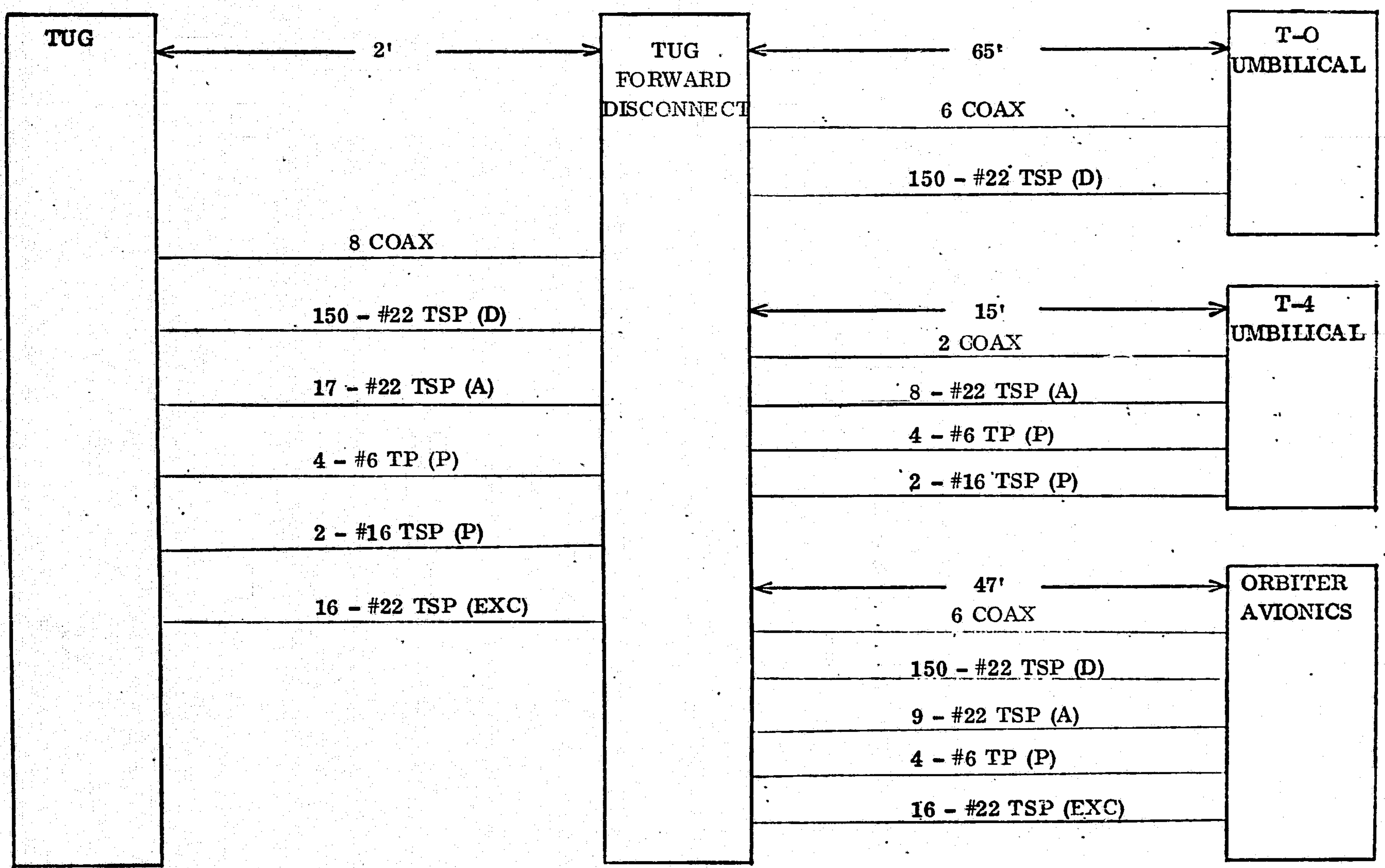


CODE:

TP = TWISTED PAIR
TSP = TWISTED SHIELDED PAIR
(D) = DISCRETE
(A) = ANALOG
(P) = POWER
(EXC) = EXCITATION (INSTRUMENTATION)
MX = MULTIPLEX

CABLING METHOD 2 D: DIRECT WIRING INTERFACING VIA A FORWARD DISCONNECT ON THE TUG

For this model, the dimensions are from the isometric showing routing through a Tug forward disconnect.



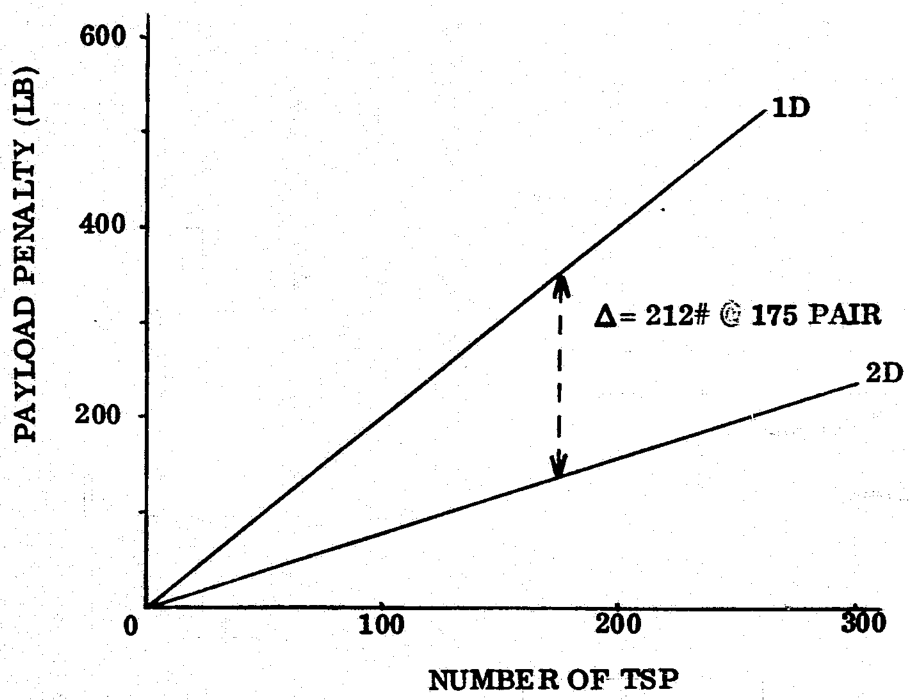
CODE:

TP = TWISTED PAIR
TSP = TWISTED SHIELDED PAIR
(D) = DISCRETE
(A) = ANALOG
(P) = POWER
(EXC) = EXCITATION (INSTRUMENTATION)
MX = MULTIPLEX

PAYLOAD PENALTY VS NUMBER OF TSPs

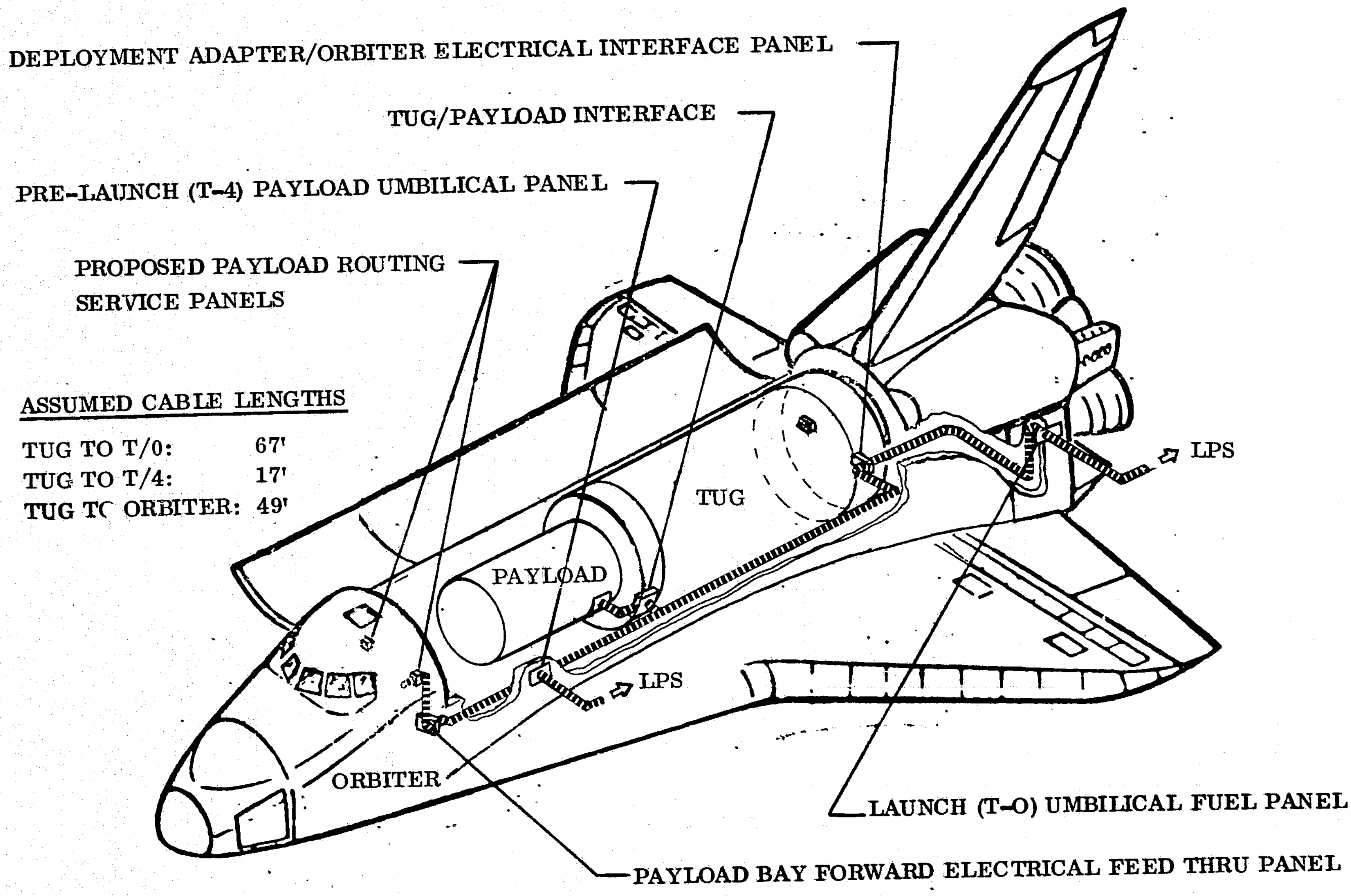
- 1D: ROUTED VIA DEPLOYMENT ADAPTER
- 2D: ROUTED VIA TUG FORWARD DISCONNECT

Using the dimensions from the models of the foregoing pages, this plot was produced to demonstrate the sensitivity of payload weight to the number of #22 twisted shielded pairs in the harness servicing payloads. For the models considered, the number of TSPs is approximately 175. About 212 lb of payload weight can be realized by utilizing a forward disconnect on the Tug. Additional weight savings (about 7 lb) are achieved in shortening the #6 power lines.



An alternate payload umbilical routing concept via a Tug forward disconnect was investigated for possible weight savings. The diagram on the facing page shows this candidate concept and the associated cable lengths from the Tug/spacecraft interface to the Orbiter T-0 umbilical panel, T-4 umbilical panel, and Orbiter MSS/PSS areas, respectively.

PAYLOAD ELECTRICAL UMBILICAL ROUTING THRU TUG FWD UMBILICAL PANEL



ASSUMED CABLE LENGTHS

TUG TO T/0:	67'
TUG TO T/4:	17'
TUG TO ORBITER:	49'

The Orbiter service panel requirements in terms of payload signal functions, wire type, wire size, and number of connector pins is shown on the facing page for the Orbiter T-4 umbilical, T-0 umbilical and the payload to Orbiter MSS/PSS interface. Connector numbers and sizes (inches - diameter) required to accommodate these signals are indicated in terms of circular connector dimensions as shown. Assuming that cross hatched areas shown in JSC 07700 No. XIV are allocated for payload use (Tug and spacecraft), then the allocated areas appear to be adequate.

Because the numbers of power and data line functions do not decrease as a result of employing multiplexing techniques, significant decreases in total connector size and area requirements are not indicated.

GENERAL DYNAMICS
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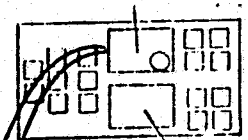
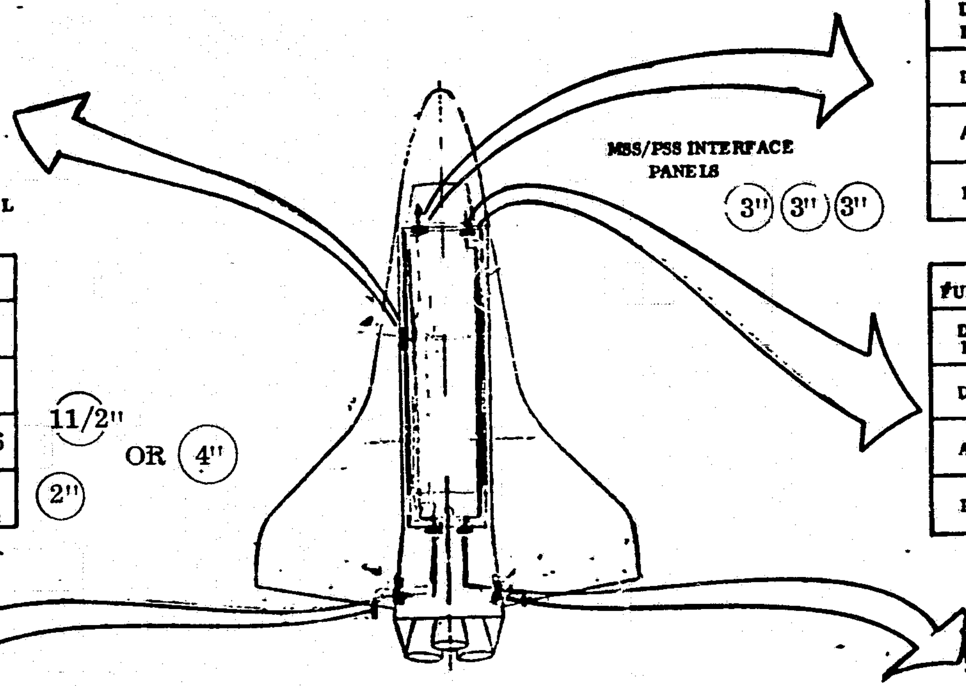
ORBITER SERVICE PANEL REQUIREMENTS FOR TUG PAYLOADS (MULTIPLEXED)



FUNCTION	WITE TYPE	WIRE SIZE	PINS
DATA LINKS	COAX		2
DISCRETES			
ANALOG	TSP	22	16
POWER	TP TSP	6 16	8 4

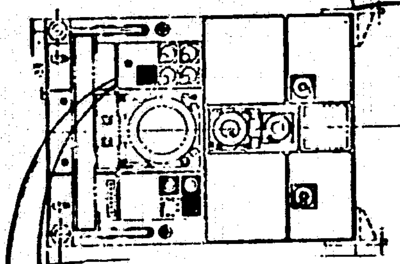
11/2'' OR 4''

2''



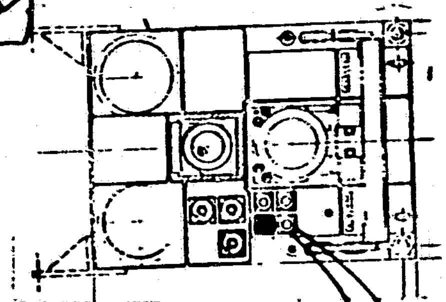
FUNCTION	WIRE TYPE	WIRE SIZE	PINS
DATA LINKS	COAX TSP	 22	6 6
DISCRETES	TSP	22	150
ANALOG			
POWER	TSP TP	6 22	8 32

FUNCTION	WIRE SIZE	WIRE SIZE	PINS
DATA LINKS			
DISCRETES			
ANALOG			
POWER			



LAUNCH UMBILICAL FUEL PANEL	
LOCATING NO.	FUNCTIONAL OPERATION
521-3	P/L LH_2 FILL & DRAIN
521-4	P/L LH_2 TANK VENT
521-5	GH_2 FILL ACCUM
521-23	P/L COLD He FILL
521-25	T0-ELECT

LAUNCH UMBILICAL OXIDIZER PAYLOAD PANEL	
LOCATING NO.	FUNCTIONAL OPERATION
531-6	P/L LO_2 FILL, DRAIN & DUMP
531-7	P/L GO_2
531-9	P/L AMBIENT He FILL
531-16	T-0 ELECT



3''

FUNCTION	WIRE TYPE	WIRE SIZE	PINS
DATA LINKS	COAX TSP	 22	6 6
DISCRETES	TSP	22	76
ANALOG			
POWER			

FUNCTION	WIRE TYPE	WIRE SIZE	PINS
DATA LINKS			
DISCRETES			
ANALOG			
POWER			

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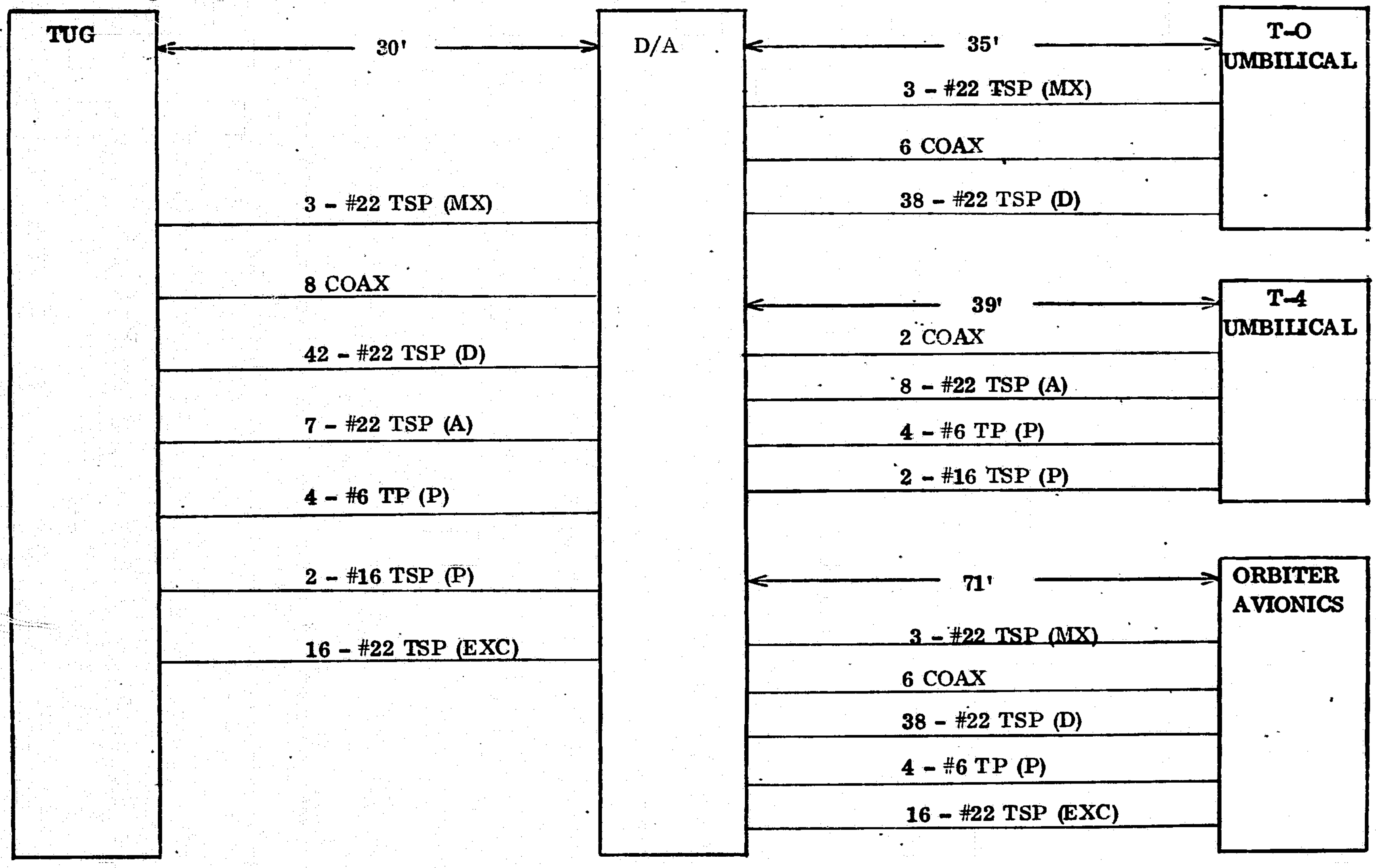
CABLING METHOD 1 M: WIRING THROUGH TUG, INTERFACING VIA DEPLOYMENT ADAPTER WITH MULTIPLEXING

This model uses the dimensions of method 1 D but adds a triply redundant multiplexing scheme with three #22 twisted shielded pairs to eliminate 75% of the direct wired signal pairs. The power, excitation, and high frequency signals are not compatible with the multiplexing scheme under consideration.

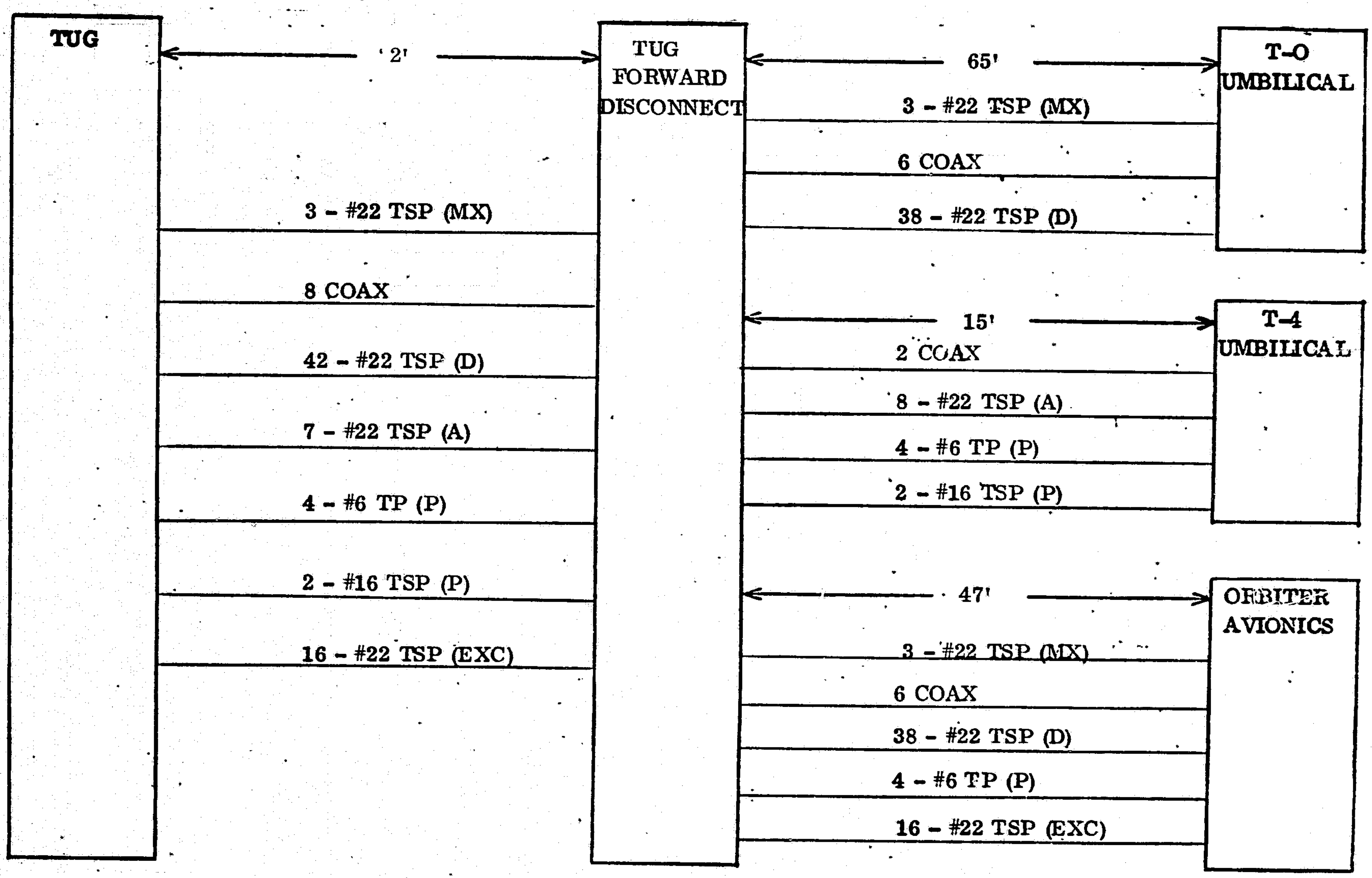


CODE:

TP = TWISTED PAIR
TSP = TWISTED SHIELDED PAIR
(D) = DISCRETE
(A) = ANALOG
(P) = POWER
(EXC) = EXCITATION (INSTRUMENTATION)
MX = MULTIPLEX

CABLING METHOD 2 M: INTERFACING VIA A FORWARD DISCONNECT ON THE TUG, WITH MULTIPLEXING

This method also has multiplexed 75% of the signal pairs, but again routes the cabling through a Tug forward disconnect.



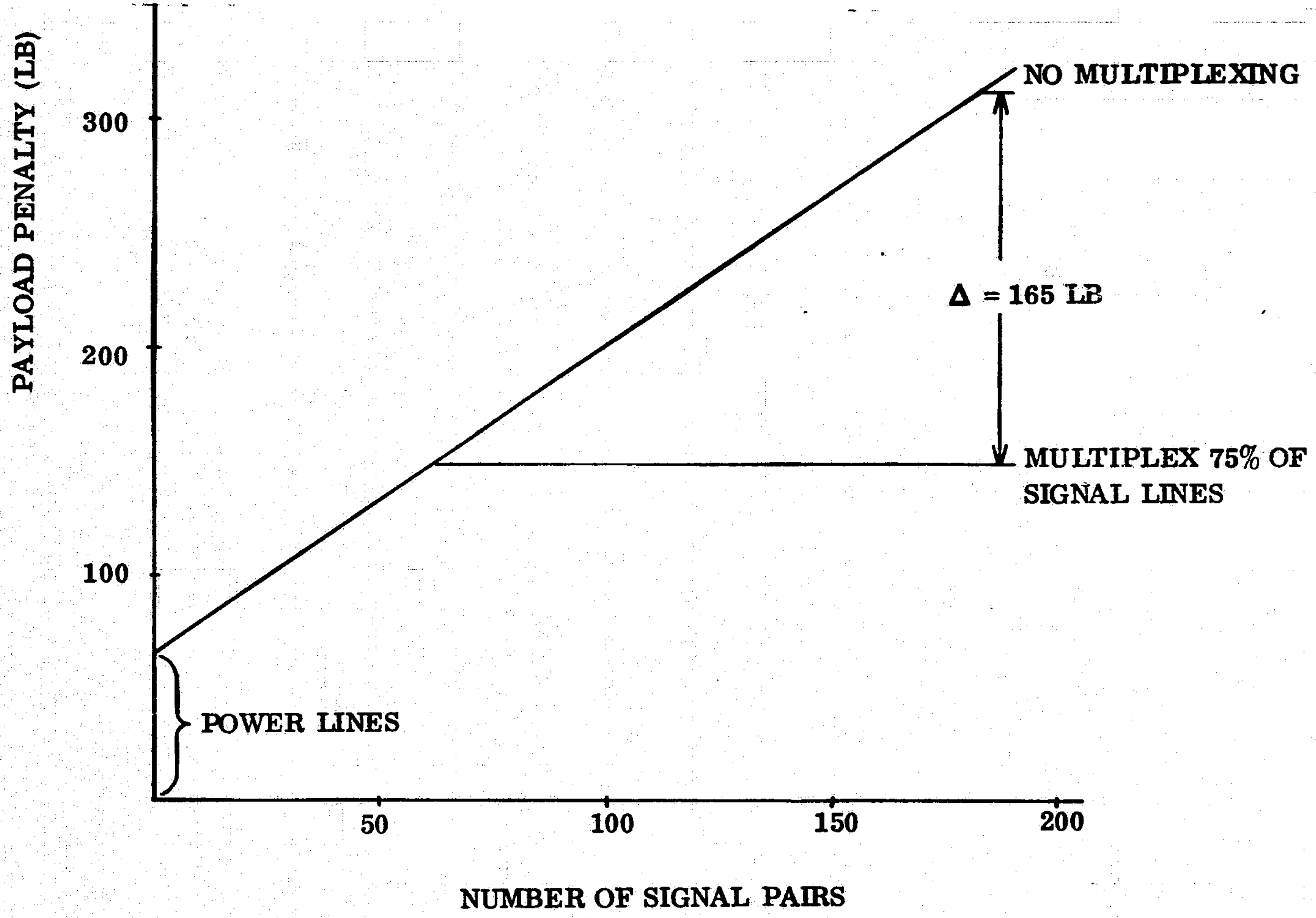
CODE:

TP = TWISTED PAIR
TSP = TWISTED SHIELDED PAIR
(D) = DISCRETE
(A) = ANALOG
(P) = POWER
(EXC) = EXCITATION (INSTRUMENTATION)
MX = MULTIPLEX

PAYLOAD WEIGHT PENALTY CAN BE REDUCED BY MULTIPLEXING

- o CONSIDERS TUG WEIGHT ONLY
- o ROUTING VIA DEPLOYMENT ADAPTER

Potential payload weight savings that can be achieved by multiplexing techniques are presented. The data is based on Method 1 dimensions and considers the payload savings due to the difference in Tug weight only. The payload weight penalty is 2.62 × Tug weight differentials. The penalty due to four No. 6 twisted pair power lines is shown for reference.



PAYLOAD PENALTY VS ROUTING/SIGNAL MULTIPLEXING

- FORWARD DISCONNECT WITH MULTIPLEXING RESULTS IN LEAST PAYLOAD WEIGHT PENALTY.
- REAR DISCONNECT USING DIRECT HARDWIRES RESULTS IN GREATEST PAYLOAD WEIGHT PENALTY.

	DESCRIPTION			
METHOD	MULTIPLEX (75% TSP)	VIA DEPLOYMENT ADAPTER	VIA TUG FORWARD DISCONNECT	PAYLOAD PENALTY (LB)
2 M	YES	NO	YES	0
2 D	NO	NO	YES	76
1 M	YES	YES	NO	151
1 D	NO	YES	NO	373

Using the foregoing models of cabling methods, with and without multiplexing, cable weights for the major cable segments were calculated, using -2.62 and -0.36 as the payload weight partials for the Tug and Orbiter respectively. For this analysis only the #22 twisted shielded pair and the #6 power cable weights were calculated since they account for about 97% of the total weights. The net penalties were:

Method	Penalty (lbs)
1D	442
2D	145
1M	220
2M	69

The table normalizes to the panalty of method 2M to show the net penalty incurred by selection of other methods.

AVIONIC PAYLOAD INTERFACE RECOMMENDATIONS

- DIFFERENTIATE BETWEEN SAFETY CRITICAL AND MISSION CRITICAL FUNCTIONS

- MULTIPLEX NON-SAFETY CRITICAL FUNCTIONS

  EXAMPLES:
  - TAPE RECORDER STATUS
  - BATTERY CHARGE COMMAND
  - TV C/O COMMAND

- WIRE DIRECT & MULTIPLEX (BACK-UP) SAFETY CRITICAL FUNCTIONS

  EXAMPLES:
  - PRESSURE VESSELS TEMPERATURES/PRESSURES
  - RTG UNIT TEMPERATURES
  - ARM/SAFE FUNCTION STATUS

- DISABLE GROUPS OF PAYLOAD SAFETY FUNCTIONS WHILE IN ORBITER PAYLOAD BAY BY POWER BUS ARM/SAFE TECHNIQUE

  EXAMPLES:
  - TUG/PAYLOAD DEPLOYMENT/SEPARATION COMMANDS
  - PROPELLANT VALVES/CONTROL COMMANDS
  - PAYLOAD STRUCTURAL DEPLOYMENT FUNCTIONS (SOLAR PANELS ETC.)

Because of redundancy, and multiple payload requirements, a relatively small number of payload service functions (including data links, monitor and control discretes, analog data, and power) may require the implementation of a relatively large interface umbilical to Tug, Orbiter, and GSE. The chart on the facing page lists several recommendations which could reduce the size of this interface resulting in Tug/Orbiter weight savings and smaller more compact umbilical interface mechanism requirements.

Current NASA traffic models do not specify multiple payload combinations or provide time phased data on multiple payloads. With 92 earth observation and communications satellites launched between 1984 and 1991, numerous possible combinations of 2-3 payloads exist.

In order to minimize the impact of multiple payloads on number of orbiter interfaces, consideration should be given to: manifolding fluids lines on the payload side of the interface; time sharing between payloads for communications, control, caution & warning, and similar functions; and branching power busses on the payload side of the interface.

It is recommended that: traffic models be revised to reflect multiple payload combinations; and that the subject of reduction of Tug/orbiter interfaces with multiple payloads be addressed in the MDC "IUS/Tug Payload Requirements Compatibility Study."

Velocity packages can be treated in the same fashion as multiple payloads.

MULTIPLE PAYLOAD IMPACT

- CURRENT TRAFFIC MODELS DO NOT DESIGNATE MULTIPLE PAYLOAD COMBINATIONS
- MULTIPLE PAYLOAD COMBINATIONS ARE LIMITED TO EARTH OBSERVATION AND COMMUNICATION SATELLITES
  - COMBINATIONS OF 2-3 POSSIBLE
  - 92 LAUNCHED BETWEEN 1984 & 1991
  - 15 LAUNCHED IN 1988
- MULTIPLE PAYLOAD IMPACT CAN BE MINIMIZED
  - MANIFOLD FLUIDS LINES ON PAYLOAD SIDE OF INTERFACE - (FILL, DRAIN, DUMP, VENT)
  - USE TIME SHARING BETWEEN PAYLOADS FOR COMMUNICATIONS, CONTROL, CAUTION & WARNING, ETC.
  - BRANCH POWER BUS ON PAYLOAD SIDE OF INTERFACE
- TRAFFIC MODELS SHOULD BE REVISED TO REFLECT MULTIPLE PAYLOAD COMBINATIONS
- REDUCTION IN NUMBER OF TUG/ORBITER INTERFACES FOR MULTIPLE PAYLOADS SHOULD BE ADDRESSED IN MDC "IUS/TUG PAYLOAD REQUIREMENTS COMPATIBILITY STUDY"
- VELOCITY PACKAGE CAN BE TREATED SAME AS MULTIPLE PAYLOAD

APPENDIX B

STRUCTURAL SUPPORT REACTION AND DYNAMIC ANALYSIS BACKUP DATA

B.1 Convair Memo STI 74-37, 30 October 1974

Sent to: Hal Lambert
Johnson Space Center
Houston, Texas

and

Ed Stluka
Marshall Space Flight Center
Huntsville, Alabama

Subject: Information of Orbiter Reactions Caused by Tug for both JSC and MSFC Acceleration Models

Reaction Exceedance Comparison
Using MSFC & JSC Accelerations

Since all support configurations exhibited substantial exceedance (Σ_{Min} = 184.0K) using accelerations per MSFC 68M00039-1 to compute reactions, a comparison with reactions computed using accelerations per JSC 07700, Vol. XIV, Rev. C, was conducted at NASA request. This comparison is summarized in the adjacent table.

The accumulated exceedance using JSC accelerations is less in all 21 support configurations with substantial reductions in most.

Two configurations (4-1, 4-2) exhibit zero exceedance using JSC accelerations and $\Sigma < 50K$ for seven others. The five best configurations, however, are either doubly redundant or require dual hydraulic load balancing systems to decouple the redundant supports and provide statical determinacy. Consequently, they tend to be heavier, more costly, and lower performing than the four previously recommended systems.

As indicated, the four recommended systems all slipped in the overall rankings and in each case the exceedance is determined almost entirely by high X-reactions (which are nonetheless lower than those due to MSFC accelerations).

The selection of a preferred Tug support arrangement and the extent of the associated Orbiter modification, if any, depends upon the adoption of a realistic set of cargo bay accelerations for subsequent structural interface analyses. However, it is not clear that either of the above acceleration sets is appropriate. For example, the JSC accelerations do not include any allowance for dynamic response of the cargo (Tug + spacecraft) yet infinite rigidity is unattainable and hence some dynamic response will occur and allowance must be made for it. Conversely, the MSFC accelerations include allowance for cargo dynamic response but these same data have been specified for both LST and the Tug, whose response characteristics are probably quite different, and their applicability to Tug is therefore uncertain. To further complicate the problem, Rockwell International in their 17 July 1974 payload accommodations brochure, has established the objectives and analysis schedule for determining dynamic response of several Shuttle payloads but Tug is not included among them!

It is essential that prediction of Tug/SC dynamic response be undertaken immediately so that a suitable set of cargo bay accelerations can be determined, permitting selection of a preferred support arrangement based on further assessment of Tug and Orbiter impacts.

GENERAL DYNAMICS
Convair Division

REACTION EXCEEDANCE COMPARISON USING MSFC & JSC ACCELERATIONS*

CONFIGURATION		EXCEEDANCE COMPARISON			
		MSFC*		JSC*	
NO.	REDUN-DANCY	Σ	RANKING	Σ	RANKING
1-1	0	344.9	16	218.1	18
1-2		243.4	6	41.6	9
2-1	1	193.4	2	184.8	17
2-2		213.0	3	29.2	8
2-3		287.6	12	143.8	14
3-1	1	341.5	15	17.3	7
3-2		282.4	11	16.5	6
3-3		409.5	18	121.3	11
4-1	2	266.0	9	0	1
4-2		239.0	4	0	1
4-3		266.4	10	92.4	10
5-1	2	250.6	7	14.6	5
5-2		184.0	1	3.2	3
5-3		242.6	5	8.2	4
6-1	0	430.7	19	172.7	16
6-2		365.7	17	125.7	12
7-1	0	578.0	20	242.9	20
7-2		617.2	21	250.9	21
8-1	1	338.6	14	229.7	19
8-2		256.0	8	160.6	15
8-3		317.4	13	130.6	13

*REF: MSFC 68M00039-1, FIGURE 6
JSC 07700, VOL XIV, REV "C," TABLE 7.6

OBSERVATIONS

- EXCEEDANCE (Σ) LOWER IN ALL CONFIGURATIONS WITH JSC ACCELERATIONS
- RECOMMENDED CONFIGURATIONS RANK WORSE WITH JSC ACCELERATIONS
- 2 CONFIGURATIONS EXHIBIT REACTIONS WITHIN ORBITER CAPABILITY WITH JSC ACCELERATIONS
  - $\Sigma < 50K$ IN 9 CONFIGURATIONS
  - REDUNDANCY = 2 FOR TOP 5 CONFIGURATIONS

BUT

- JSC ACCELERATIONS DO NOT INCLUDE ALLOWANCE FOR TUG/SC DYNAMIC RESPONSE
- DYNAMIC RESPONSE IS REAL — SOME ALLOWANCE NECESSARY
- MSFC ACCELERATIONS INCLUDE RESPONSE ALLOWANCE BUT APPLICABILITY TO TUG UNCERTAIN

TUG/SC DYNAMIC RESPONSE PREDICTION/IMPACT ASSESSMENT REQUIRED ASAP

24104CVE0682

Support Reactions Exceed Orbiter Capability

Each of the 21 candidate support concepts was analyzed to determine its maximum support reactions. The limit payload bay accelerations specified in MSFC 68M00039-1 were used in determining critical load conditions and the associated support reactions. To obtain a measure of goodness for candidate screening, the computed reactions were compared with Orbiter capability as defined in JSC 07700, Vol. XIV, Rev. C. Unfortunately the specified Orbiter capability was exceeded by every candidate support system for most or all of its reactions.

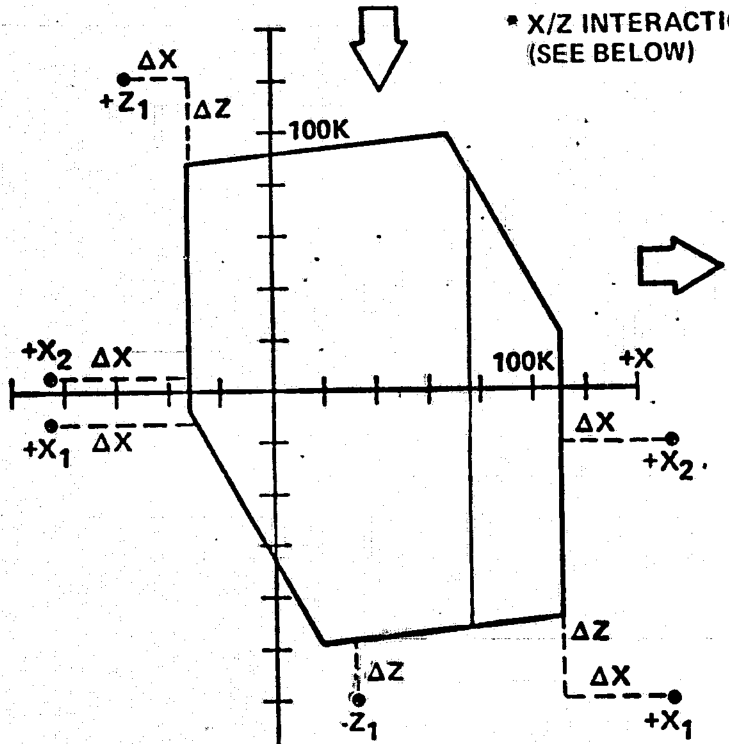
To determine the relative unacceptability of the candidates, a technique was developed in which the excessive reaction magnitude was accumulated for each concept. This process is shown on the facing page. Computed maximum candidate reactions were tabulated vs Orbiter capability and, in the case of X and Z reactions at a single support point, were also plotted on a graph containing the allowable X/Z interaction envelope. The value by which the computed reaction magnitude exceeded the allowable capability was determined for each reaction. The summation (accumulation) of each concept's reaction exceedance is tabulated and ranked on the facing page. Configurations exhibiting the lowest exceedance are judged best from the standpoint of Orbiter compatibility, since they tend to imply least potential Orbiter impact. However, an absolute correlation between ranking and Orbiter weight and/or cost impact is unlikely since the various elements of exceedance occur in different proportions among the 21 configurations and the nature and extent of the weight impact associated with each is unique.

GENERAL DYNAMICS
Convair Division

SUPPORT REACTIONS EXCEED ORBITER CAPABILITY

CONFIG		REACTIONS (1,000 LB)								
		X_1 & X_2		Y_1	Z_1		Z_2		Z_3	
		+	−	±	+	−	+	−	+	−
1-1	MAG	152.0	85.5	57.4	120.6	120.6	60.4	52.2	103.2	112.3
	ORB CAP	*	*	56	*	*	*	*	52	67

* X/Z INTERACTION (SEE BELOW)



ACCUMULATED EXCEEDANCE	
X ONLY	−
X IN X/Z	216.0
Y	1.4
Z ONLY	96.5
Z IN X/Z	31.0
Σ	344.9

COMPARATIVE ASSESSMENT		
CONFIG.	Σ	RANKING
1-1	344.9	16
1-2	243.4	6
2-1	193.4	2
2-2	213.0	3
2-3	287.6	12
3-1	341.5	15
3-2	282.4	11
3-3	409.5	18
4-1	266.0	9
4-2	239.0	4
4-3	266.4	10
5-1	250.6	7
5-2	184.0	1
5-3	242.6	5
6-1	430.7	19
6-2	365.7	17
7-1	578.0	20
7-2	617.2	21
8-1	338.6	14
8-2	256.0	8
8-3	317.4	13

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Candidate Tug/Orbiter structural support arrangements were generated to utilize the acceptable Orbiter fitting and Tug frame locations identified in the preceding chart. Three categories of support arrangements are included: 1) statically determinate systems which are non-redundant and conform to the contemplated Orbiter support technique, 2) single redundant/load balanced systems which reduce Tug torsion and bending, and 3) doubly redundant/load balanced system which offer further reduction in asymmetry of flight loads. The detail description of each candidate shown in the table below is arranged to correspond with the arrangement sketch location on the facing page.

STATICALLY DETERMINATE SYSTEMS

NO.	DESCRIPTION	ADAPTER	SUPPORT STATIONS X_1, X_2	Y_1	Y_2	Z_1	Z_2	Z_3	Z_4
1-1	GDC STSS PREFERRED	YES	1246	1249	-	1246	1246	951	-
1-2		NO	1187	1181	-	1187	1187	951	-
6-1	NASA BASELINE	YES	1246	1128	-	1128	1128	951	-
6-2		NO	1187	1128	-	1128	1128	951	-
7-1	GDC STSS ALTERNATIVE	YES	1246	951	-	951	951	1246	-
7-2		NO	1197	951	-	951	951	1187	-

SINGLY REDUNDANT/LOAD BALANCED SYSTEMS

NO.	DESCRIPTION	ADAPTER	SUPPORT STATIONS X_1, X_2	Y_1	Y_2	Z_1	Z_2	Z_3	Z_4
2-1	DUAL FWD Z + AFT Y FWD Z BALANCED	YES	1246	1243	-	1246	1246	951	951
2-2		NO	1187	1181	-	1187	1187	951	951
2-3		YES	1246	1128	-	1128	1128	951	951
3-1	DUAL Y X BALANCED	YES	1246	1243	951	1246	1246	951	-
3-2		NO	1187	1181	951	1187	1187	951	-
3-3		YES	1246	1128	951	1128	1128	951	-
8-1	DUAL FWD Z + FWD Y AFT Z BALANCED	YES	1246	951	-	951	951	1246	1246
8-2		NO	1187	951	-	951	951	1187	1187
8-3		YES	1246	951	-	951	951	1128	1128

DOUBLY REDUNDANT/LOAD-BALANCED SYSTEMS

NO.	DESCRIPTION	ADAPTER	SUPPORT STATIONS X_1, X_2	Y_1	Y_2	Z_1	Z_2	Z_3	Z_4
4-1	DUAL FWD Z, DUAL Y X & FWD Z BALANCED	YES	1246	1249	951	1246	1246	951	951
4-2		NO	1157	1181	951	1187	1187	951	951
4-3		YES	1246	1125	951	1128	1128	951	951
5-1	DUAL FWD Z, DUAL Y X & AFT Z BALANCED	YES	1246	1243	951	951	951	1246	1246
5-2		NO	1187	1181	951	951	951	1187	1187
5-3		YES	1246	1128	951	951	951	1128	1128

CANDIDATE SUPPORT ARRANGEMENTS

GENERAL DYNAMICS
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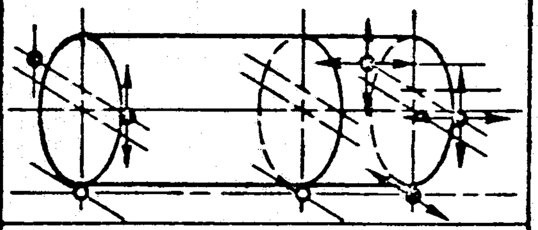
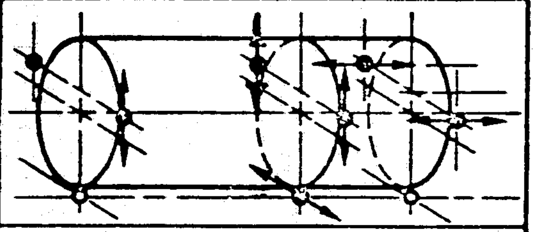
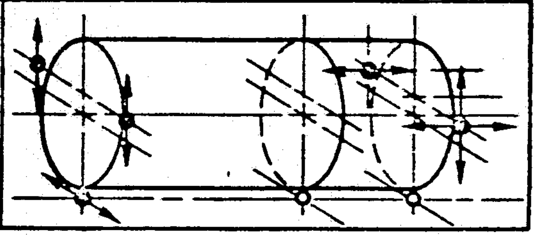
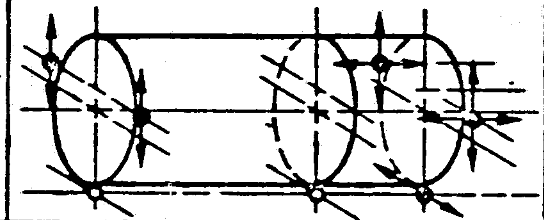
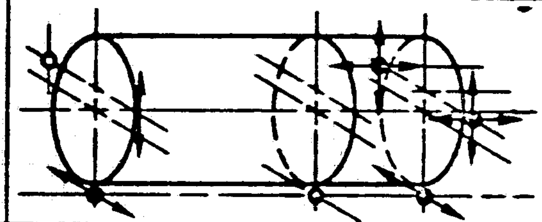
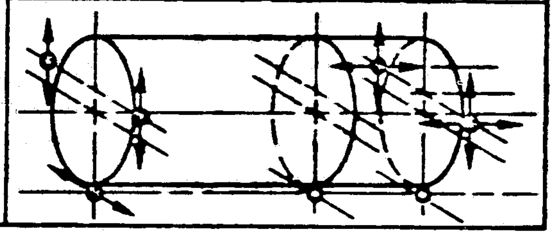
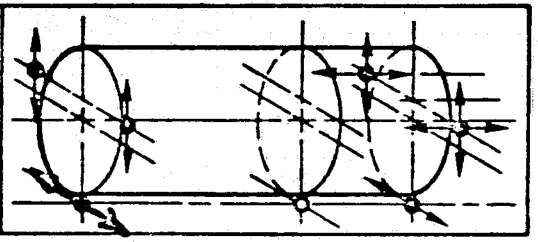
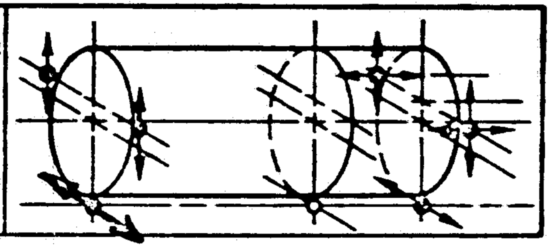
STATICALLY DETERMINATE SYSTEMS

NO.	DESCRIPTION	ARRANGEMENT
1	GDC STSS PREFERRED	
6	NASA BASELINE	
7	GDC STSS ALTERNATIVE	

SINGLE REDUNDANT/LOAD BALANCED SYSTEMS

NO.	DESCRIPTION	ARRANGEMENT
2	DUAL FWD Z + AFT Y FWD Z BALANCED	
3	DUAL Y X BALANCED	
8	DUAL FWD Z + FWD Y AFT Z BALANCED	

DOUBLY REDUNDANT/LOAD BALANCED SYSTEMS

NO.	DESCRIPTION	ARRANGEMENT
4	DUAL FWD Z & DUAL Y X & FWD Z BALANCED	
5	DUAL FWD Z & DUAL Y X & AFT Z BALANCED	

19094CVE0406

Support locations included in the candidate evaluation analysis were limited to those compatible with identified Orbiter provisions and baseline Tug configuration. Primary Orbiter structural attachment locations on the payload bay longerons and keel were obtained from JSC 07700 Vol XIV Rev C. Tug geometry considerations were used to further screen available support fitting locations. All Orbiter identified support stations between 951 and 1249, except 1010 and 1069, were found to be acceptable. Stations 1010 and 1069 are located adjacent to the Tug hydrogen tank, which allows insufficient space for moment carrying Tug support frames.

The nomenclature used to identify various support reactions does not agree with those of the NASA/MSFC baseline Tug documentation. This discrepancy occurred since the selection and preliminary analysis of candidate support concepts was started prior to receiving the NASA information.

GENERAL DYNAMICS
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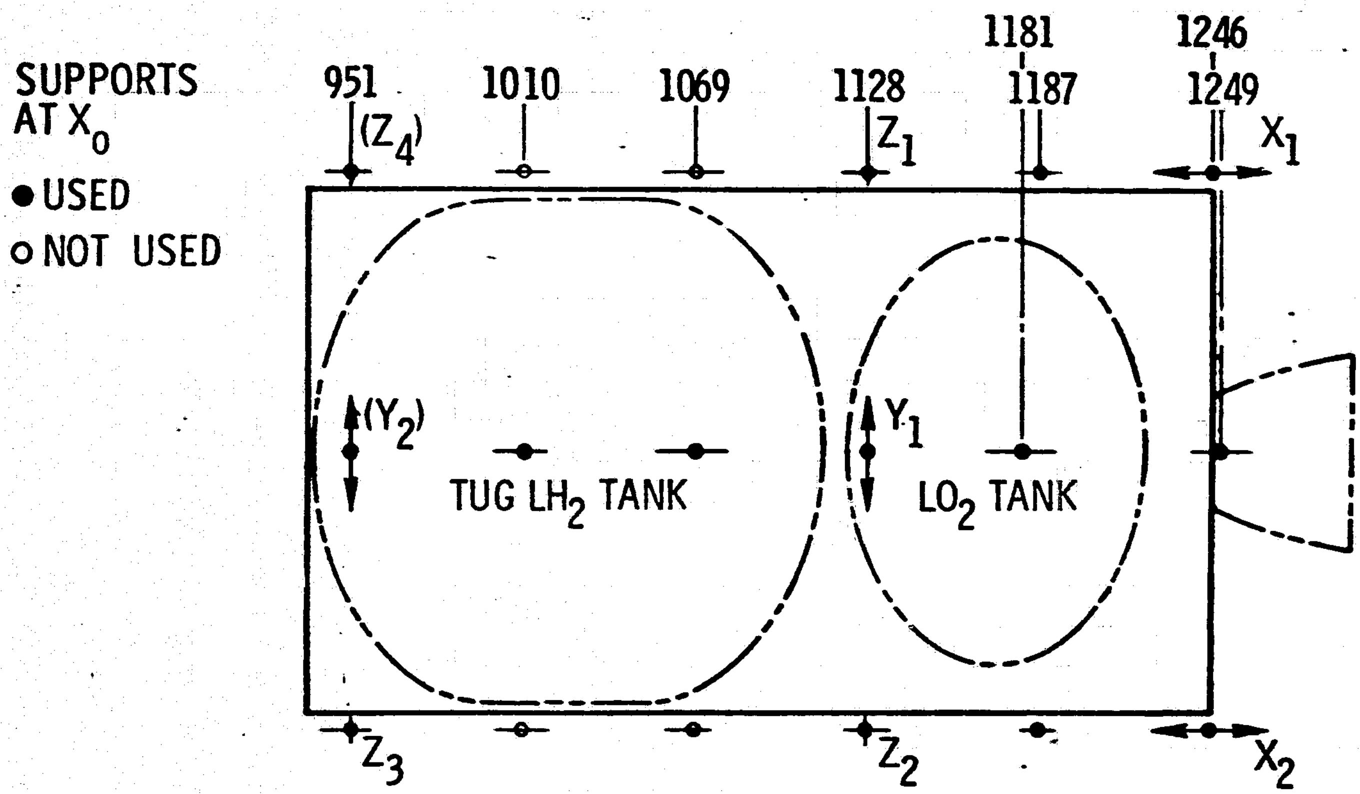
CANDIDATE SUPPORT LOCATIONS & SUPPORT REACTION DESIGNATIONS
Looking Down



- SUPPORTS AT X_0 1010, 1069 NOT USED
- Z_1/Z_2 AFT OF $Z_3/(Z_4)$, AS SHOWN, EXCEPT IN SUPPORT CONCEPTS WITH SINGLE AFT Z OR BALANCED AFT Z's
- SUPPORT REACTION DESIGNATIONS DO NOT AGREE WITH NASA BASELINE (DWG 10M23300)

19094CVE0405

WEIGHT/CG/INERTIA DATA FOR REACTIONS USING JSC ACCELS.

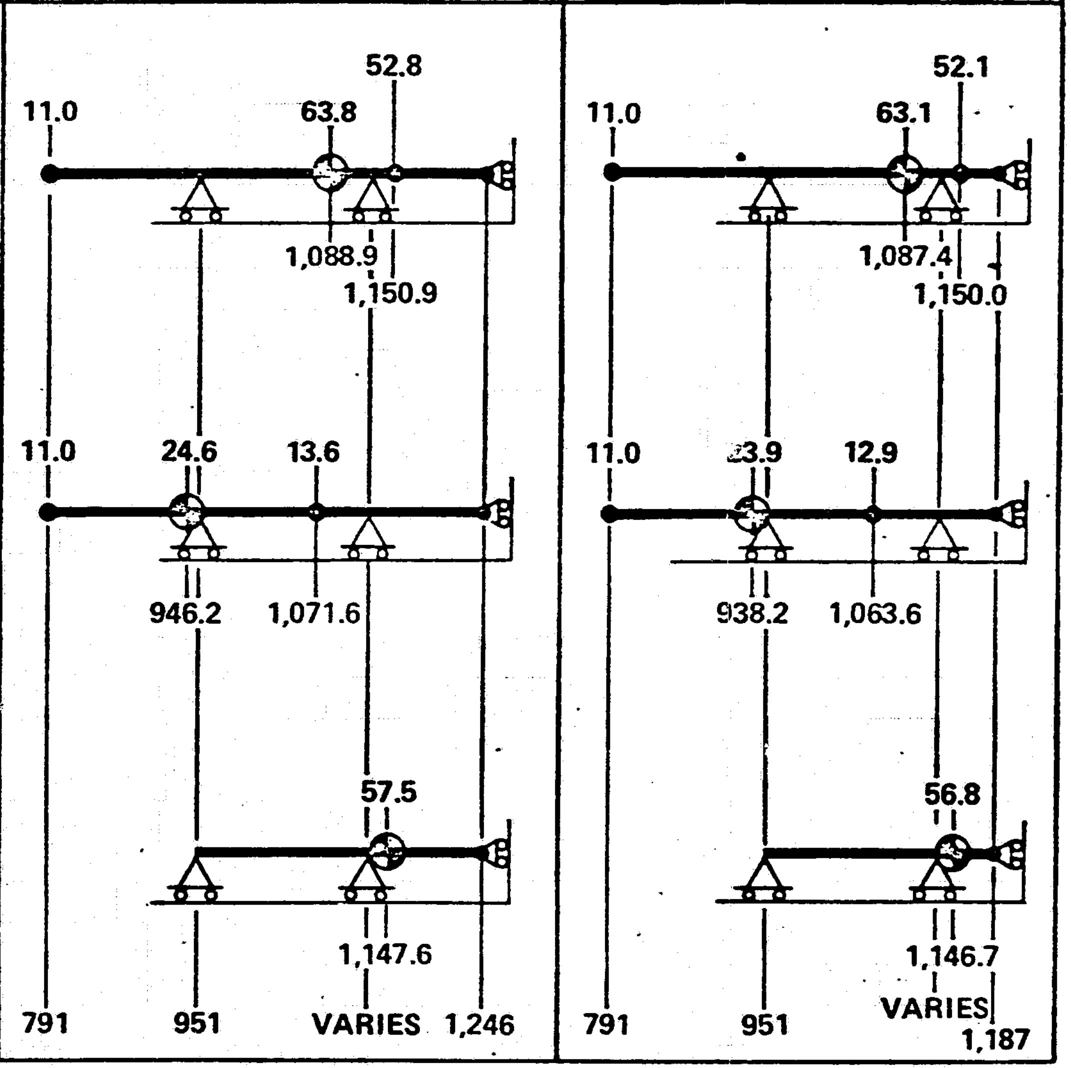
REF: "WT & CG CHARACTERISTICS FOR CRITICAL LOAD CONDITIONS"

CONFIGURATION		MISSION		W	X_{CG}	I_X	I_Y	I_Z
FAMILY	DASH NO.	TYPE	PHASE	(lb)	(in)		(In-sec^2-in)	
All	-1, -3	Deploy	Ascent	63808	1088.88	190926	4007606	4007606
		Deploy	Abort Descent (w/fuel)	24620	946.24	190926	1804279	1804279
		Retrieve	Ascent	57487	1147.58	80609	753607	753607
All	-2	Deploy	Ascent	63100	1087.43	176725	3968674	3968674
		Deploy	Abort Descent	23912	938.18	176725	1656649	1656649
		Retrieve	Ascent	56779	1146.70	66408	736450	736450

WEIGHT & CG CHARACTERISTICS FOR CRITICAL LOAD CONDITIONS

GENERAL DYNAMICS
Convair Division

MISSION TYPE	MISSION PHASE	CRITICAL CONDITIONS	WEIGHT (KLB) & CG (ORBITER STA) WITH ADAPTER	WEIGHT(KLB & CG (ORBITER STA) WITHOUT ADAPTER
DEPLOY	ASCENT	LAUNCH RELEASE, SRM CUTOFF/ SEPARATION		
DEPLOY	ABORT DESCENT (WITH FUEL)	RE-ENTRY		
RETRIEVE	ASCENT	LAUNCH RELEASE, SRM CUTOFF/ SEPARATION		



19094CVE0475

ORBITER CAPABILITY "EXCEEDANCE"

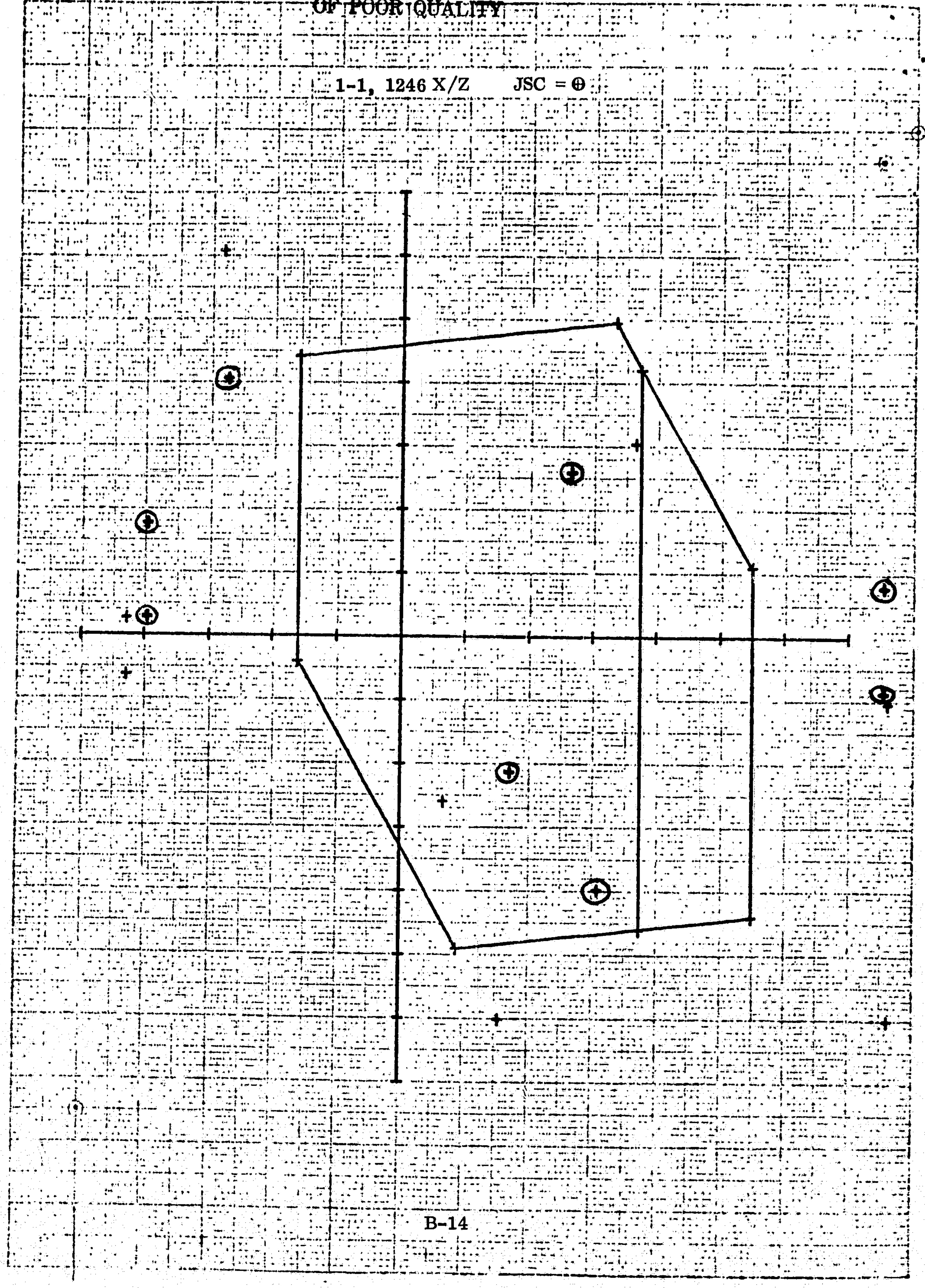
JSC Accels (a + α)

CONFIG.	ACCUMULATED Δ - REACTION						RANKING	
	X-ONLY	X IN X/Z	Y	Z-ONLY	Z IN X/Z	Σ	OVERALL	IN-FAMILY
1-1	-	176.2	8.6	10.3	23.0	218.1	18	2
1-2	-	31.2	0	10.4	0	41.6	9	1
2-1	-	176.2	8.6	0	0	184.8	17	3
2-2	-	29.2	0	0	0	29.2	8	1
2-3	51.4	-	0	92.4	-	143.8	14	2
3-1	-	0	0	10.3	7.0	17.3	7	2
3-2	-	0	0	10.4	6.1	16.5	6	1
3-3	0	-	0	121.3	-	121.3	11	3
4-1	-	0	0	0	0	0	1	1
4-2	-	0	0	0	0	0	1	1
4-3	0	-	0	92.4	-	92.4	10	3
5-1	-	0	0	14.6	0	14.6	5	3
5-2	-	0	0	3.2	0	3.2	3	1
5-3	0	-	0	8.2	-	8.2	4	2
6-1	51.4	-	0	121.3	-	172.7	16	2
6-2	8.6	-	0	117.1	-	125.7	12	1
7-1	34.7	112.2	0	43.0	53.0	242.9	20	1
7-2	22.6	124.1	0	47.1	57.1	250.9	21	2
8-1	-	139.4	0	14.6	75.7	229.7	19	3
8-2	-	90.7	0	3.2	66.7	160.6	15	2
8-3	122.4	-	0	8.2	-	130.6	13	1

REACTIONS (1000 LB)

Config.		X_1 & X_2 +	X_1 & X_2 −	Y_1 ±	Y_2 ±	Z_1 +	Z_1 −	Z_2 +	Z_2 −	Z_3 +	Z_3 −	Z_4 +	Z_4 −
1-1A		113.5	54.2	64.6	-	81.0	81.0	52.1	44.0	53.1	76.2	-	-
1-1	JSC	150.7	79.4	64.6	-	79.8	79.8	51.1	42.9	53.1	76.2	-	-
	MSFC	149.4	85.5	57.4	-	120.6	120.6	60.4	52.2	103.2	112.3	-	-
	ORB CAP	*	*	56.0	-	*	*	*	*	52.0	67.0	-	-
1-2A		112.4	54.3	63.9	-	80.1	80.1	67.5	57.4	42.4	77.4	-	-
1-2	JSC	126.5	65.1	63.9	-	80.1	80.1	67.5	57.4	42.4	77.4	-	-
	MSFC	138.8	75.6	56.8	-	120.2	120.2	90.5	80.4	81.4	100.0	-	-
	ORB CAP	*	*	67.0	-	*	*	*	*	52.0	67.0	-	-
	JSC												
	MSFC												
	ORB CAP												

NOTES:
1. Reactions are those applied to the Orbiter by Tug.
2. Sign convention is: +X Aft; +Y RT, Looking Forward; +Z Up.
3. "ORB CAP" values from "Orbiter Support Fitting Capabilities" table.
4. * X/Z Interaction, see attached plot


1-1, 1246 X/Z JSC = ⊕

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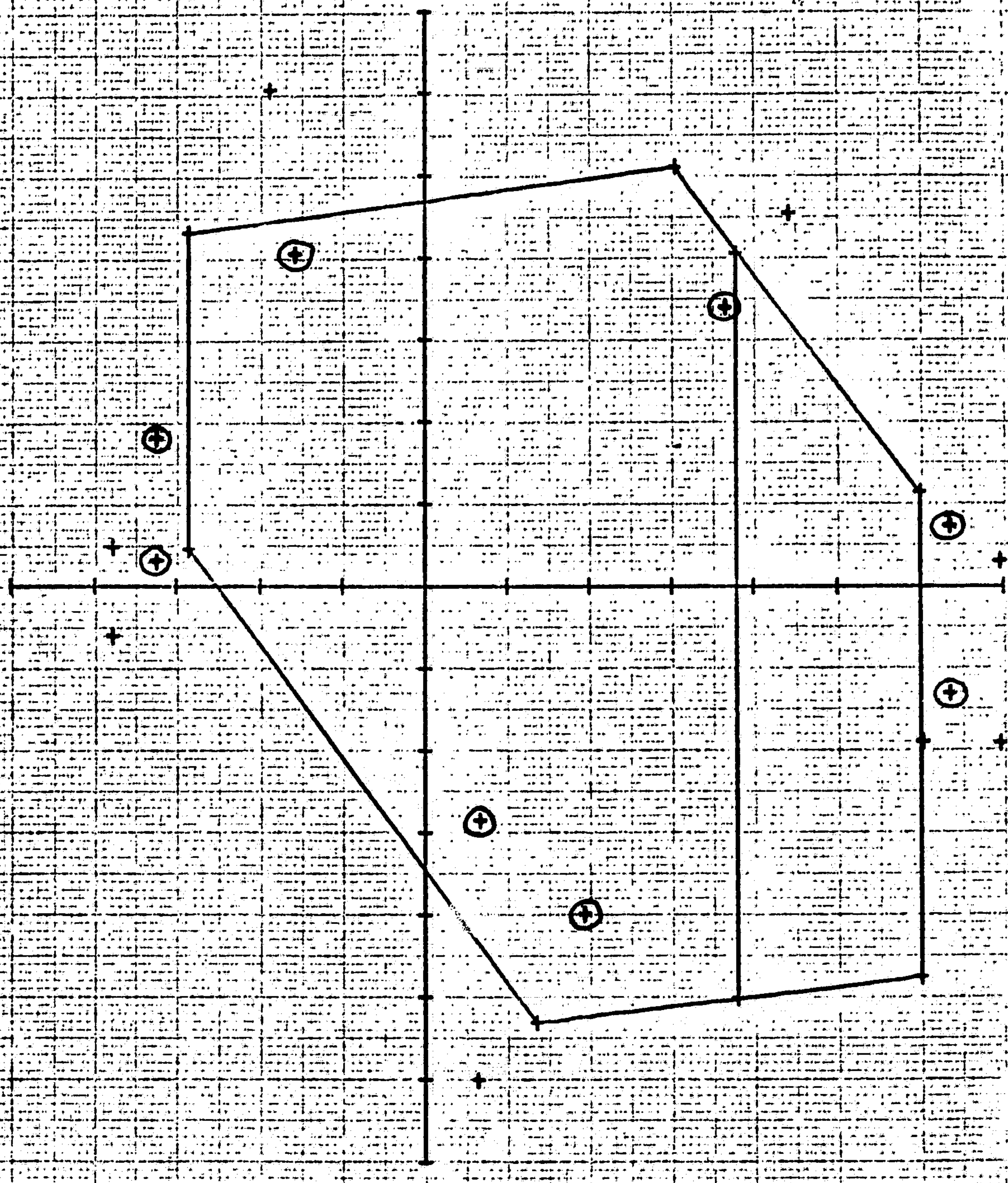
1-2, 1187 X/Z JSC = ⊕

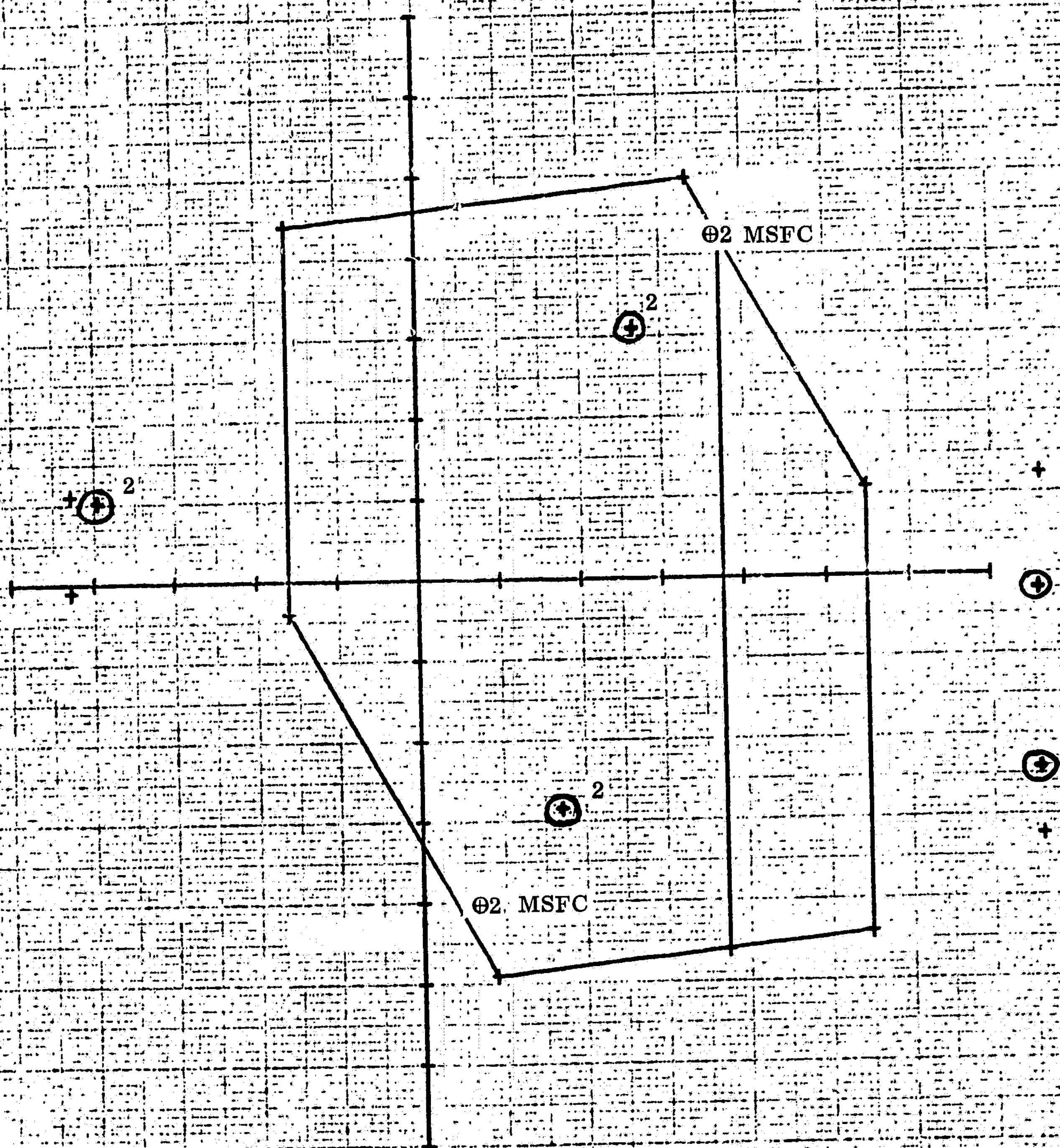


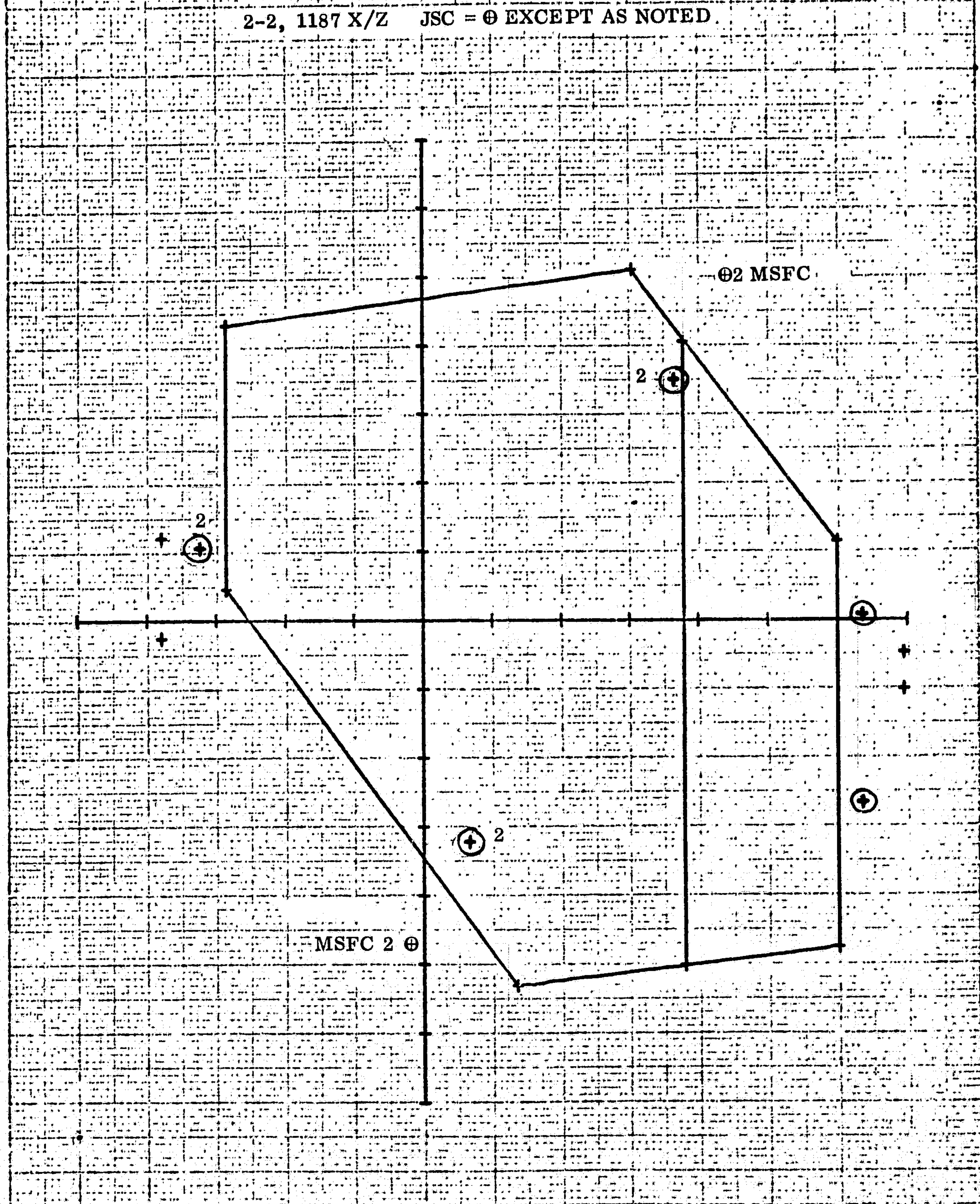
REACTIONS (1000 LB)

Config.		X_1 & X_2		Y_1	Y_2	Z_1		Z_2		Z_3		Z_4	
		+	-	±	±	+	-	+	-	+	-	+	-
2-1A		113.5	54.2	64.6	-	62.5	58.4	62.5	58.4	26.6	38.1	26.6	38.1
2-1	JSC	150.7	79.4	64.6	-	61.4	57.3	61.4	57.3	26.6	38.1	26.6	38.1
2-1	MSFC	151.9	85.5	57.4	-	84.5	80.4	84.5	80.4	51.6	56.1	51.6	56.1
2-1	ORB CAP	*	*	56.0	-	*	*	*	*	52.0	67.0	52.0	67.0
2-2A		112.4	54.3	63.9	-	69.7	64.6	69.7	64.6	21.2	38.7	21.2	38.7
2-2	JSC	126.5	65.1	63.9	-	69.7	64.6	69.7	64.6	21.2	38.7	21.2	38.7
2-2	MSFC	138.8	75.7	56.8	-	99.3	94.3	99.3	94.3	40.7	50.0	40.7	50.0
2-2	ORB CAP	*	*	67.0	-	*	*	*	*	52.0	67.0	52.0	67.0
2-3	JSC	113.5	54.2	64.6	-	84.5	77.7	84.5	77.7	21.7	39.7	21.7	39.7
2-3	MSFC	132.9	69.1	57.4	-	126.7	119.9	126.7	119.9	22.2	50.0	22.2	50.0
2-3	ORB CAP	110.0	32.0	72.0	-	51.0	65.0	51.0	65.0	52.0	67.0	52.0	67.0

NOTES:
1. Reactions are those applied to the Orbiter by Tug.
2. Sign convention is: +X Aft; +Y RT, Looking Forward; +Z Up.
3. "ORB CAP" values from "Orbiter Support Fitting Capabilities" table.
4. * X/Z Interaction, see attached plot

2-1, 1246 X/Z JSC = ⊕ EXCEPT AS NOTED

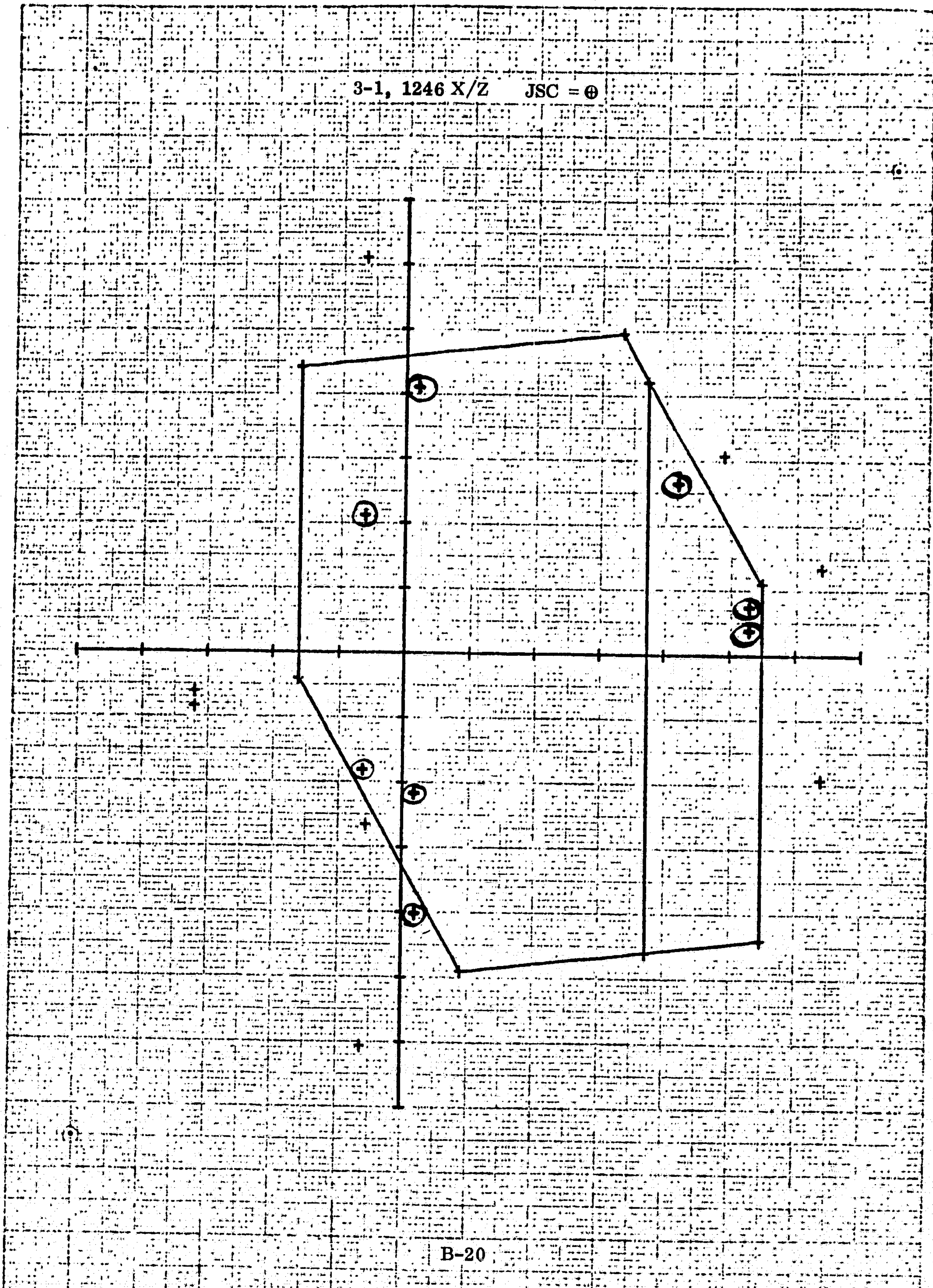


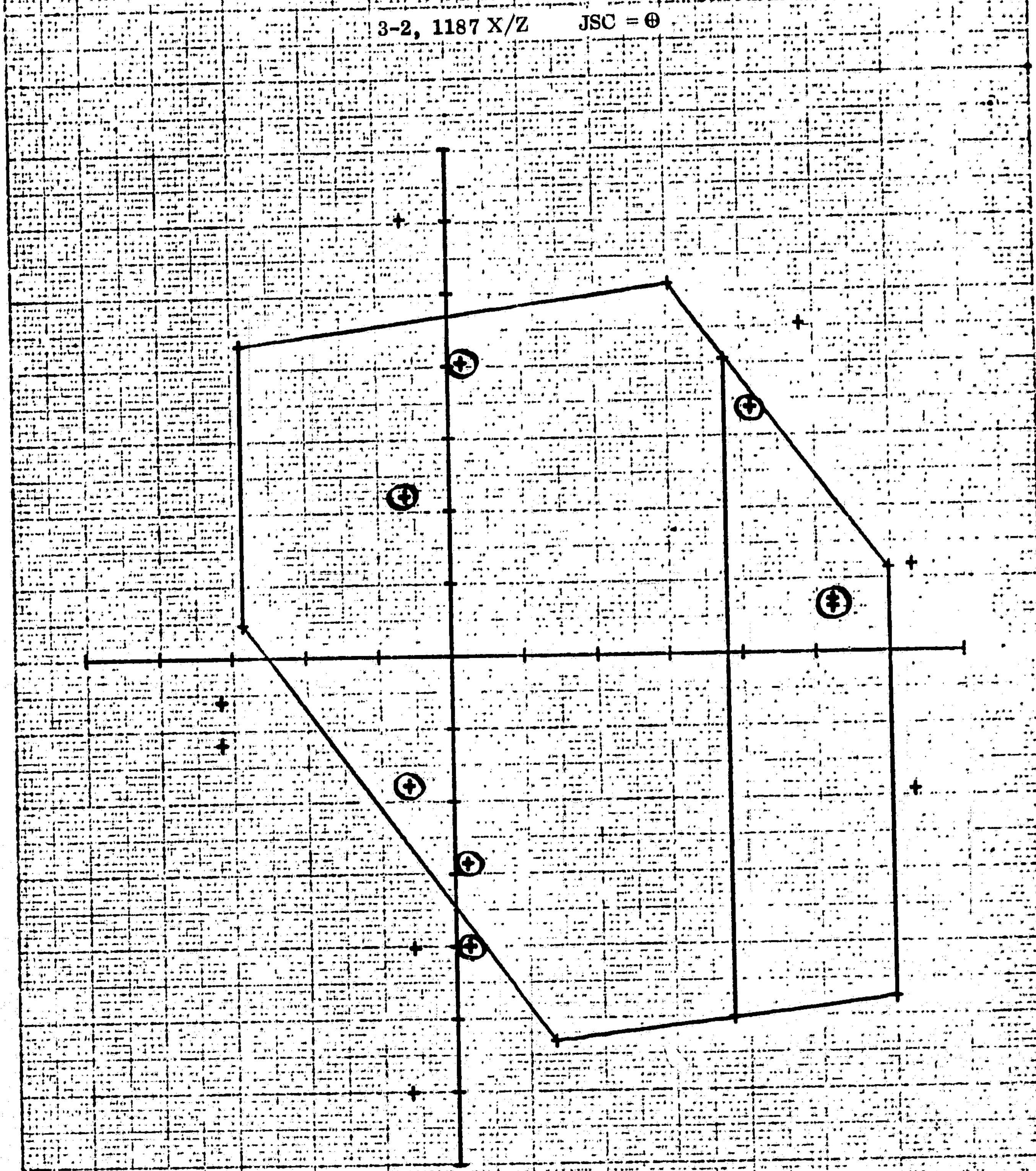

2-2, 1187 X/Z JSC = ⊕ EXCEPT AS NOTED
⊕2 MSFC
2
2
2
MSFC 2 ⊕

REACTIONS (1000 LB)

Config.		X_1 & X_2 +	X_1 & X_2 −	Y_1 ±	Y_2 ±	Z_1 +	Z_1 −	Z_2 +	Z_2 −	Z_3 +	Z_3 −	Z_4 +	Z_4 −
3-1	JSC	105.3	13.0	38.7	44.3	81.0	81.0	52.1	44.0	53.1	76.2	-	-
	MSFC	127.6	63.8	34.1	30.9	121.5	121.5	61.2	53.0	103.2	112.3	-	-
	ORB CAP	*	*	56.0	70.0	*	*	*	*	52.0	67.0	-	-
3-2	JSC	104.1	12.7	49.3	45.9	80.1	80.1	67.5	57.4	42.4	77.4	-	-
	MSFC	126.2	63.1	43.5	23.1	120.2	120.2	90.5	80.4	81.4	100.0	-	-
	ORB CAP	*	*	67.0	70.0	*	*	*	*	52.0	67.0	-	-
3-3	JSC	105.3	13.0	65.2	47.8	81.0	81.0	96.3	82.6	43.5	79.4	-	-
	MSFC	127.6	63.8	57.5	17.7	121.5	121.5	144.0	130.4	44.3	100.0	-	-
	ORB CAP	110.0	32.0	72.0	70.0	51.0	65.0	51.0	65.0	52.0	67.0	-	-

NOTES: 1. Reactions are those applied to the Orbiter by Tug.
2. Sign convention is: +X Aft; +Y RT, Looking Forward; +Z Up.
3. "ORB CAP" values from "Orbiter Support Fitting Capabilities" table.
4. * X/Z Interaction, see attached plot


3-1, 1246 X/Z JSC = ⊕


3-2, 1187 X/Z
JSC = ⊕

REACTIONS (1000 LB)

Config.		X_1 & X_2		Y_1	Y_2	Z_1		Z_2		Z_3		Z_4	
		+	-	±	±	+	-	+	-	+	-	+	-
4-1	JSC	105.3	13.0	38.7	44.3	62.5	58.4	62.5	58.4	26.6	38.1	26.6	38.1
	MSFC	127.6	63.8	34.1	30.9	85.3	81.2	85.3	81.2	51.6	56.1	51.6	56.1
	ORB CAP	*	*	56.0	70.0	*	*	*	*	52.0	67.0	52.0	67.0
4-2	JSC	104.1	12.7	49.3	45.9	69.7	64.6	69.7	64.6	21.2	38.7	21.2	38.7
	MSFC	126.2	63.1	43.5	23.1	99.3	94.3	99.3	94.3	40.7	50.0	40.7	50.0
	ORB CAP	*	*	67.0	70.0	*	*	*	*	52.0	67.0	52.0	67.0
4-3	JSC	105.3	13.0	65.2	47.8	84.5	77.7	84.5	77.7	21.8	39.7	21.8	39.7
	MSFC	127.6	63.8	57.5	17.7	126.7	119.9	126.7	119.9	22.2	50.0	22.2	50.0
	ORB CAP	110.0	32.0	72.0	70.0	51.0	65.0	51.0	65.0	52.0	67.0	52.0	67.0

NOTES: 1. Reactions are those applied to the Orbiter by Tug.
2. Sign convention is: +X Aft; +Y RT, Looking Forward; +Z Up.
3. "ORB CAP" values from "Orbiter Support Fitting Capabilities" table.
4. * X/Z Interaction, see attached plot

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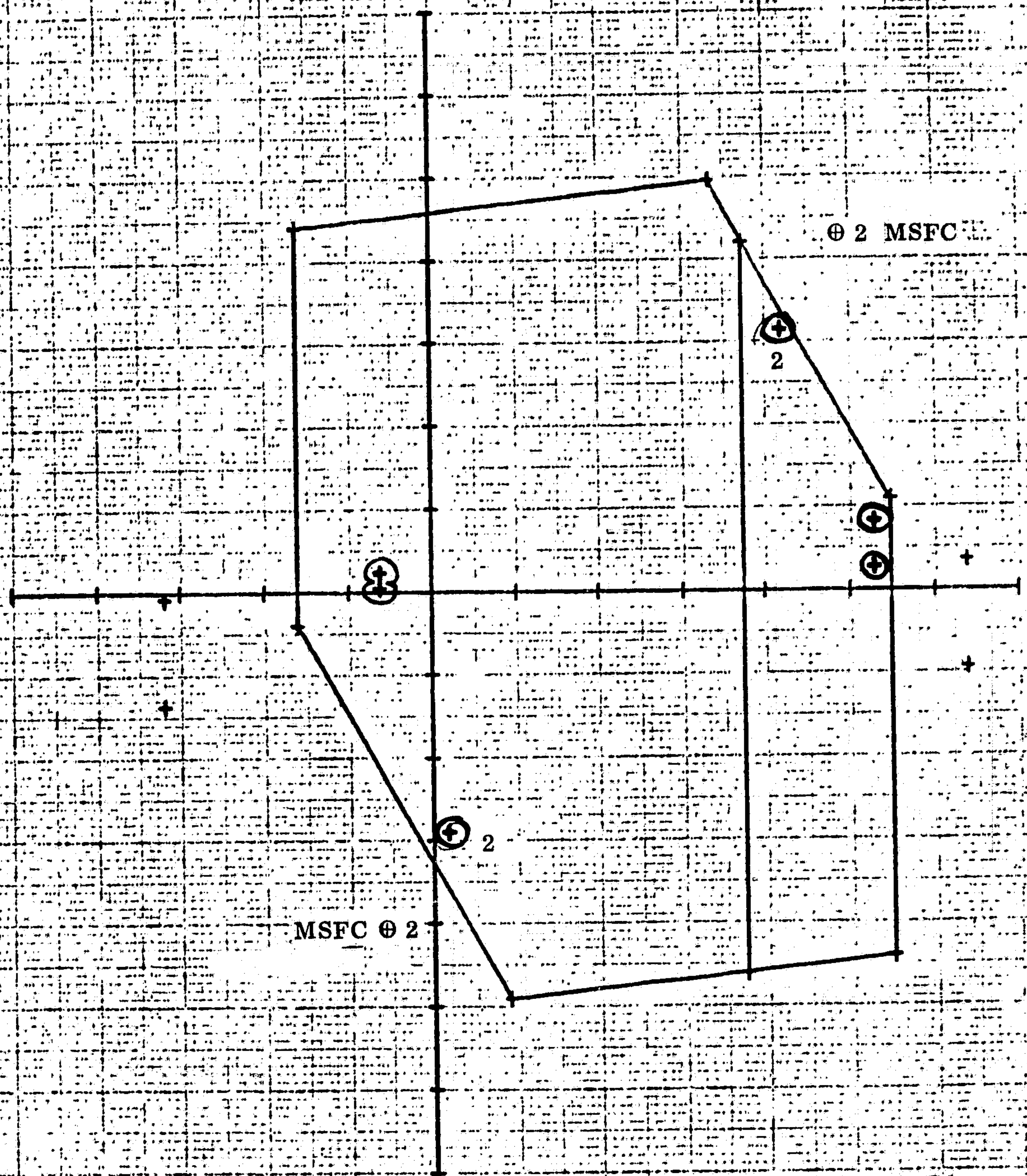
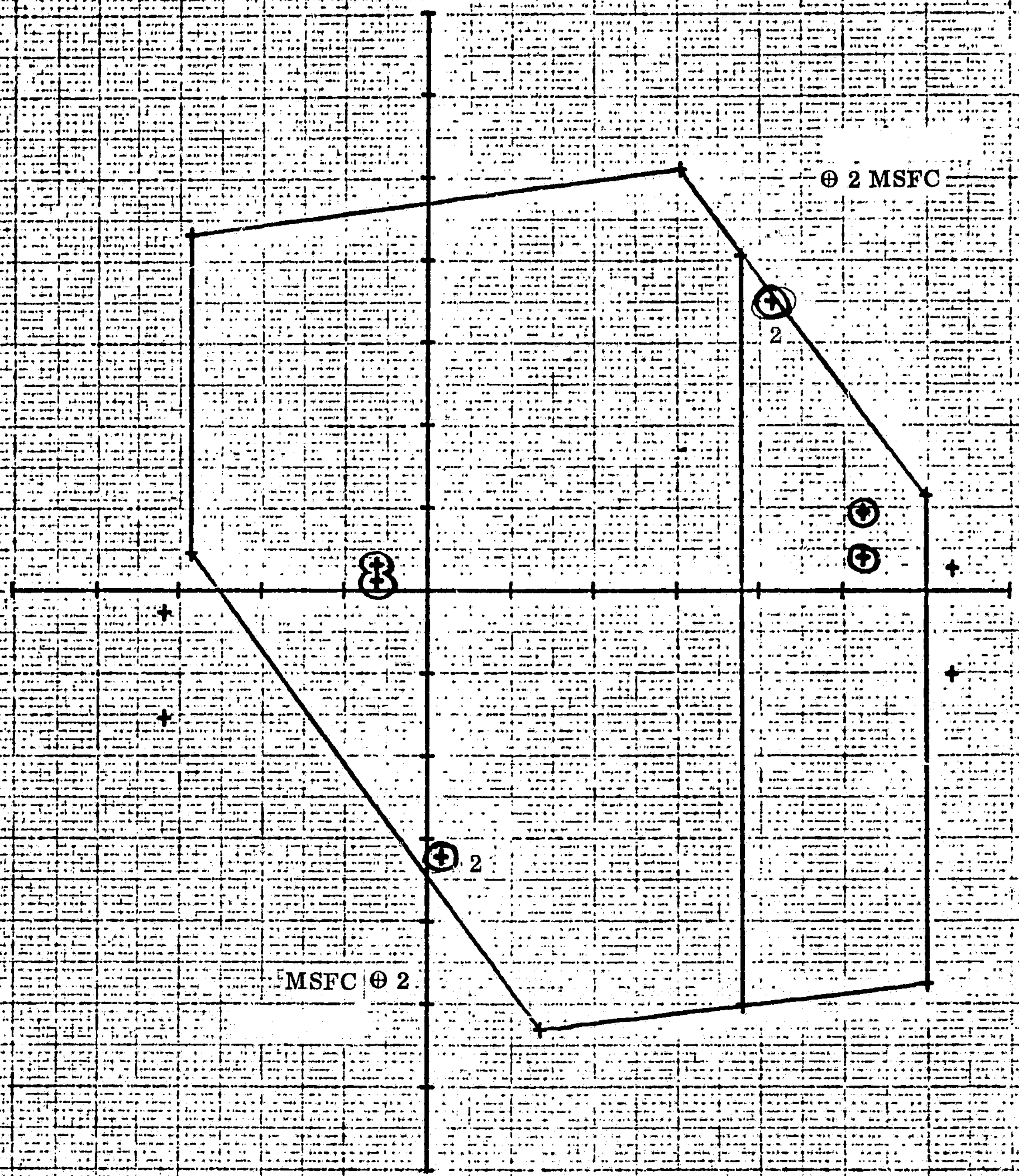
4-1, 1246 X/Z   JSC = ⊕ EXCEPT AS NOTED



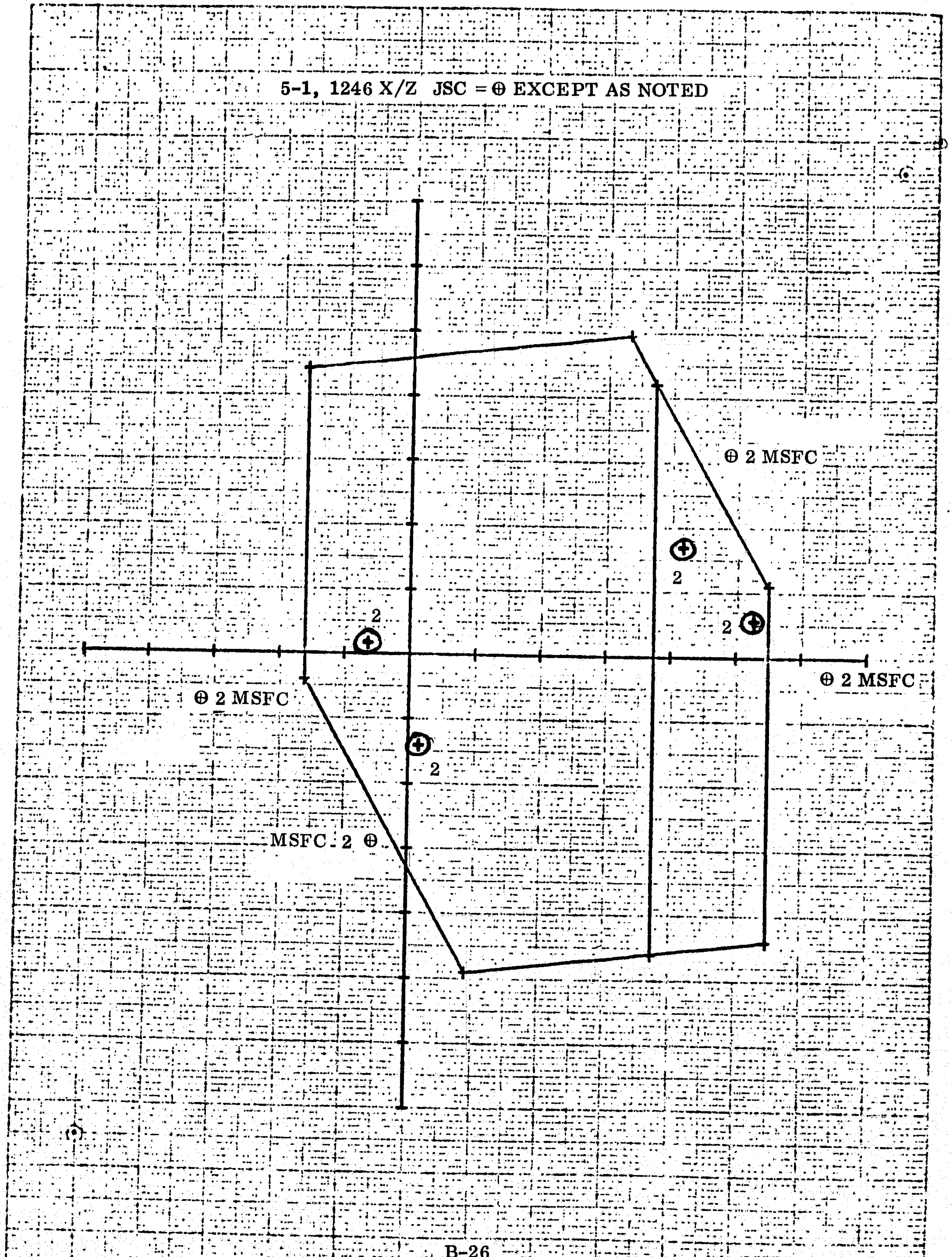
4-2, 1187 X/Z JSC = ⊕ EXCEPT AS NOTED



REACTIONS (1000 LB)

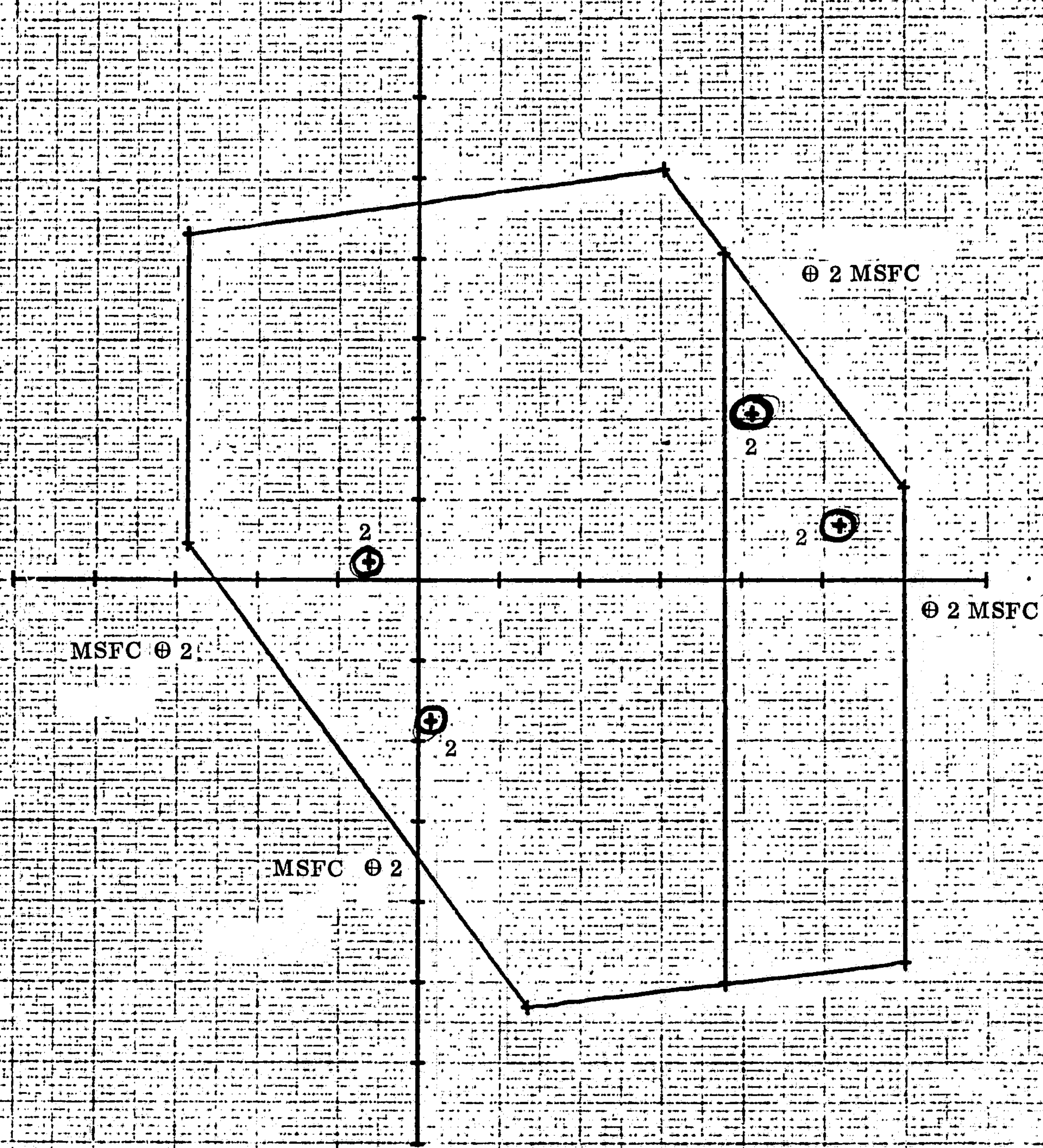
Config.		X_1 & X_2		Y_1	Y_2	Z_1		Z_2		Z_3		Z_4	
		+	−	±	±	+	−	+	−	+	−	+	−
5-1	JSC	105.3	13.0	38.7	44.3	59.3	63.8	59.3	63.8	33.1	29.0	33.1	29.0
	MSFC	127.6	63.8	34.1	30.9	77.4	81.9	77.4	81.9	62.1	58.0	62.1	58.0
	ORB CAP	*	*	56.0	70.0	52.0	67.0	52.0	67.0	*	*	*	*
5-2	JSC	104.1	12.7	49.3	45.9	53.6	59.2	53.6	59.2	40.7	35.6	40.7	35.6
	MSFC	126.2	63.1	43.5	23.1	66.2	71.8	66.2	71.8	76.4	71.3	76.4	71.3
	ORB CAP	*	*	67.0	70.0	52.0	67.0	52.0	67.0	*	*	*	*
5-3	JSC	105.3	13.0	65.2	47.8	44.8	52.4	44.8	52.4	55.1	48.3	55.1	48.3
	MSFC	127.6	63.8	57.5	17.7	48.0	58.7	48.0	58.7	103.5	96.7	103.5	96.7
	ORB CAP	110.0	32.0	72.0	70.0	52.0	67.0	52.0	67.0	51.0	65.0	51.0	65.0

NOTES: 1. Reactions are those applied to the Orbiter by Tug.
2. Sign convention is: +X Aft; +Y RT, Looking Forward; +Z Up.
3. "ORB CAP" values from "Orbiter Support Fitting Capabilities" table.
4. * X/Z Interaction, see attached plot



5-1, 1246 X/Z JSC = ⊕ EXCEPT AS NOTED
⊕ 2 MSFC
2
2
2
⊕ 2 MSFC
⊕ 2 MSFC
2
MSFC 2 ⊕

5-2, 1187 X/Z JSC = ⊕ EXCEPT AS NOTED



REACTIONS (1000 LB)

Config.		X_1 & X_2		Y_1	Y_2	Z_1		Z_2		Z_3		Z_4	
		+	-	±	±	+	-	+	-	+	-	+	-
6-1	JSC	113.5	54.2	64.6	-	81.0	81.0	96.3	82.6	43.5	79.4	-	-
	MSFC	132.9	69.1	57.4	-	121.5	121.5	144.0	130.4	44.3	100.0	-	-
	ORB CAP	110.0	32.0	72.0	-	51.0	65.0	51.0	65.0	52.0	67.0	-	-
6-2	JSC	112.4	54.3	63.9	-	80.1	80.1	94.6	81.1	43.7	80.2	-	-
	MSFC	131.6	68.5	56.8	-	120.2	120.2	141.4	127.9	45.4	101.4		
	ORB CAP	120.0	50.0	72.0	-	51.0	65.0	51.0	65.0	52.0	67.0	-	-
	JSC												
	MSFC												
	ORB CAP												

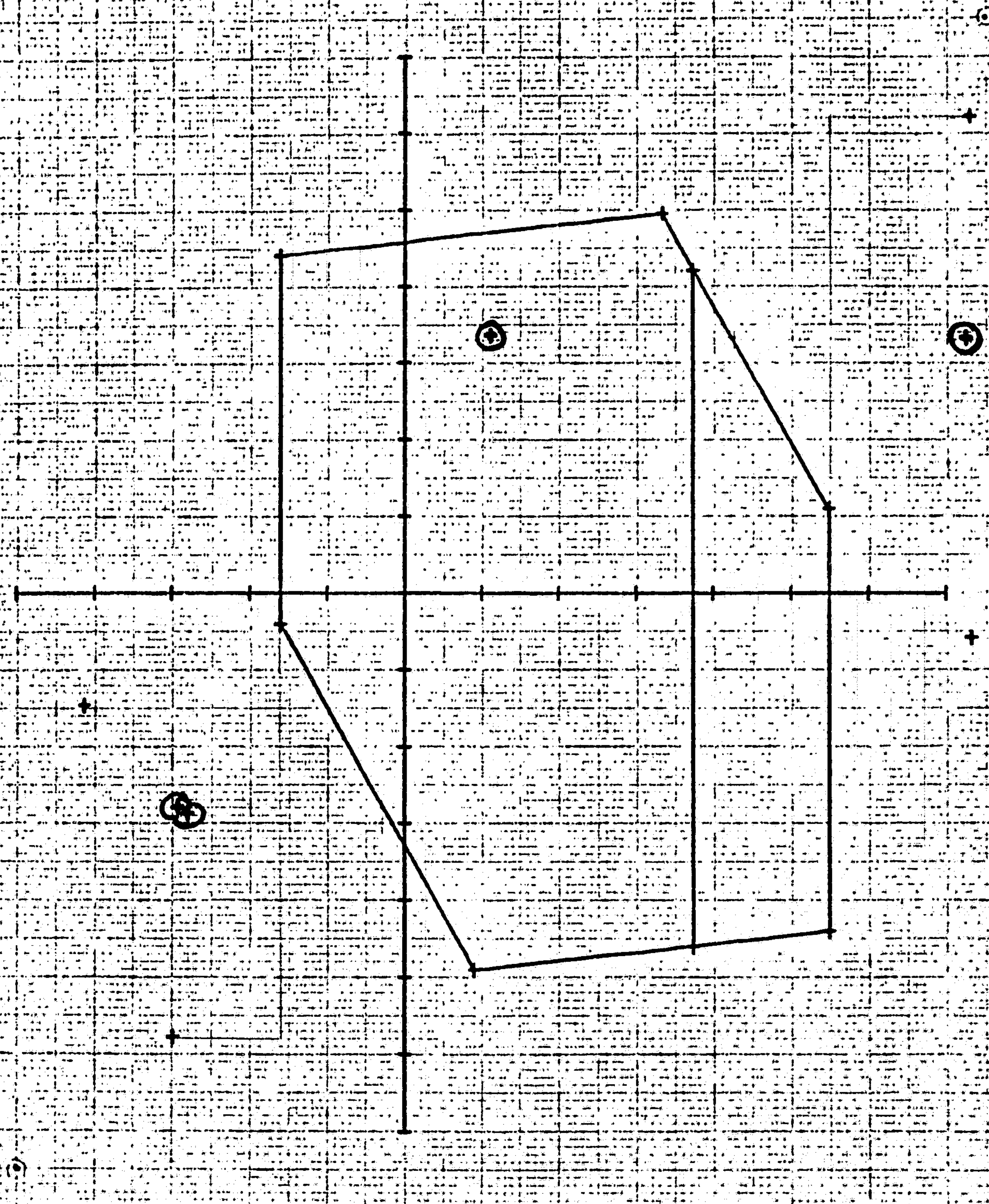
NOTES:
1. Reactions are those applied to the Orbiter by Tug.
2. Sign convention is: +X Aft; +Y RT, Looking Forward; +Z Up.
3. "ORB CAP" values from "Orbiter Support Fitting Capabilities" table.
4. * X/Z Interaction, see attached plot

REACTIONS (1000 LB)

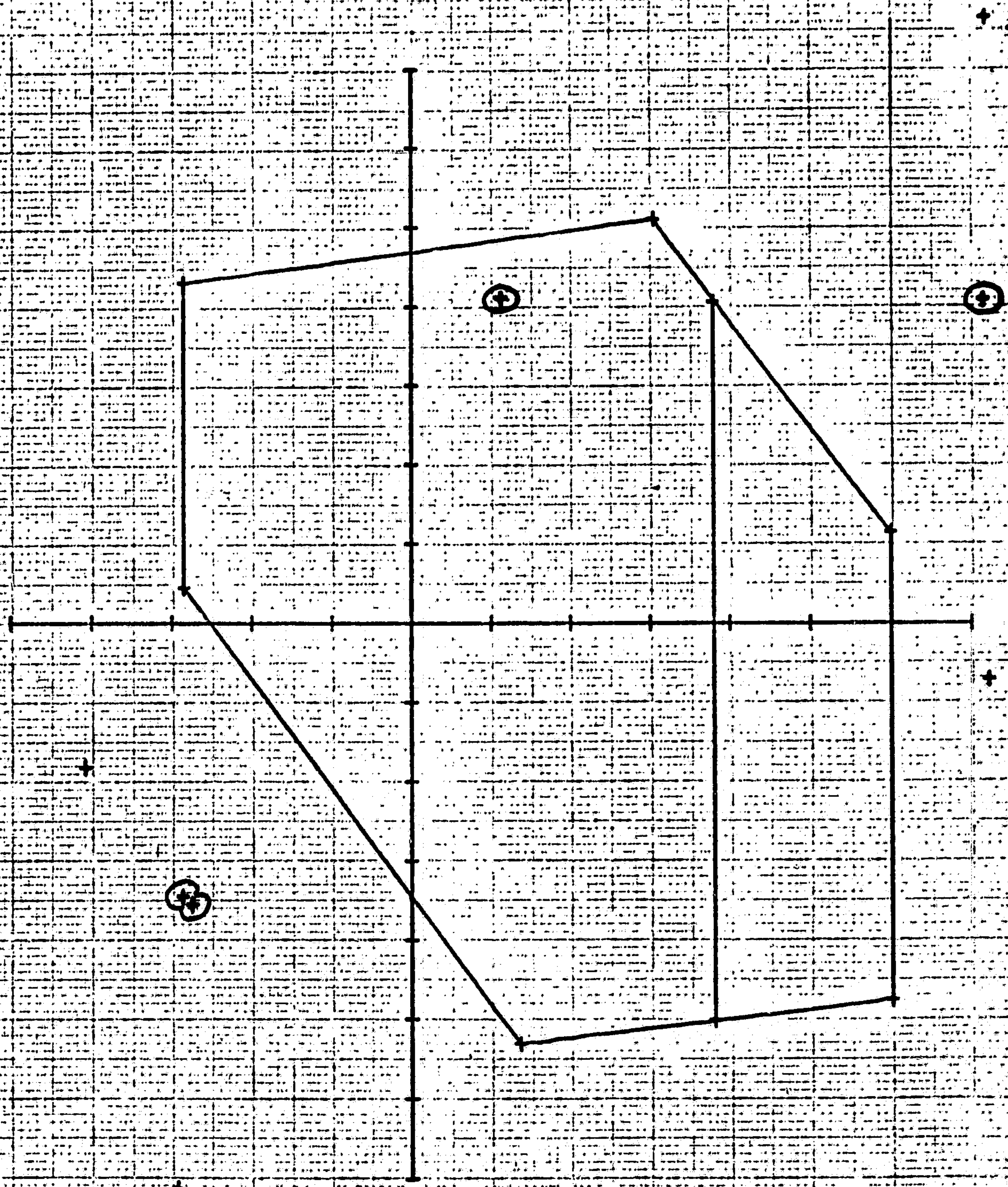
Config.		X_1 & X_2		Y_1	Y_2	Z_1		Z_2		Z_3		Z_4	
		+	-	±	±	+	-	+	-	+	-	+	-
7-1	JSC	144.7	58.5	64.6	-	81.0	81.0	44.0	52.1	66.2	58.0	-	-
	MSFC	146.3	82.5	57.4	-	121.5	121.5	53.0	61.2	124.2	116.0	-	-
	ORB CAP	X_1:110 X_2: *	X_1:32 X_2; *	70.0	-	52.0	67.0	52.0	67.0	*	*	-	-
7-2	JSC	142.6	57.5	63.9	-	80.1	80.1	57.4	67.5	81.3	71.2	-	-
	MSFC	144.5	81.4	56.8	-	120.2	120.2	80.4	90.5	152.7	142.6	-	-
	ORB CAP	X_1:120 X_2: *	X_1:50 X_2; *	70.0	-	52.0	67.0	52.0	67.0	*	*	-	-
	JSC												
	MSFC												
	ORB CAP												

NOTES:
1. Reactions are those applied to the Orbiter by Tug.
2. Sign convention is: +X Aft; +Y RT, Looking Forward; +Z Up.
3. "ORB CAP" values from "Orbiter Support Fitting Capabilities" table.
4. * X/Z Interaction, see attached plot

7-1, 1246 X/Z JSC = ⊕



7-2, 1187 X/Z   JSC = ⊕

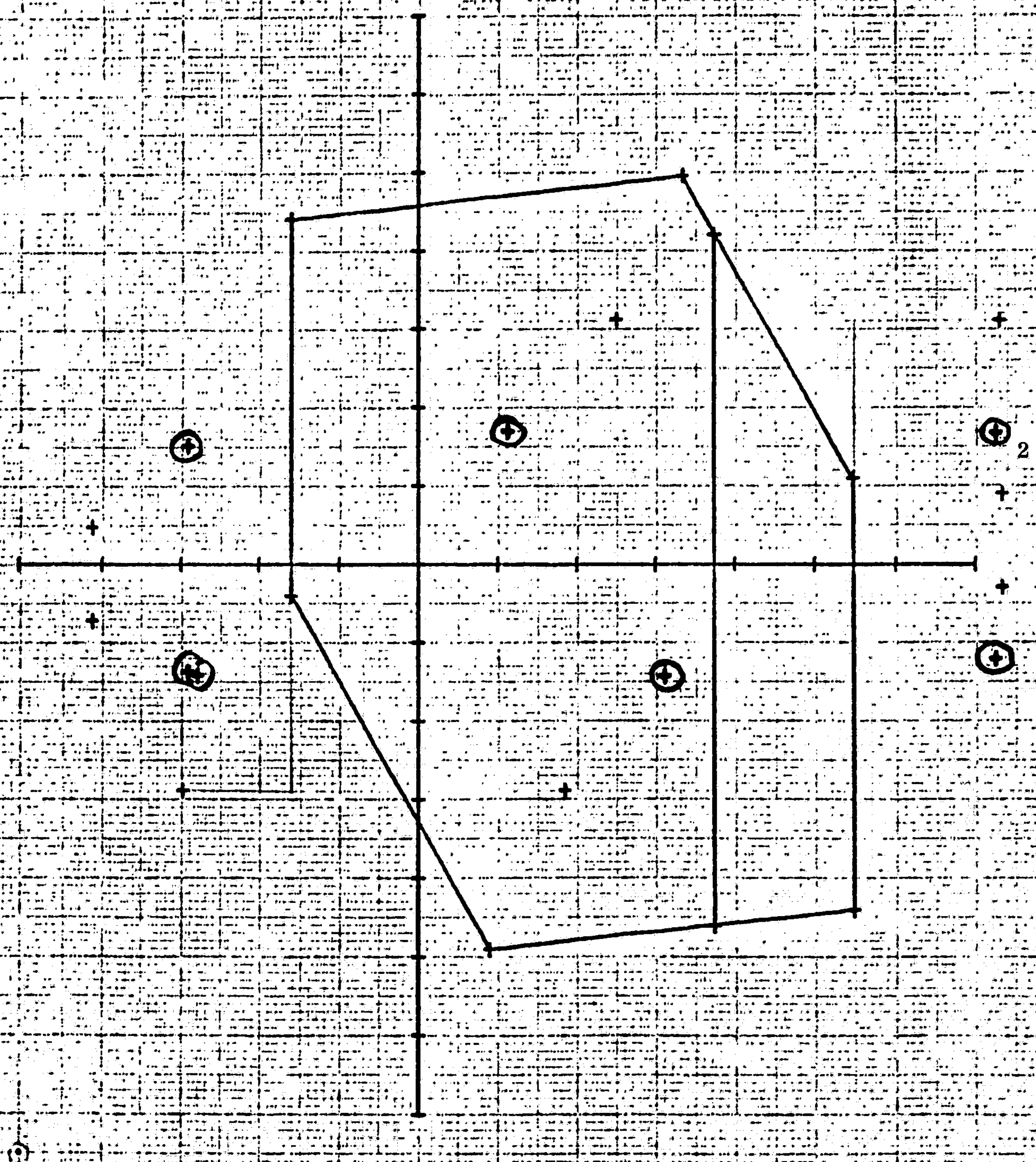


REACTIONS (1000 LB)

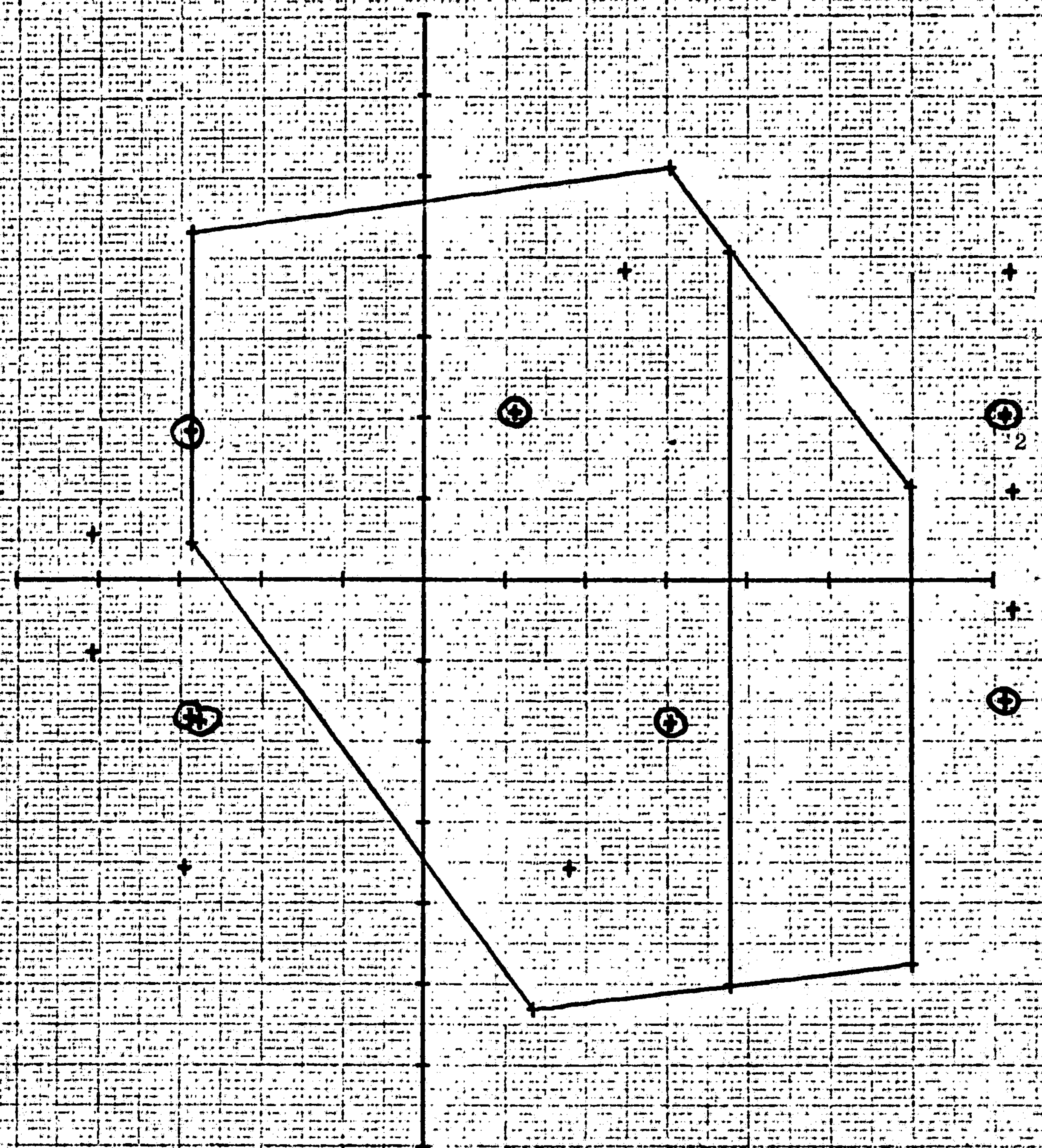
Config.		X_1 & X_2		Y_1	Y_2	Z_1		Z_2		Z_3		Z_4	
		+	−	±	±	+	−	+	−	+	−	+	−
8-1	JSC	144.7	58.5	64.6	−	59.3	63.8	59.3	63.8	33.1	29.0	33.1	29.0
	MSFC	146.3	82.5	57.4	−	77.4	81.9	77.4	81.9	62.1	58.0	62.1	58.0
	ORB CAP	*	*	70.0	−	52.0	67.0	52.0	67.0	*	*	*	*
8-2	JSC	142.6	57.5	63.9	−	53.6	59.2	53.6	59.2	40.7	35.6	40.7	35.6
	MSFC	144.5	81.4	56.8	−	66.2	71.8	66.2	71.8	76.4	71.3	76.4	71.3
	ORB CAP	*	*	70.0	−	52.0	67.0	52.0	67.0	*	*	*	*
8-3	JSC	144.7	58.5	64.6	−	44.8	52.4	44.8	52.4	55.1	48.3	55.1	48.3
	MSFC	146.3	82.5	57.4	−	48.0	58.7	48.0	58.7	103.5	96.7	103.5	96.7
	ORB CAP	110.0	32.0	70.0	−	52.0	67.0	52.0	67.0	51.0	65.0	51.0	65.0

NOTES:
1. Reactions are those applied to the Orbiter by Tug.
2. Sign convention is: +X Aft; +Y RT, Looking Forward; +Z Up.
3. "ORB CAP" values from "Orbiter Support Fitting Capabilities" table.
4. * X/Z Interaction, see attached plot

8-1, 1246 X/Z JSC = ⊕



8-2, 1187 X/Z JSC = ⊕



X/Z INTERACTION (JSC "C" a +α) GOVERNING LOAD CONDITIONS

Sta.	Config.	X_1		X_2		Z_1		Z_2		Z_3		Z_4	
		+	-	+	-	+	-	+	-	+	-	+	-
1246	1-1	D A49	D D34	D A34	D D41	D A11	D A32	R A50	R A5	-	-	-	-
	7-1	-	-	R A50	R A1	-	-	-	-	R A41	R A3	-	-
	2-1	D A49	D D34	D A34	D D41	R A41	R A30	R A50	R A5	-	-	-	-
	8-1	R A33	R A18	R A50	R A1	-	-	-	-	R A41	R A3	R A41	R A3
	3-1	D A145	D D1	D A145	D D1	D A11	D A32	R A50	R A5	-	-	-	-
	4-1	D A145	D D1	D A145	D D1	R A41	R A30	R A50	R A5	-	-	-	-
	5-1	D A145	D D1	D A145	D D1	-	-	-	-	R A41	R A3	R A91	R A3
1187	1-2	D A49	D D34	D A34	D D41	D A11	D A32	R A50	R A5	-	-	-	-
	7-2	-	-	R A50	R A1	-	-	-	-	R A41	R A3	-	-
	2-2	D A49	D D34	D A34	D D41	R A41	R A30	R A50	R A5	-	-	-	-
	8-2	R A33	R A18	R A50	R A1	-	-	-	-	R A41	R A3	R A41	R A3
	3-2	D A145	D D1	D A145	D D1	D A11	D A32	R A50	R A5	-	-	-	-
	4-2	D A145	D D1	D A145	D D1	R A41	R A30	R A50	R A5	-	-	-	-
	5-2	D A145	D D1	D A145	D D1	-	-	-	-	R A41	R A3	R A41	R A3

X/Z INTERACTION CRITICAL LOAD CASES		a_x	a_y	a_z	α_x	α_y	α_z
A- Ascent	1	-0.10	1.00	1.50	0.10	0.15	0.15
	3	-0.10	1.00	1.50	0.10	-0.15	-0.15
	5	-0.10	1.00	1.50	-0.10	-0.15	0.15
	11	-0.10	1.00	-1.50	-0.10	-0.15	-0.15
	18	-0.10	-1.00	-1.50	0.10	0.15	-0.15
	30	-0.10	-1.00	1.50	0.10	-0.15	-0.15
	32	-0.10	-1.00	1.50	0.10	0.15	0.15
	33	-2.90	1.00	1.50	0.10	0.15	0.15
	34	-2.90	1.00	1.50	0.10	0.15	-0.15
	41	-2.90	1.00	-1.50	-0.10	0.15	0.15
	49	-2.90	-1.00	-1.50	0.10	0.15	0.15
	50	-2.90	-1.00	-1.50	0.10	0.15	-0.15
	145	-3.30	0.20	-0.30	0.20	0.25	0.25
D- Descent	1	1.06	0	2.50	0.25	0.75	0.30
	34	0.75	1.25	1.00	0.25	0.30	-0.75
	41	0.75	-1.25	1.00	-0.25	0.30	0.75

X/Z INTERACTION — JSC "C" ACCELS (a + α)

	Config.	X/Z LOCS 1→ 2→	$+X_{1max}$ $+X_{2max}$	Z Z	$-X_{1max}$ $-X_{2max}$	Z Z	X X	$+Z_{max}$ $+Z_{max}$	X X	$-Z_{max}$ $-Z_{max}$
1246	1-1	X_1/Z_1 X_2/Z_2	+150722 +150722	+15903 -17398	-79374 -79374	+4818 +34171	-55010 +52613	+79809 +51096	+61390 +33618	-79809 -42912
	7-1	X_2/Z_3	+144712	+66167	-58482	-56395	+22000	+66167	-55991	-57983
	2-1	X_1/Z_1 X_2/Z_2	+150722 +150722	-3970 -48502	-79374 -79374	+19494 +19494	+52613 +52613	+61436 +61436	+33618 +33618	-57344 -57344
	8-1	X_1/Z_4 X_2/Z_3	+144712 +144712	-24378 +33084	-58482 -58482	+29264 -28198	+144712 +22000	+33084 +33084	+61740 -55991	-28991 -28991
	3-1	X_1/Z_1 X_2/Z_2	+105283 +105283	+14524 +7211	-13049 -13049	-36864 +41340	+3190 +83356	+80977 +52147	+3190 +2874	-80977 -43963
	4-1	X_1/Z_1 X_2/Z_2	+105283 +105283	+16463 +5272	-13049 -13049	+304 +4172	+83556 +83356	+62487 +62487	+2874 +2874	-58395 -58395
	5-1	X_1/Z_4 X_2/Z_3	+105283 +105283	+10868 +10868	-13049 -13049	+2238 +2238	+83356 +83356	+33084 +33084	+2874 +2874	-28991 -28991
1187	1-2	X_1/Z_1 X_2/Z_2	+126465 +126465	+14543 -26271	-65090 -65090	+5492 +35306	-31815 +72451	+80107 +67495	+38125 +12718	-80107 -57390
	7-2	X_2/Z_3	+142635	+81349	-57466	-69332	+22024	+81349	-55065	-71245
	2-2	X_1/Z_1 X_2/Z_2	+126465 +126465	+1433 -53095	-65090 -65090	+20399 +20399	+72451 +72451	+69699 +69699	+12718 +12718	-64647 -64647
	8-2	X_1/Z_4 X_2/Z_3	+142635 +142635	-29950 +40675	-57466 -57466	+35959 -34666	+142635 +22024	+40675 +40675	+60743 -55065	-35622 -35622
	3-2	X_1/Z_1 X_2/Z_2	+104115 +104115	+14316 +12414	-12673 -12673	-36055 +43522	+3155 +82330	+80107 +67495	+3155 +2839	-80107 -57390
	4-2	X_1/Z_1 X_2/Z_2	+104115 +104115	+18882 +7849	-12673 -12673	+1792 +5676	+82330 +82330	+69699 +69699	+2839 +2839	-64647 -64647
	5-2	X_1/Z_4 X_2/Z_3	+104115 +104115	+13365 +13365	-12673 -12673	+3734 +3734	+82330 +82330	+40675 +40675	+2839 +2839	-35622 -35622

B.2 Convair Memo STI 74-44, 18 November 1974

Sent to: Ed Stluka/Steve Denton
Marshall Space Flight Center
Huntsville, Alabama

Subject: Tug Reaction Changes Caused by Variation of Y Support Station

SUPPORT ARRANGEMENT 1-1:

ACCUMULATED EXCEEDANCE
WITH VARIATION IN Y-SUPPORT STATION

Y-SUPPORT STATION	ACCUMULATED Δ-REACTION (10^3 #)					
	X-ONLY	X IN X/Z	Y	Z-ONLY	Z IN X/Z	Σ
1249	0.0	190.8	1.4	96.5	54.2	342.9
1181	0.0	172.8	0.0	96.5	92.2	361.0
1128	0.0	129.0	0.0	96.5	155.2	380.7

*Accelerations per MSFC 68M00039-1

REACTIONS (1000 LB)

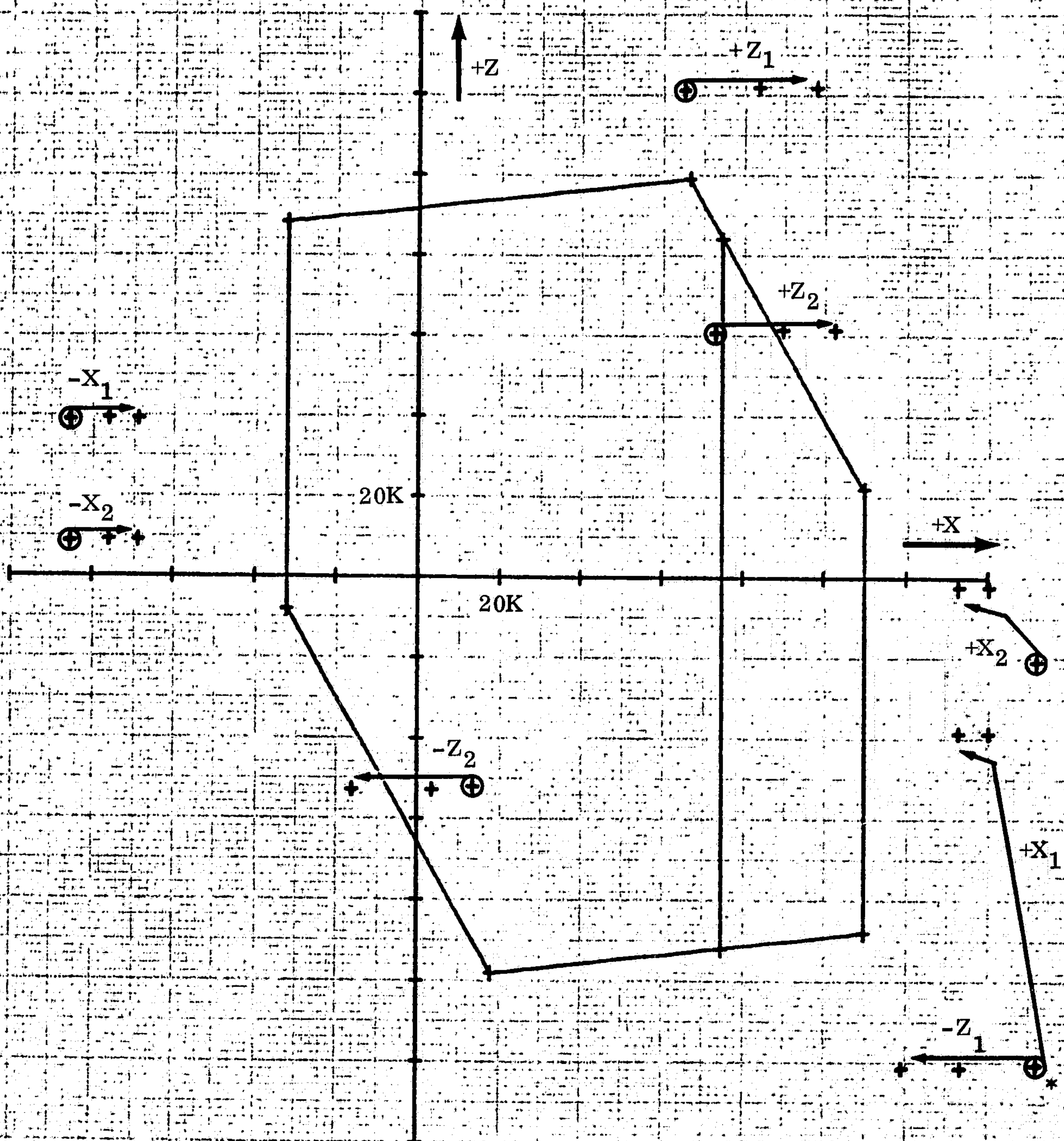
SUPPORT ARRANGEMENT 1-1:

Config.		X_1 & X_2		Y_1	Y_2	Z_1		Z_2		Z_3		Z_4	
		+	-	±	±	+	-	+	-	+	-	+	-
Y_1 @ 1249	JSC		161.6 †										
	MSFC	151.9	85.5	57.4	-	120.6	120.6	60.4	52.2	103.2	112.3	-	-
	ORB CAP	*	*	56.0		*	*	*	*	52.0	67.0		
Y_1 @ 1181	JSC		142.0 †										
	MSFC	140.1	76.3	57.4	-	121.5	121.5	61.2	53.0	103.2	112.3	-	-
	ORB CAP	*	*	67.0		*	*	*	*	52.0	67.0		
Y_1 @ 1128	JSC		126.8 †										
	MSFC	132.9	69.1	57.4	-	121.5	121.5	61.2	53.0	103.2	112.3	-	-
	ORB CAP	*	*	72.0		*	*	*	*	52.0	67.0		

NOTES: 1. Reactions are those applied to the Orbiter by Tug.
2. Sign convention is: +X Aft; +Y RT, Looking Forward; +Z Up.
3. "ORB CAP" values from "Orbiter Support Fitting Capabilities" table.
4. * X/Z Interaction, see attached plot

† Quasi limit crash (w/fuel)

X/Z INTERACTION @ X_o 1246
WITH VARIATION IN Y-SUPPORT STATION
FOR MSFC BASELINE TUG WITH GDC CONFIG 1-1
SUPPORT ARRANGEMENT, SUBJECTED TO MSFC
ACCELERATIONS



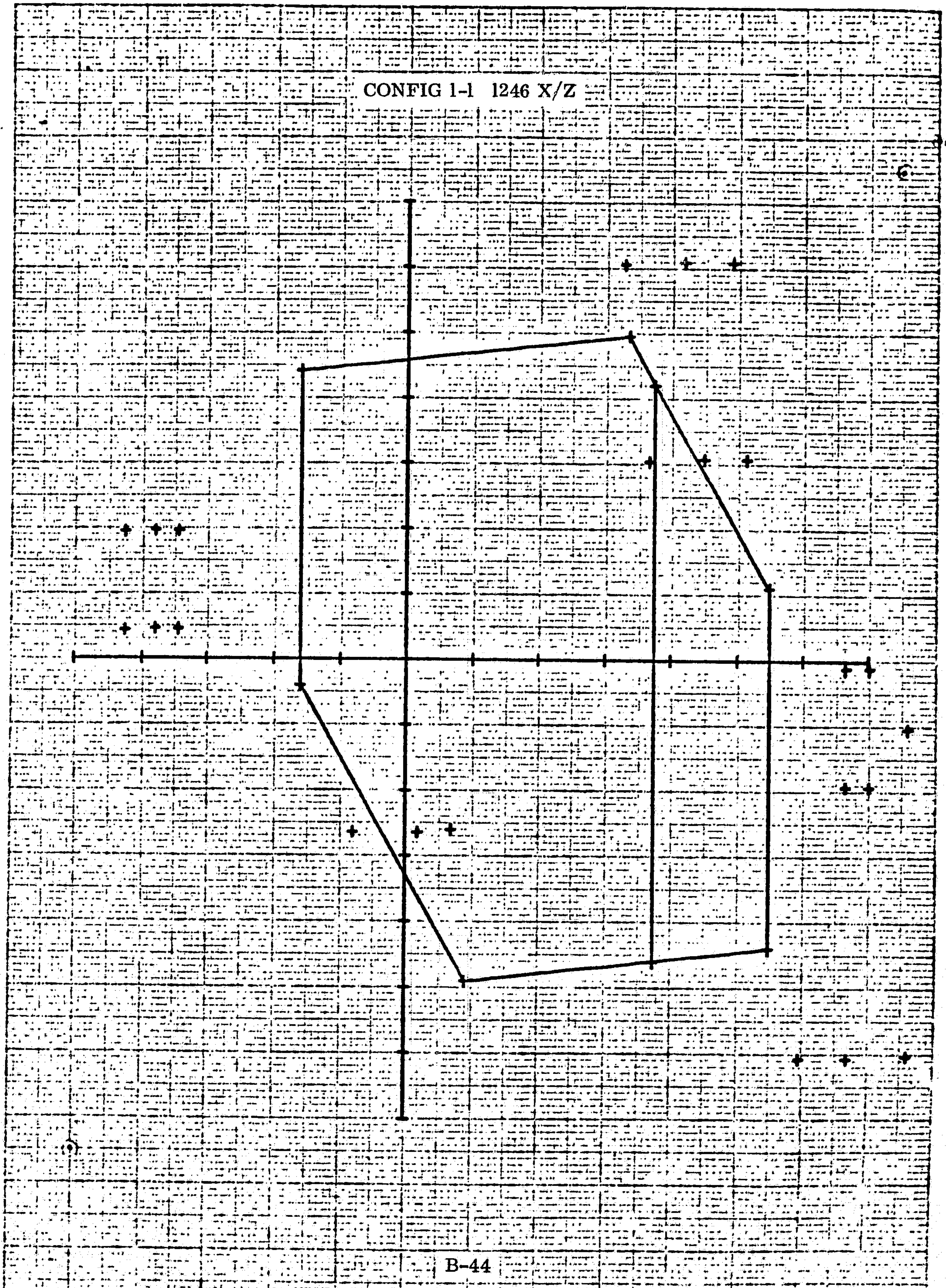
⊕ INDICATES Y SUPPORT AT X_o 1249
→ INDICATES CHANGE AS Y SUPPORT RELOCATED AT X_o 1181 THEN X_o 1128
* SAME LOAD CONDITION MAXIMIZES $+X_1$, $-Z_1$ WITH Y SUPPORT @ X_o 1249

X/Z INTERACTION - CONDITIONS & REACTIONS

	Config.	X/Z LOC. 1 → 2 →	$+X_{1\ max}$ $+X_{2\ max}$	Z Z	$-X_{1\ max}$ $-X_{2\ max}$	Z Z	X X	$+Z_{max}$ $+Z_{max}$	X X	$-Z_{max}$ $-Z_{max}$
CASE	1-1	X_1/Z_1	DA-13		DA-34		DA-15		DA-13	
REACT	Y_1		+151.9	-120.6	-85.5	+38.0	+65.0	+120.6	+151.9	-120.6
CASE	@	X_2/Z_2	DA-15		DA-36		RA-14		RA-9	
REACT	1249		+151.9	-20.8	-85.5	+8.0	+72.9	+60.4	+13.3	-52.2
CASE	1-1	X_1/Z_1	DA-37		DA-34		DA-15		DA-13	
REACT	Y_1		+140.1	-38.4	-76.3	+38.4	+83.5	+121.5	+133.5	-121.5
CASE	@	X_2/Z_2	DA-39		DA-36		RA-14		RA-9	
REACT	1181		+140.1	-2.4	-76.3	+8.5	+89.6	+61.2	+3.3	-53.0

X/Z INTERACTION - CONDITIONS & REACTIONS

	Config.	X/Z LOC. 1 → 2 →	$+X_{1\,max}$ $+X_{2\,max}$	Z Z	$-X_{1\,max}$ $-X_{2\,max}$	Z Z	X X	$+Z_{max}$ $+Z_{max}$	X X	$-Z_{max}$ $-Z_{max}$
CASE	1-1	X_1/Z_1	DA-37		DA-34		DA-15		DA-13	
REACT	Y_1		+132.9	-38.4	-69.1	+38.4	+97.9	+121.5	+119.1	-121.5
CASE	@	X_2/Z_2	DA-39		DA-36		RA-14		RA-9	
REACT	1128		+132.9	-2.4	-69.1	+8.5	+102.5	+61.2	-16.3	-53.0
CASE										
REACT										
CASE										
REACT										


CONFIG 1-1 1246 X/Z

SUPPORT ARRANGEMENT 2-1:

ACCUMULATED EXCEEDANCE
WITH VARIATION IN Y-SUPPORT STATION

Y-SUPPORT STATION	ACCUMULATED Δ-REACTION (10^3 #)					
	X-ONLY	X IN X/Z	Y	Z-ONLY	Z IN X/Z	Σ
1249	0.0	190.8	1.4	0.0	0.0	192.2
1181	0.0	148.8	0.0	0.0	97.0	245.8
1128	0.0	120.0	0.0	0.0	191.0	311.0

*Accelerations per MSFC 68M00039-1

REACTIONS (1000 LB)

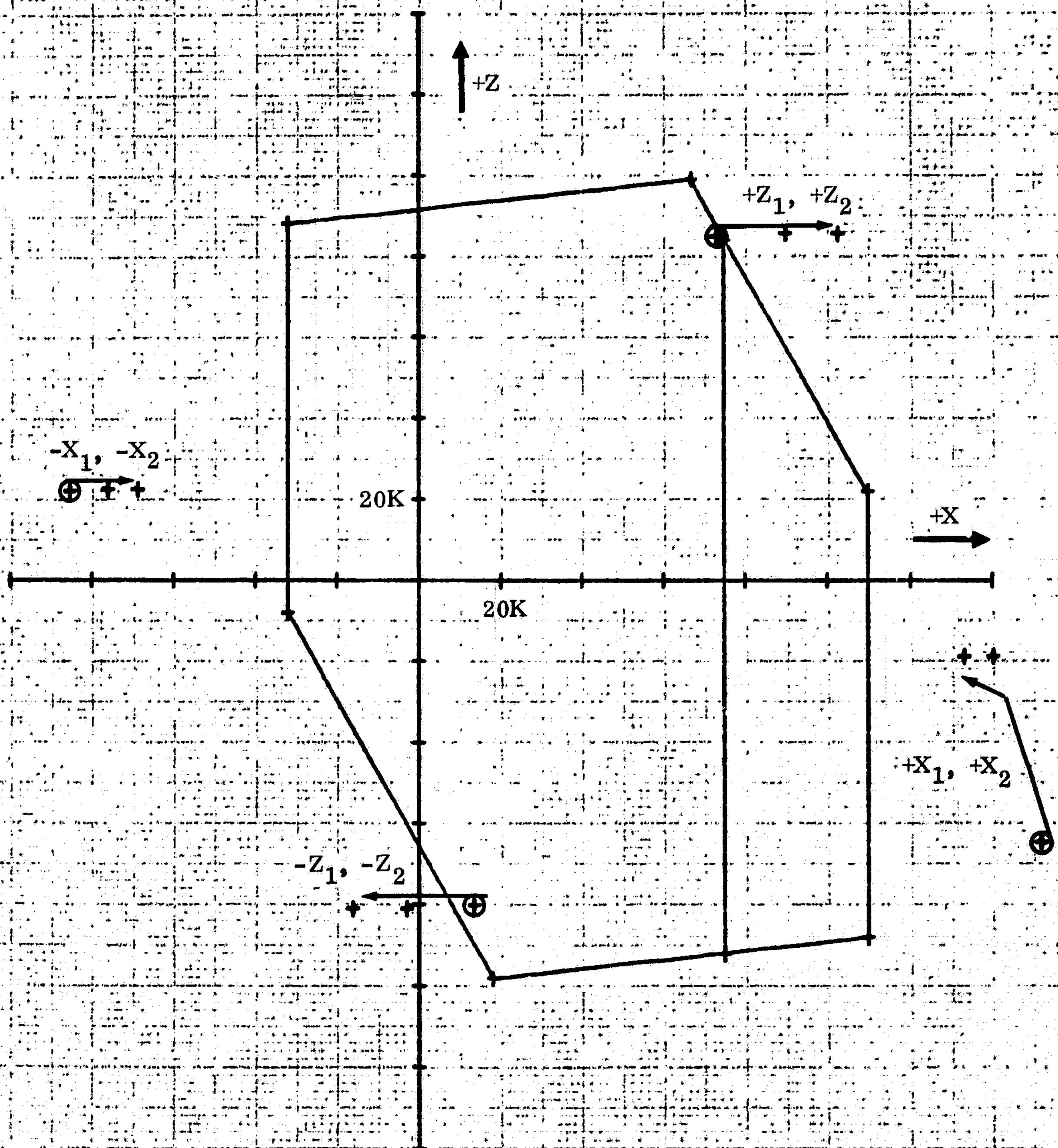
SUPPORT ARRANGEMENT 2-1:

Config.		X_1 & X_2		Y_1	Y_2	Z_1		Z_2		Z_3		Z_4	
		+	-	±	±	+	-	+	-	+	-	+	-
Y_1 @ 1249	JSC MSFC	151.9	161.6† 85.5	57.4	-	84.5	80.4	84.5	80.4	51.6	56.1	51.6	56.1
	ORB CAP	*	*	56.0		*	*	*	*	52.0	67.0	52.0	67.0
Y_1 @ 1181	JSC MSFC	140.1	142.0† 76.3	57.4	-	85.3	81.2	85.3	81.2	51.6	56.1	51.6	56.1
	ORB CAP	*	*	67.0		*	*	*	*	52.0	67.0	52.0	67.0
Y_1 @ 1128	JSC MSFC	132.9	126.8† 69.1	57.4	-	85.3	81.2	85.3	81.2	51.6	56.1	51.6	56.1
	ORB CAP	*	*	72.0		*	*	*	*	52.0	67.0	52.0	67.0

NOTES:
1. Reactions are those applied to the Orbiter by Tug.
2. Sign convention is: +X Aft; +Y RT, Looking Forward; +Z Up.
3. "ORB CAP" values from "Orbiter Support Fitting Capabilities" table.
4. * X/Z Interaction, see attached plot

† Quasi limit crash (w/fuel)

X/Z INTERACTION @ X_o 1246
WITH VARIATION IN Y-SUPPORT STATION
FOR MSFC BASELINE TUG WITH GDC CONFIG. 2-1
SUPPORT ARRANGEMENT. SUBJECTED TO MSFC
ACCELERATIONS



⊕ INDICATES Y SUPPORT AT X_o 1249
→ INDICATES CHANGE AS Y-SUPPORT
RELOCATED AT X_o 1181 THEN X_o 1128

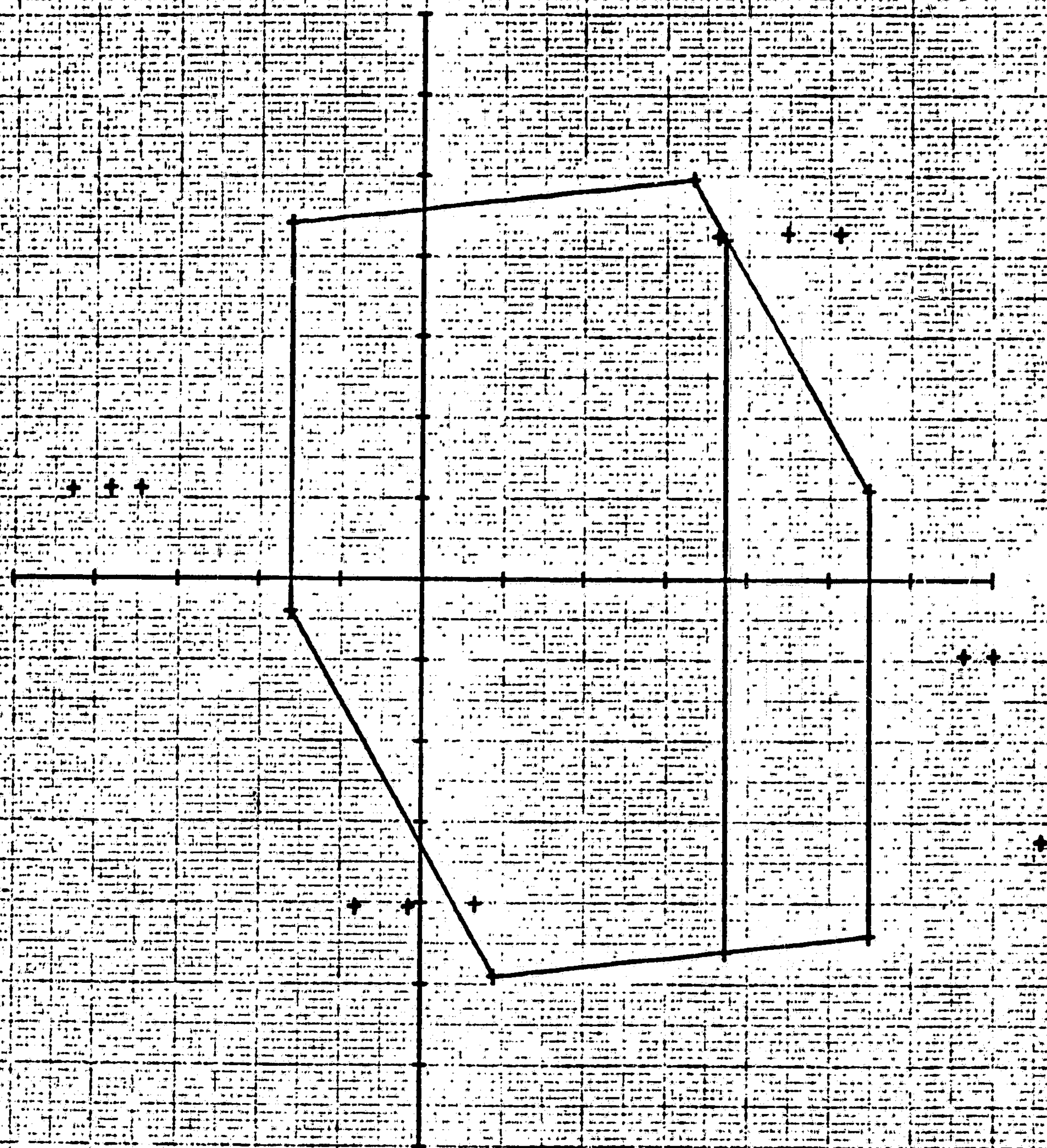
X/Z INTERACTION - CONDITIONS & REACTIONS

	Config.	X/Z LOC. 1 → 2 →	$+X_{1\,max}$ $+X_{2\,max}$	Z Z	$-X_{1\,max}$ $-X_{2\,max}$	Z Z	X X	$+Z_{max}$ $+Z_{max}$	X X	$-Z_{max}$ $-Z_{max}$
CASE	2-1	X_1/Z_1	DA-13		DA-34		RA-15		RA-12	
REACT	1249		+151.9	-64.5	-85.5	+21.3	+72.9	+84.5	+13.3	-80.4
CASE	Y	X_2/Z_2	DA-16		DA-35		RA-14		RA-9	
REACT			+151.9	-64.5	-85.5	+21.3	+72.9	+84.5	+13.3	-80.4
CASE	2-1	X_1/Z_1	DA-37		DA-34		RA-15		RA-12	
REACT	1181		+140.1	-18.8	-76.3	+21.8	+89.6	+85.3	-3.3	-81.2
CASE	Y	X_2/Z_2	DA-40		DA-36		RA-14		RA-9	
REACT			+140.1	-18.8	-76.3	-21.8	+89.6	+85.3	-3.3	-81.2

X/Z INTERACTION - CONDITIONS & REACTIONS

	Config.	X/Z LOC. 1 → 2 →	$+X_{1\ max}$ $+X_{2\ max}$	Z Z	$-X_{1\ max}$ $-X_{2\ max}$	Z Z	X X	$+Z_{max}$ $+Z_{max}$	X X	$-Z_{max}$ $-Z_{max}$
CASE	2-1	X_1/Z_1	DA-37		DA-34		RA-15		RA-12	
REACT	1128		+132.9	-18.8	-69.1	+21.8	+102.5	+85.3	-16.3	-81.2
CASE	Y	X_2/Z_2	DA-40		DA-35		RA-14		RA-9	
REACT			+132.9	-18.8	-69.1	+21.8	+102.5	+85.3	-16.3	-81.2
CASE										
REACT										
CASE										
REACT										

CONFIG 2-1 1246 X/Z



Y-SUPPORT LOCATION VARIATION - MAX REACTIONS AND GOVERNING LOAD CONDITIONS

Config.	Y_1 Sta.	Item	X_1 +	X_1 -	X_2 +	X_2 -	Y_1 +	Y_1 -	Z_1 +	Z_1 -	Z_2 +	Z_2 -	Z_3 +	Z_3 -	Z_4 +	Z_4 -
1-1	1249	Max R	151.9	85.5	151.9	85.5	57.4	57.4	120.6	120.6	52.2	60.4	103.2	112.3	-	-
		Load Case	DA13	DA33	DA15	DA35	DA19	DA17	DA10	DA12	RA14	RA9	DA10	DA13	-	-
		Other	DA14	DA34	DA16	DA36	DA20	DA18	DA15	DA13	None	None	DA11	DA16	-	-
	1181	Max R	140.1	76.3	140.1	76.3	57.4	57.4	121.5	121.5	61.2	53.0	103.2	112.3	-	-
		Load Case	DA37	DA33	DA39	DA35	DA19	DA17	DA10	DA12	RA14	RA9	DA10	DA13	-	-
		Other	DA38	DA34	DA40	DA36	-	-	DA15	DA13	None	None	-	-	-	-
	1128	Max R	132.9	69.1	132.9	69.1	57.4	57.4	121.5	121.5	61.2	53.0	103.2	112.3	-	-
		Load Case	DA37	DA33	DA39	DA35	DA19	DA17	DA10	DA12	RA14	RA9	DA10	DA13	-	-
		Other	DA38	DA34	DA40	DA36	-	-	DA15	DA13	None	None	-	-	-	-
2-1	1249	Max R	151.9	85.5	151.9	85.5	57.4	57.4	84.5	80.4	84.5	80.4	51.6	56.1	51.6	56.1
		Load Case	DA13	DA33	DA15	DA35	DA19	DA17	RA15	RA12	RA14	RA9	DA10	DA13	DA10	DA13
		Other	DA14	DA34	DA16	DA36	DA20	DA18	None	None	None	None	DA11	DA16	DA11	DA16
	1181	Max R	140.1	76.3	140.1	76.3	57.4	57.4	85.3	81.2	85.3	81.2	51.6	56.1	51.6	56.1
		Load Case	DA37	DA33	DA39	DA35	DA19	DA17	RA15	RA12	RA14	RA9	DA10	DA13	DA10	DA13
		Other	DA38	DA34	DA40	DA36	-	-	None	None	None	None	-	-	-	-
	1128	Max R	132.9	69.1	132.9	69.1	57.4	57.4	85.3	81.2	85.3	81.2	51.6	56.1	51.6	56.1
		Load Case	DA37	DA33	DA39	DA35	DA19	DA17	RA15	RA12	RA14	RA9	DA10	DA13	DA10	DA13
		Other	DA38	DA34	DA40	DA36	-	-	-	-	-	-	-	-	-	-

RA = Retrieval configuration, Ascent mission phases

DA = Deployment config., Ascent mission phases

B.3 Convair Memo D-75-3, 14 January 1975

To: E. H. Bock

From: Structural Dynamics - 642-4

SUBJECT: DYNAMIC LOADS ANALYSIS FOR TUG/SHUTTLE INTERFACE STUDY FOR THE SHUTTLE LIFT-OFF CONDITION

References:

1) "Space Shuttle System Summary", Rockwell International Space Division Presentation Viewgraph No. 63SSV5298B, July 1973.
2) "Payload Accommodations", Rockwell International Space Division Presentation Viewgraph No. 64SSV21628B.

Enclosures:

a) Plots of Vibration Modes of 4 Tug Support Configurations
b) Response Time Histories of Support Case No. 1 Subject to Shuttle Lift-off Transient.

This report presents the results of the dynamic modal and transient analyses performed on four attachment configurations under investigation for the Tug/Shuttle interface study. The resultant modal frequencies and dynamic responses for the lift-off condition are summarized in Tables 1 and 2.

DISCUSSION

Four Tug/Shuttle interface attachment configurations are analyzed for the shuttle lift-off transient. These configurations as shown in Figure 1 are:

Case (1): non-redundant system, one forward Z support

Case (2): non-redundant system, two forward Z supports with load balancing system

Case (3): redundant system, two forward Z supports

Case (4): non-redundant system, one forward Z support with forward Y support

Vibrations modes are determined from a simplified 3-dimensional NASTRAN model as shown in Figure 2, with the appropriate attachment constraints. By this method the shells of the Tug and deploy adapter are modeled as a single beam located at the centerline. Directional springs representing the attachment structure and any local shell flexibility are attached to rigid arms extending to the outside of the shell at Stations 951 and 1246 (1128 for the forward Y support case). The engine and the fuel tanks are considered rigid, attached to the shell by the proper spring stiffness representing the connecting truss system. All stiffness properties are as defined by the Structural Analysis Group, generated by a complex SOLID SAP model of the Tug. The stiffness of the 11,000 lbs. payload is considered the same as the forward part of the tug. The tank weights are 6694 lbs. for the LH_2 and 39188 lbs. for the LO_2.

The modal frequencies calculated for each support configuration are shown in Table 1. Plots of the first five modes for each support case and the undeformed shape are shown in Enclosure a. For convenience, the plots of modes 1 and 2 for the basic support case, No. 1, are reproduced in Figures 3 and 4. These two modes of 3.3 and 4.2 Hz occur close to the fundamental driving frequency (2 to 3 Hz) of the orbiter. These particular modes will present problems because of the large amplification of the response when the vehicle is subjected to the orbiter interface excitation. By adding a second Z support at Station 951, either with or without the load balancing system, as shown for Case No. 2 and No. 3, the second mode (roll-translation) can be eliminated. However the low first frequency mode, a bending mode in the Y direction, still exists. Moving the Y support forward, as shown for Case No. 4, offers little assistance in increasing the frequency of the first mode.

To determine how much amplification will result because of these two low frequency modes, a transient response analysis is performed for support Case No. 1. This is accomplished by equating the accelerations at the orbiter support nodes (Nodes 91 through 94) to the acceleration expected during the lift-off condition. This condition produces the largest loads on the shuttle payloads. All supports in a particular direction are assumed to receive the same acceleration from the orbiter as shown in Figure 5. These time history traces are taken from Reference 1 with a modification to the maximum amplitude of the acceleration in the lateral directions as provided by Reference 2 (1.0 g's in Y direction and 1.5 g's in the Z).

Table 2 shows the results of a NASTRAN response analysis performed for support Case No. 1. Sample response time histories are shown in Figures 6 through 8 with the other plots presented in Enclosure b. Large dynamic loads of 26 g's acceleration and 24 inches deflection are primarily due to excitation of the fundamental mode of vibration. The only way to reduce these large responses is to eliminate or increase the mode at 3.3 Hz to above 5 Hz by providing additional bending constraints in the Y direction.

RECOMMENDATIONS

The basic Tug attachment configuration shown as Case No. 1 in Figure 1 receives excessive dynamic loads when subjected to the Shuttle lift-off transient. These loads can be reduced if the frequencies of the first two modes are increased to over 5 Hz. It is recommended that additional studies be performed in an effort to increase the bending stiffness in the X-Y plane. This stiffness may be provided by the addition of a Y support at Station 951. It is also recommended that an additional Z support at Station 951 also be considered as shown for Case No. 2 or 3 in Figure 1.

Prepared by: W. M. Dreyer (signature)
W. M. Dreyer

Checked by: (signature)
R. G. Huntington

Approved by: (signature)
H. A. Mitchell

cc: E. H. Bock, 610-1 (3; 2 w/o encls.)
J.E. Dyer, 969-4 (w/o enclosures)
D. L. Browning, 610-01 (w/encls.)

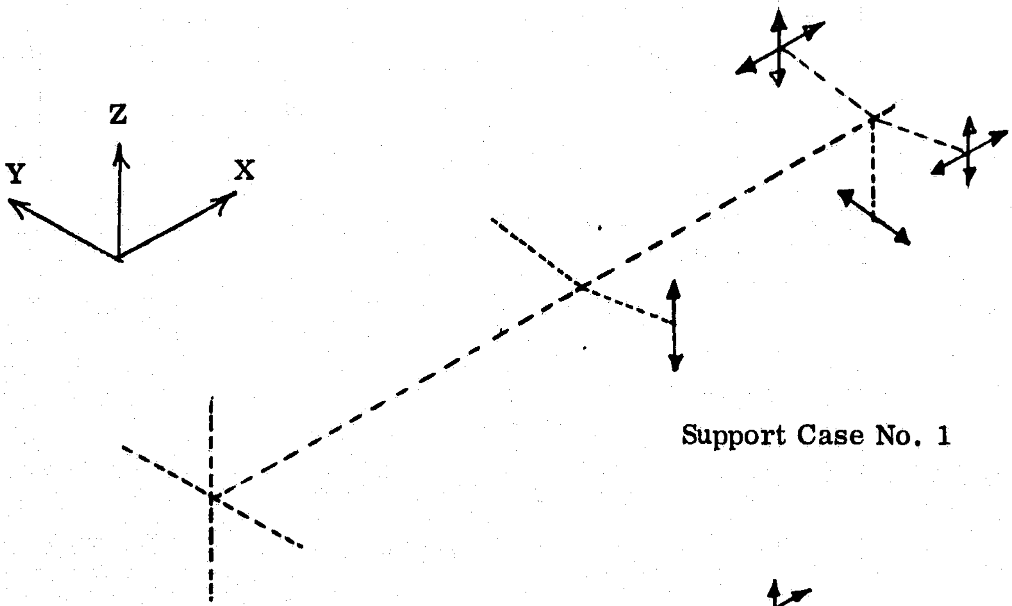
Table 1. TUG/SHUTTLE INTERFACE VIBRATION FREQUENCIES

Mode	Support Case No. 1 Hz	Support Case No. 2 Hz	Support Case No. 3 Hz	Support Case No. 4 Hz
1	3.33	3.36	3.39	3.46
2	4.22	5.57	5.63	4.40
3	5.65	5.99	5.99	5.38
4	6.10	6.72	6.72	6.11
5	11.51	11.51	11.53	11.57
6	11.75	12.04	12.04	11.97
7	12.06	13.08	13.42	12.10
8	17.16	13.42	17.16	17.15
9	17.54	17.16	21.66	17.97
10	21.67	21.67	24.36	21.95
11	24.98	24.98	24.98	24.98
12	25.48	25.63	25.63	25.49
13	26.89	26.89	26.89	27.24
14	28.34	29.23	29.23	28.34
15	31.51	31.51	31.51	31.51
16	35.45	35.43	35.47	33.98
17	40.97	40.72	41.83	42.25
18	43.72	43.73	43.75	44.03
19	48.13	55.38	55.38	48.15
20	58.15	56.54	58.15	57.32

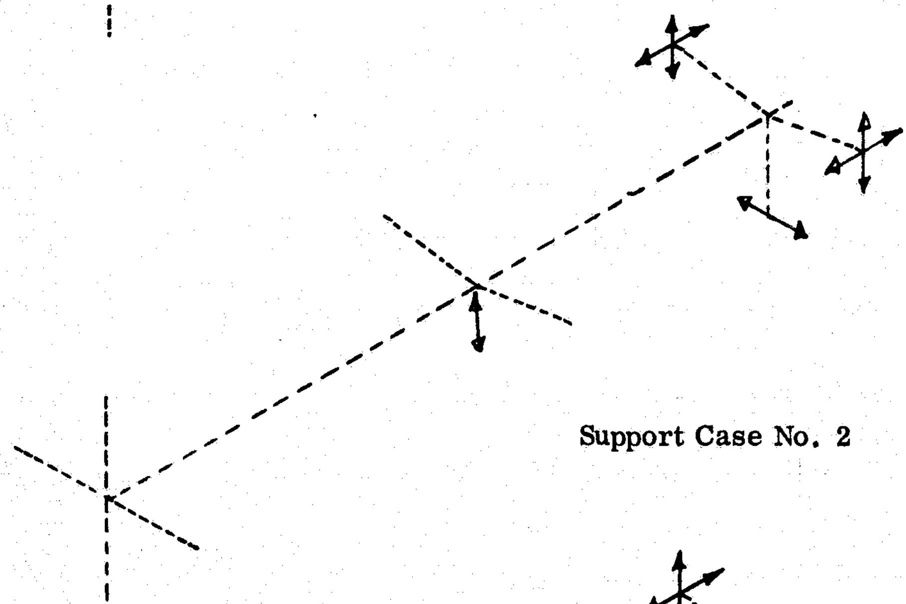
Table 2. SUMMARY OF LIFT-OFF RESPONSE ANALYSIS ON SUPPORT CONFIGURATION NO. 1

		DIRECTION	
ACCELERATION (g's)	X (Includes Gravity)	Y	Z
Node 10	3.4	26.4	8.5
20	3.4	12.4	3.7
25	3.4	4.9	2.1
52	3.4	2.9	1.6
32	3.4	9.5	3.2
41	3.4	6.0	2.8
91	-	1.0	-
92	3.43	-	1.5
93	3.43	-	1.5
94	-	-	1.5
DISPLACEMENT (in.) (Relative to Orbiter)			
Node 10	.14	24.2	6.4
20	.14	12.2	2.3
27	2.4	12.0	3.9
SUPPORT FORCE (lb.)			
91 -54	-	492000	-
92 - 53	735000	-	323000
93 - 55	740000	-	323000
94 - 26	-	-	153000

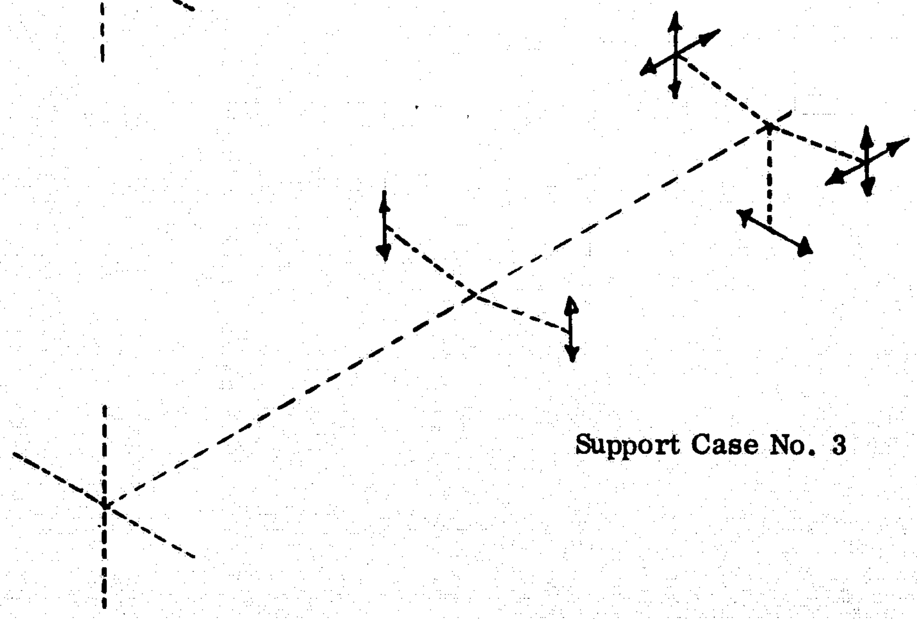
Figure 1.TUG SUPPORT CONFIGURATIONS



Support Case No. 1

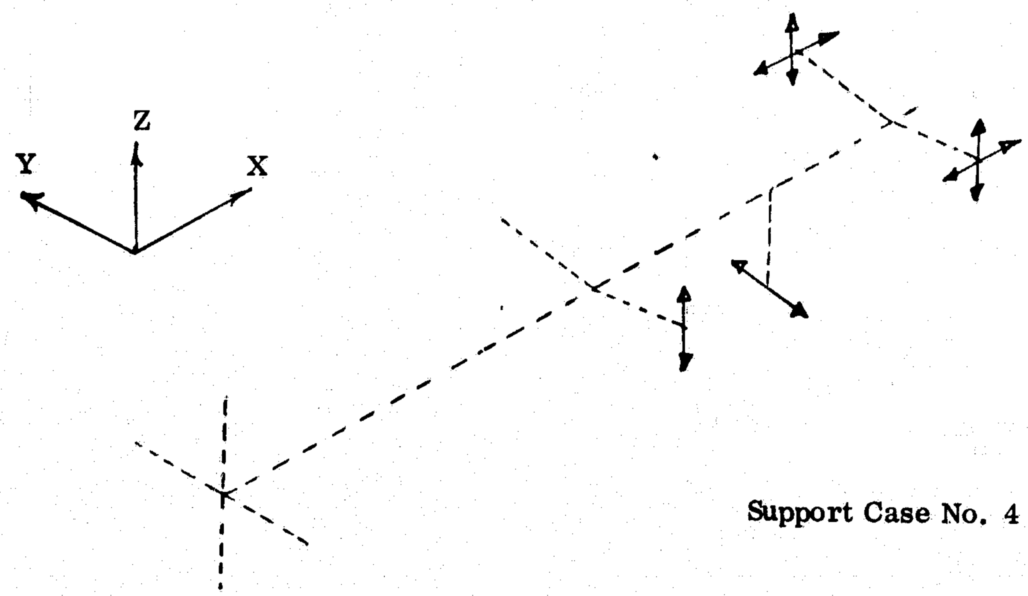


Support Case No. 2



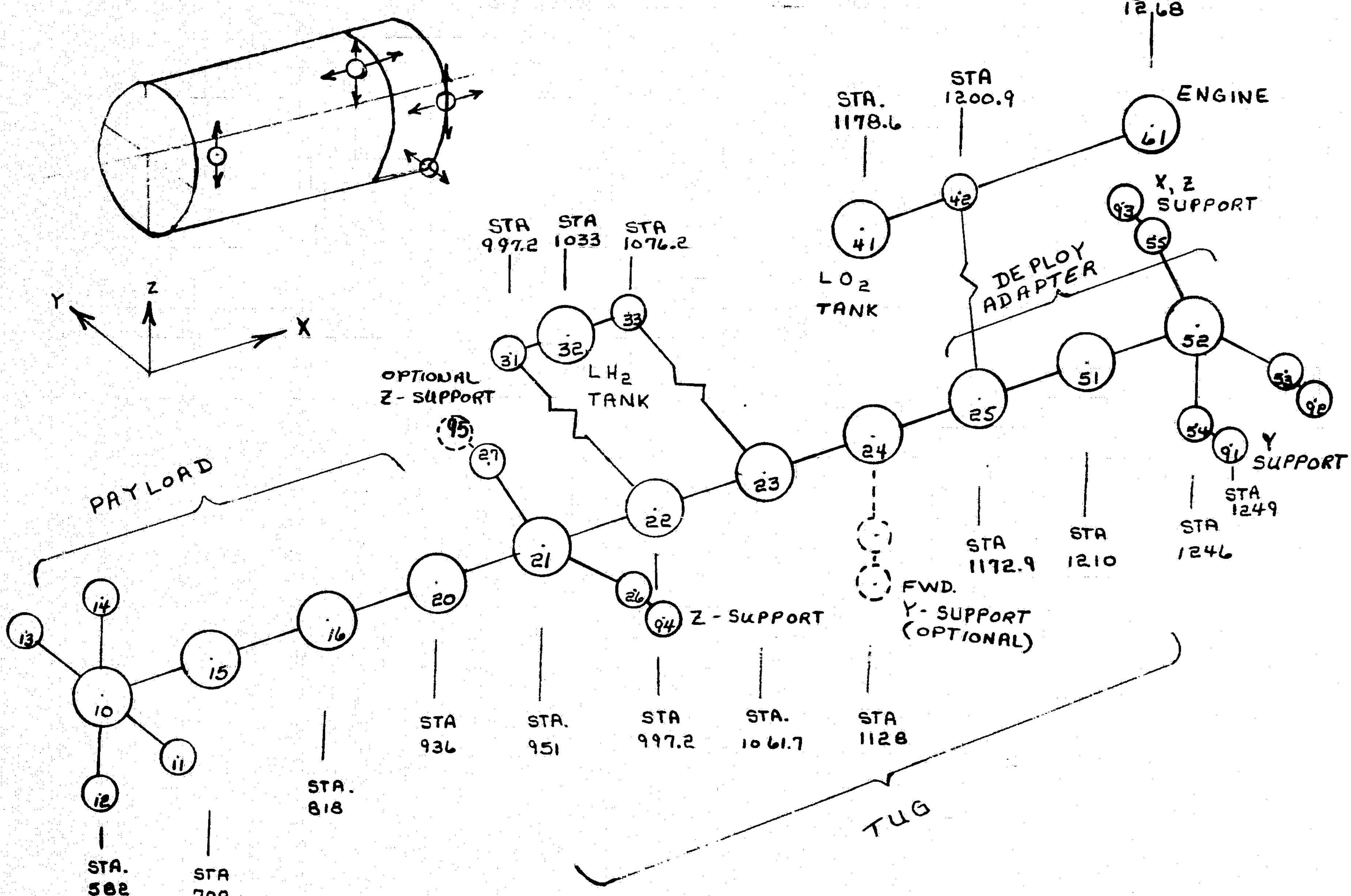
Support Case No. 3

Fig. 1 (Cont.) TUG SUPPORT CONFIGURATIONS (Cont.)



Support Case No. 4

Figure 2. DYNAMIC MODEL OF TUG



TUG NORMAL MODE ANALYSIS 12/05/74
UNDEFORMED
A1(3.33)

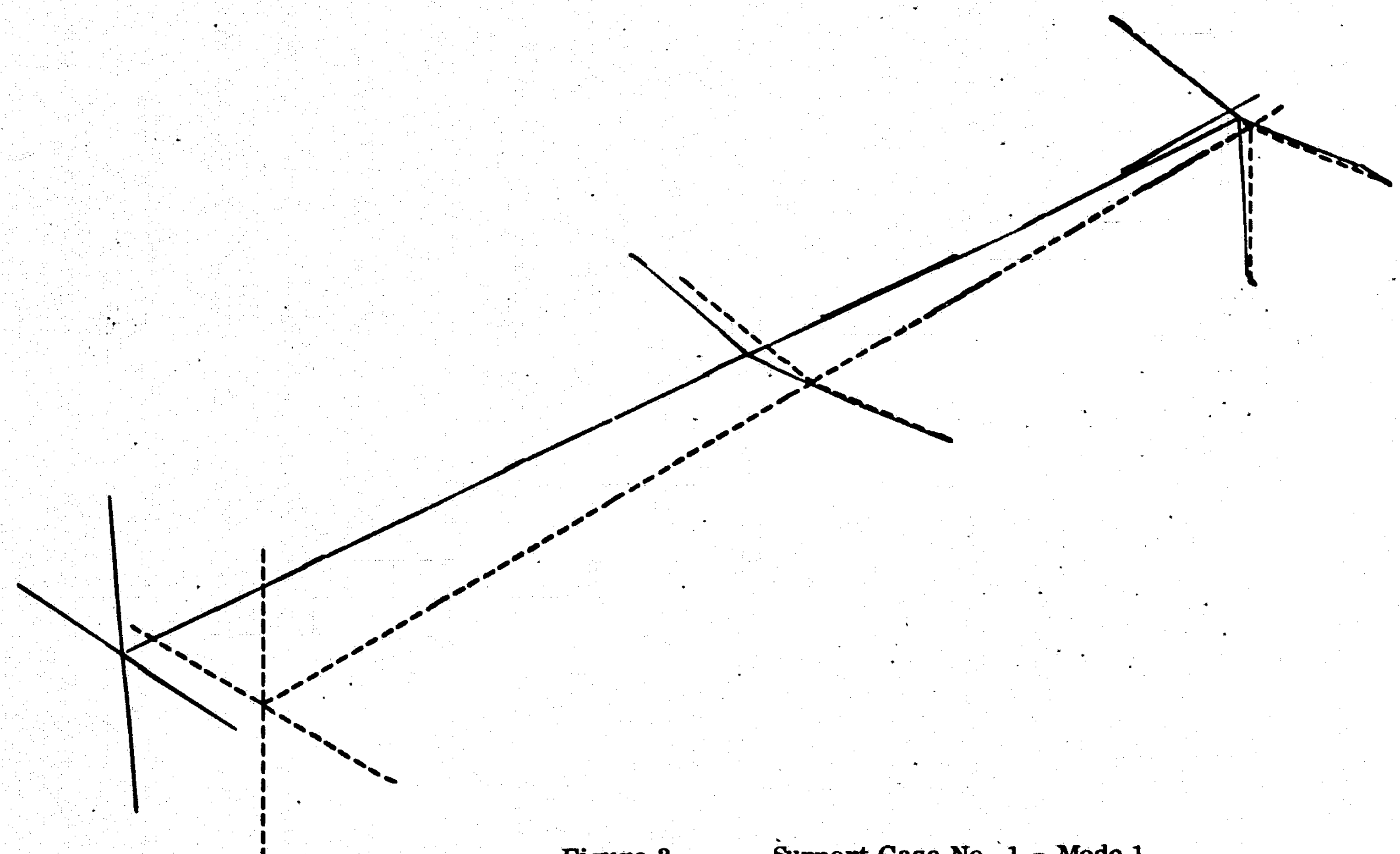


Figure 3. Support Case No. 1 - Mode 1

TUG NORMAL MODE ANALYSIS 12/05/74
A2(4.22)

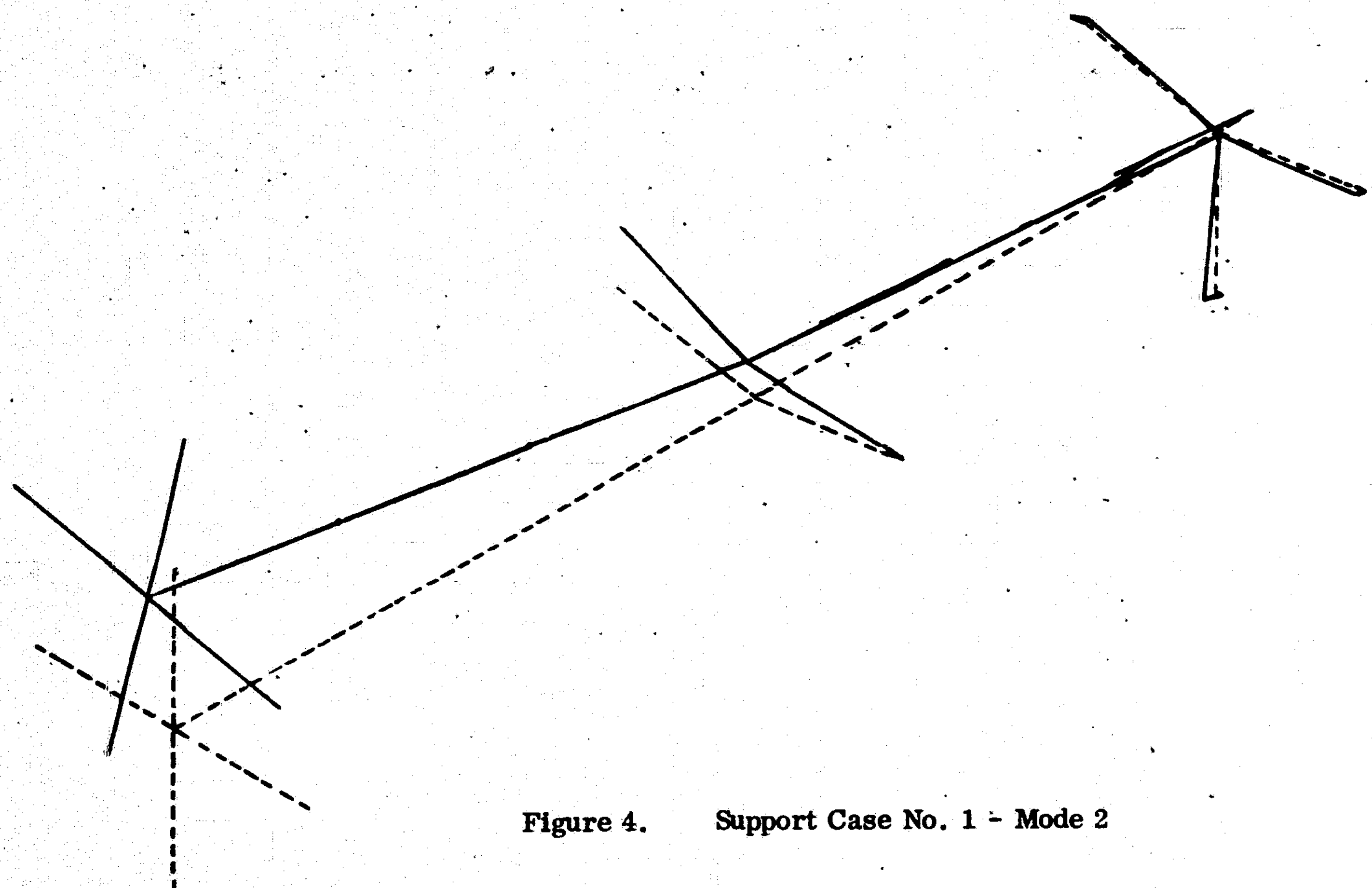
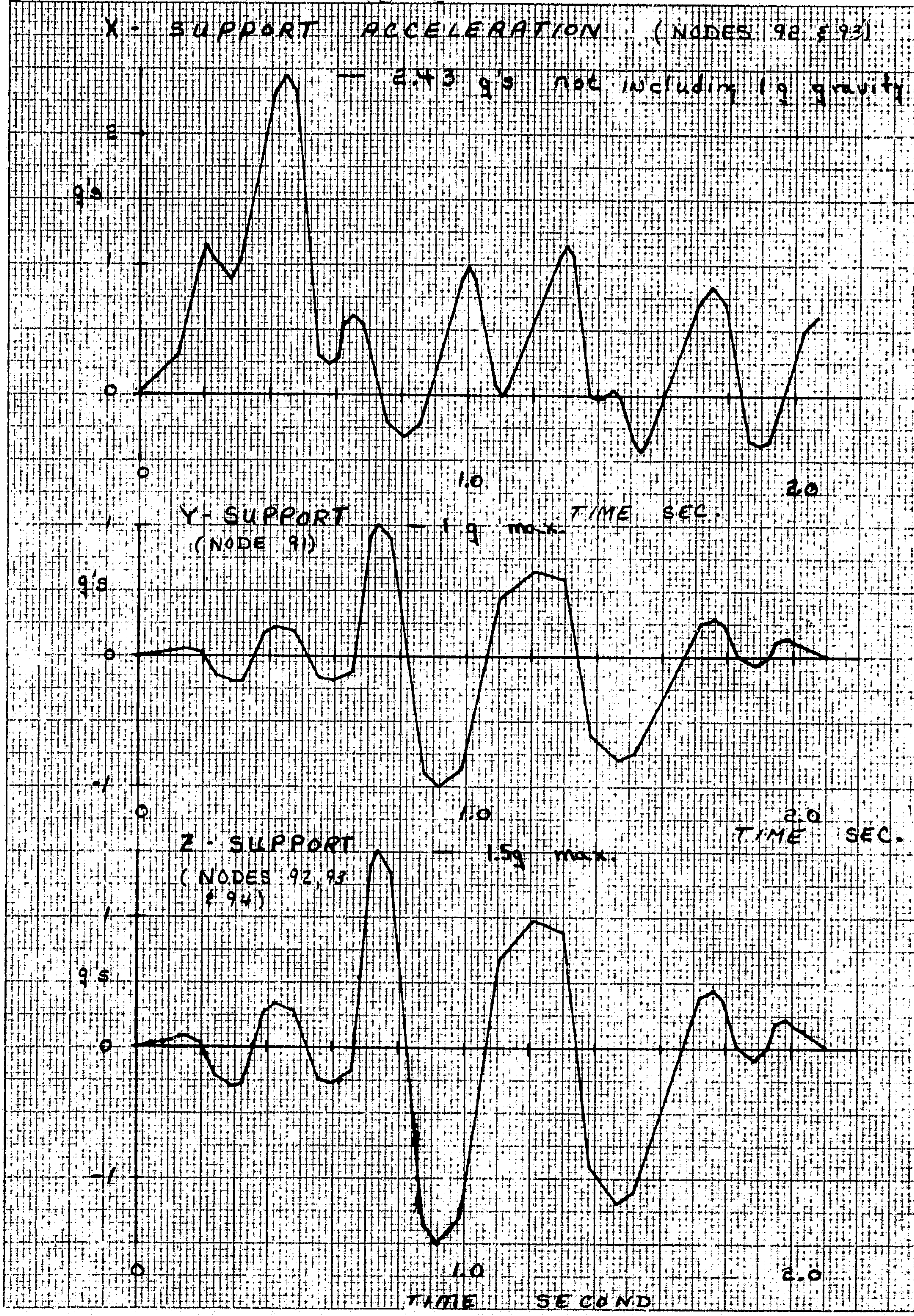


Figure 4. Support Case No. 1 - Mode 2

Figure 5


X - SUPPORT ACCELERATION (NODES 92 & 93)
— 2.43 g's not including 1g gravity
g's
2
1
0
0
1.0
2.0
TIME SEC.
Y - SUPPORT — 1 g max.
(NODE 91)
g's
1
0
-1
0
1.0
2.0
TIME SEC.
Z - SUPPORT — 1.5g max.
(NODES 92, 93
& 94)
g's
1
0
-1
0
1.0
2.0
TIME SECOND

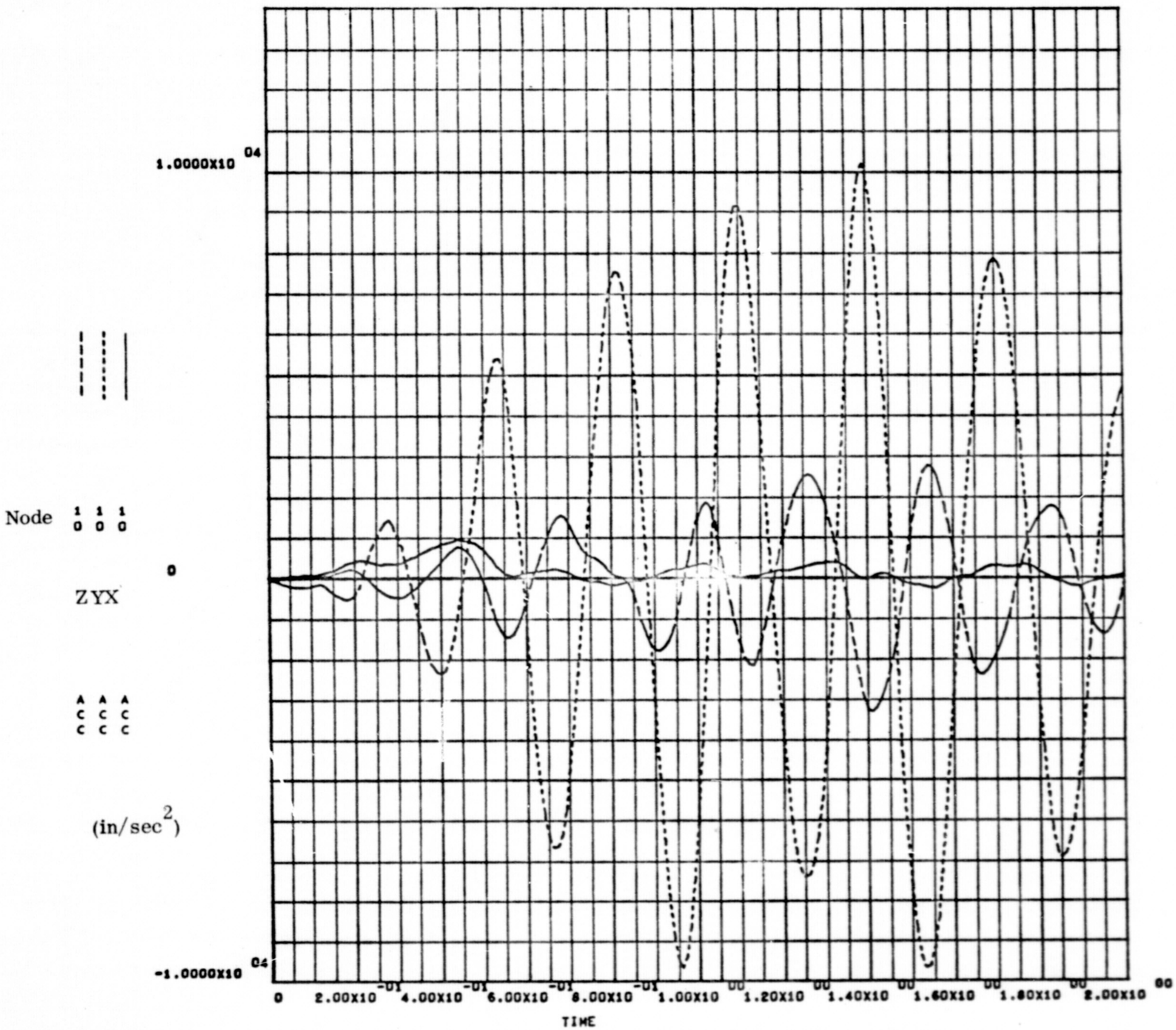


Figure 6. ACCELERATION RESPONSE OF NODE 10

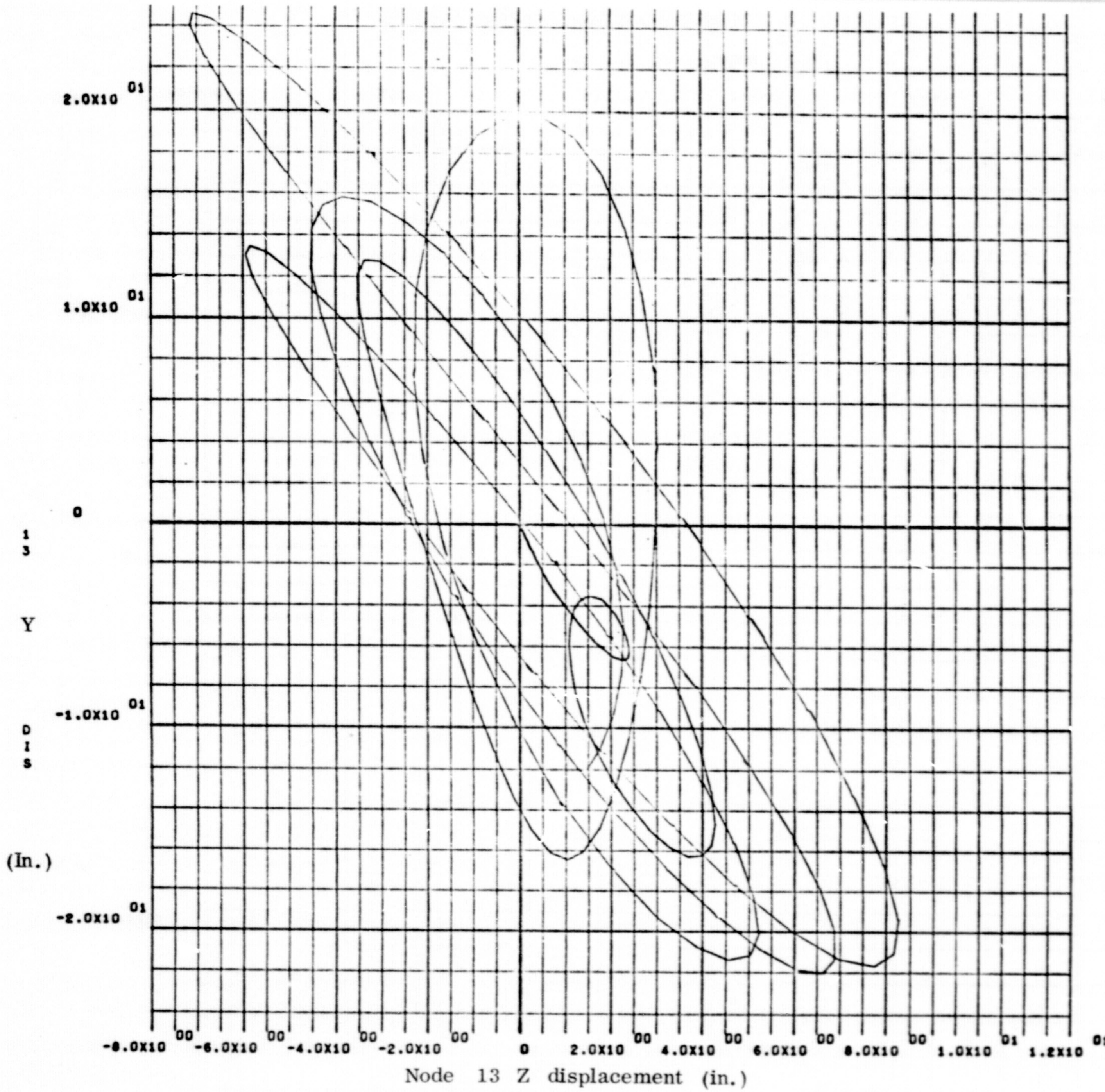


Figure 7. DISPLACEMENT RESPONSE OF NODE 13

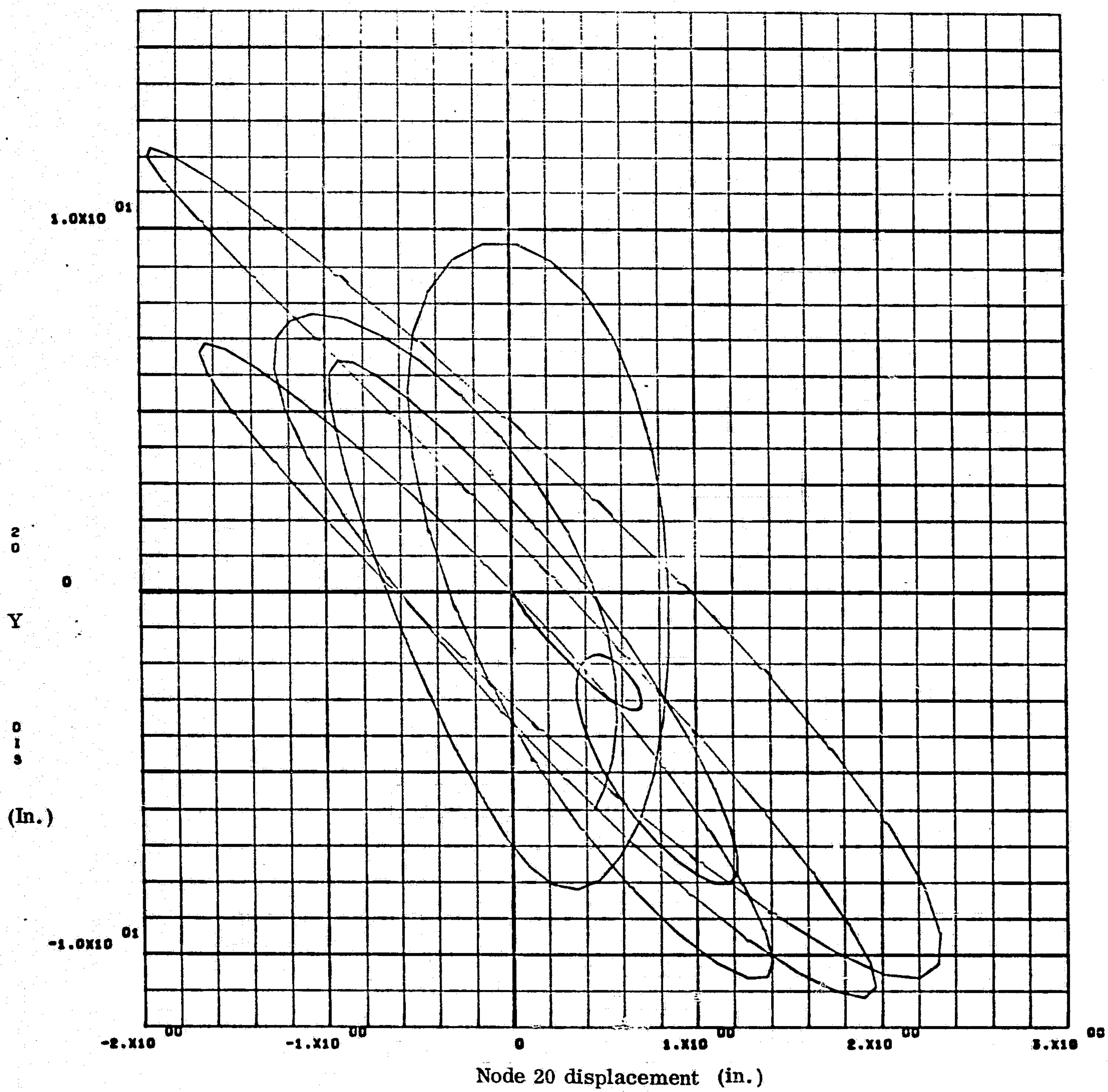
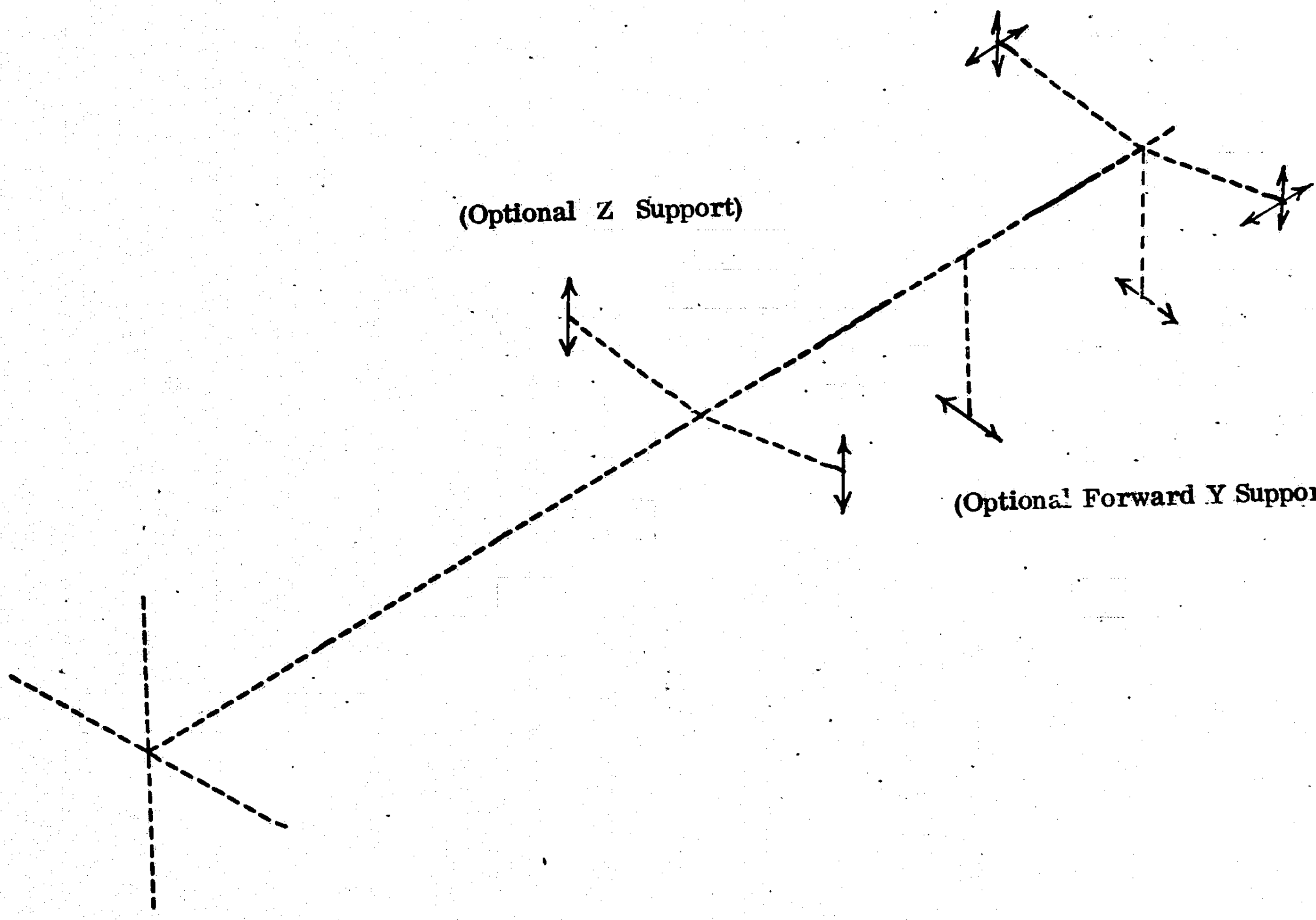


Figure 8. DISPLACEMENT RESPONSE OF NODE 20

DYNAMIC LOADS ANALYSIS FOR THE TUG/SHUTTLE INTERFACE STUDY FOR THE SHUTTLE LIFT-OFF CONDITION

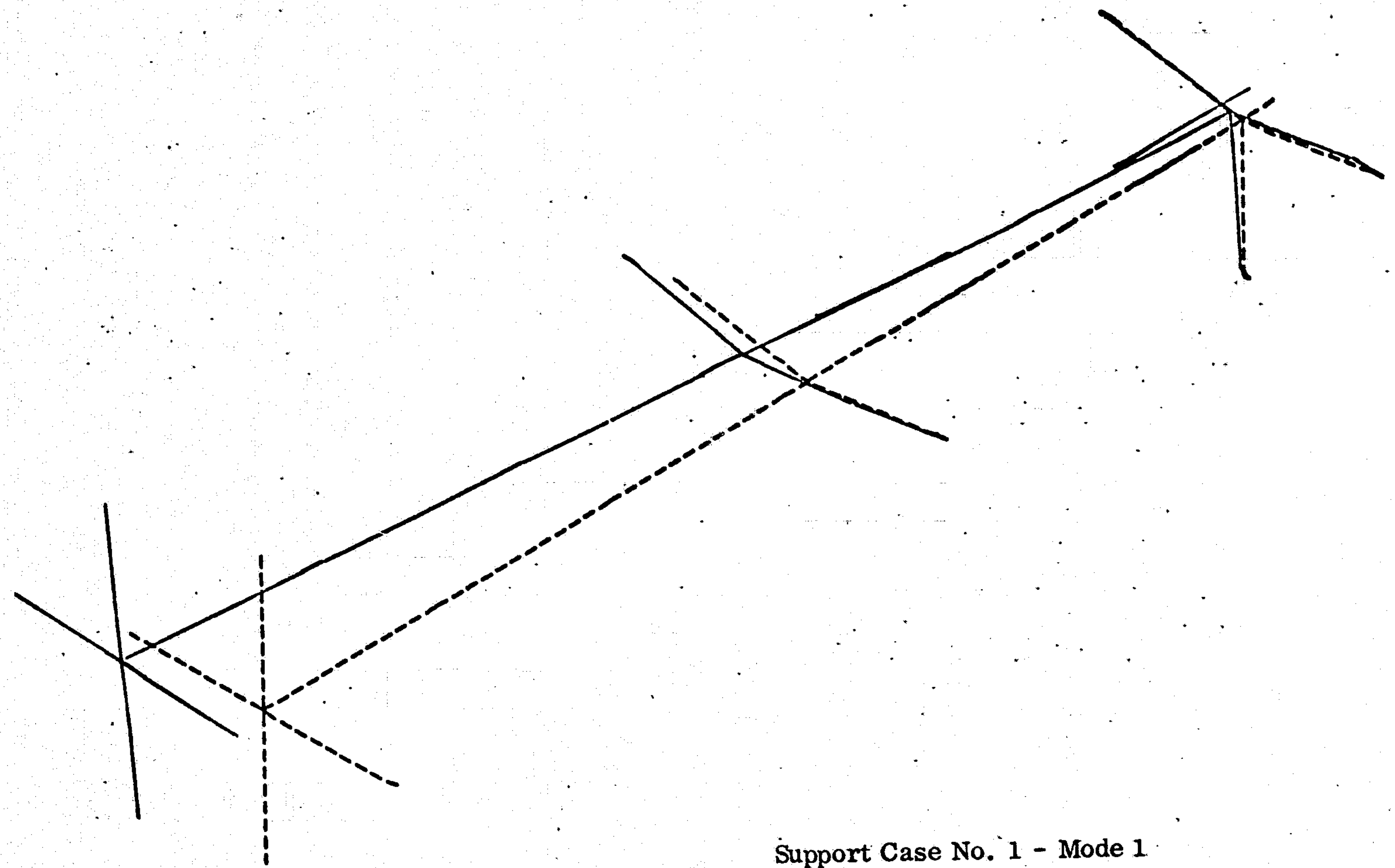
Enclosure a) Plots of vibration modes of 4 Tug support configurations.

This enclosure presents the plots of the first five dynamic modes of the four Tug support configurations as shown in Figure 1 of the text. Table 1 lists the frequency for the first twenty modes of each configuration.



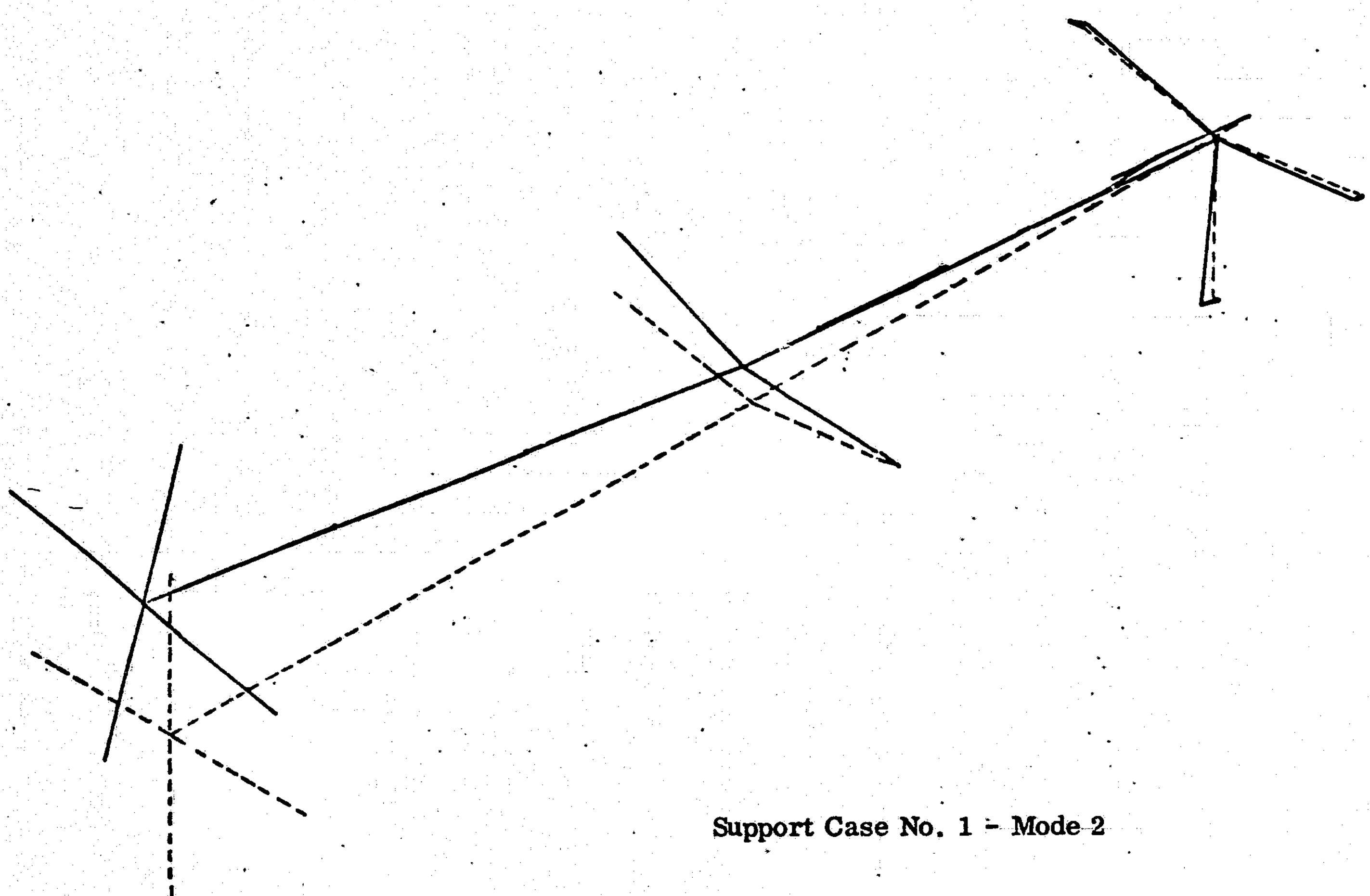
Undeformed Dynamic Model Configuration

TUG NORMAL MODE ANALYSIS 12/05/74
UNDEFORMED
A1(3.33)



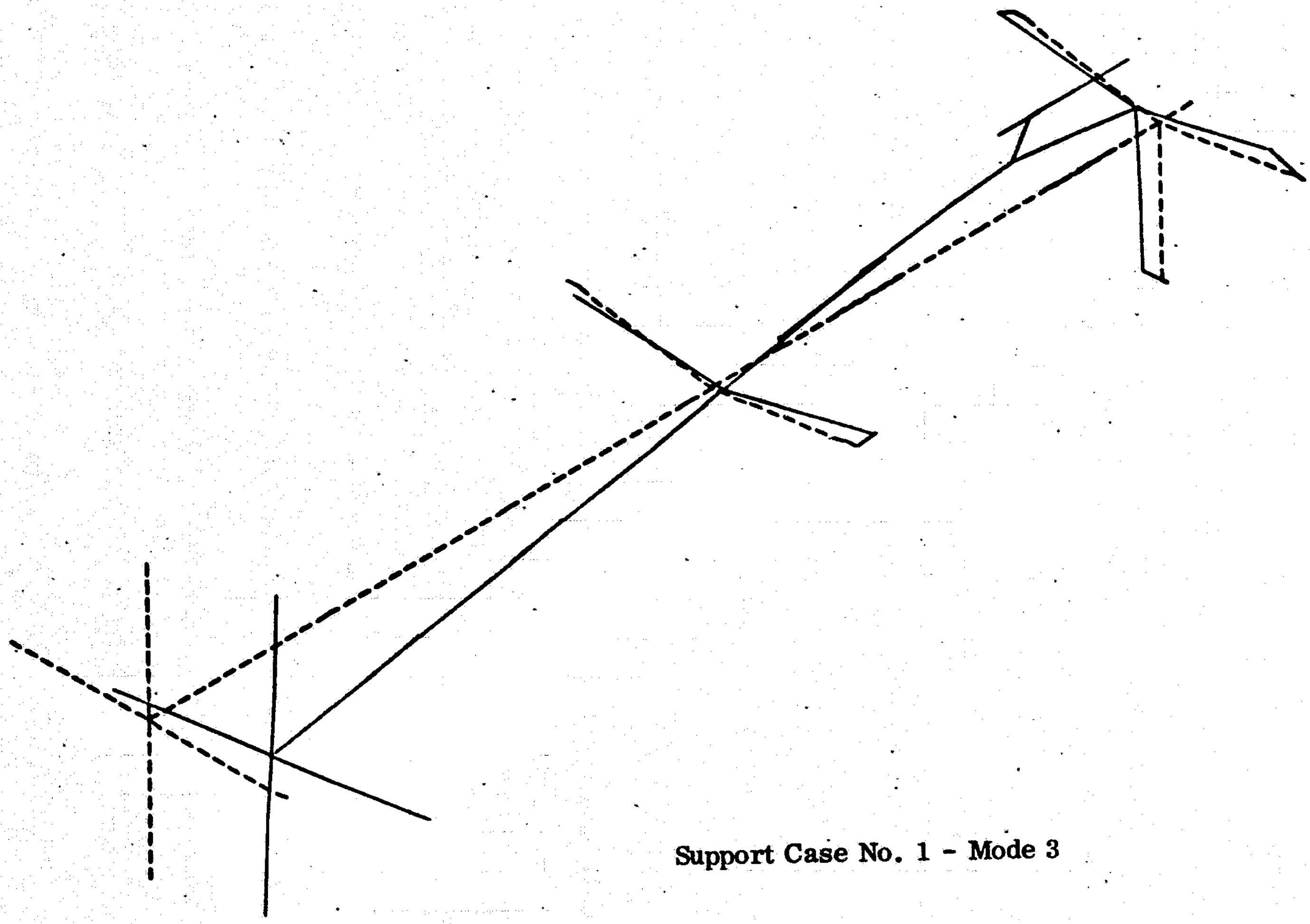
Support Case No. 1 - Mode 1

TUG NORMAL MODE ANALYSIS 12/05/74
A2(4.22)

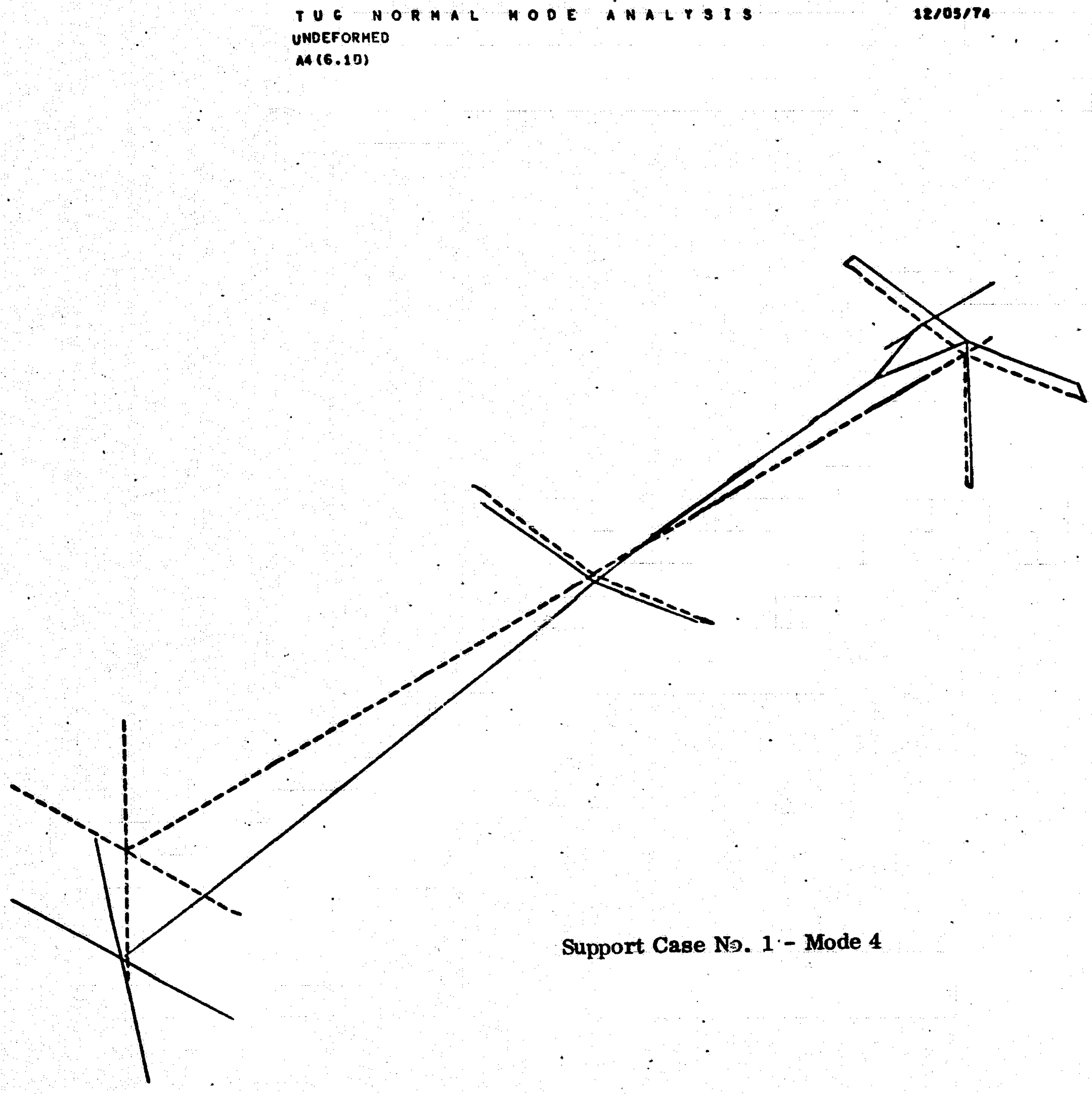


Support Case No. 1 - Mode 2

TUG NORMAL MODE ANALYSIS 12/05/74
UNDEFORMED
A3(5.65)

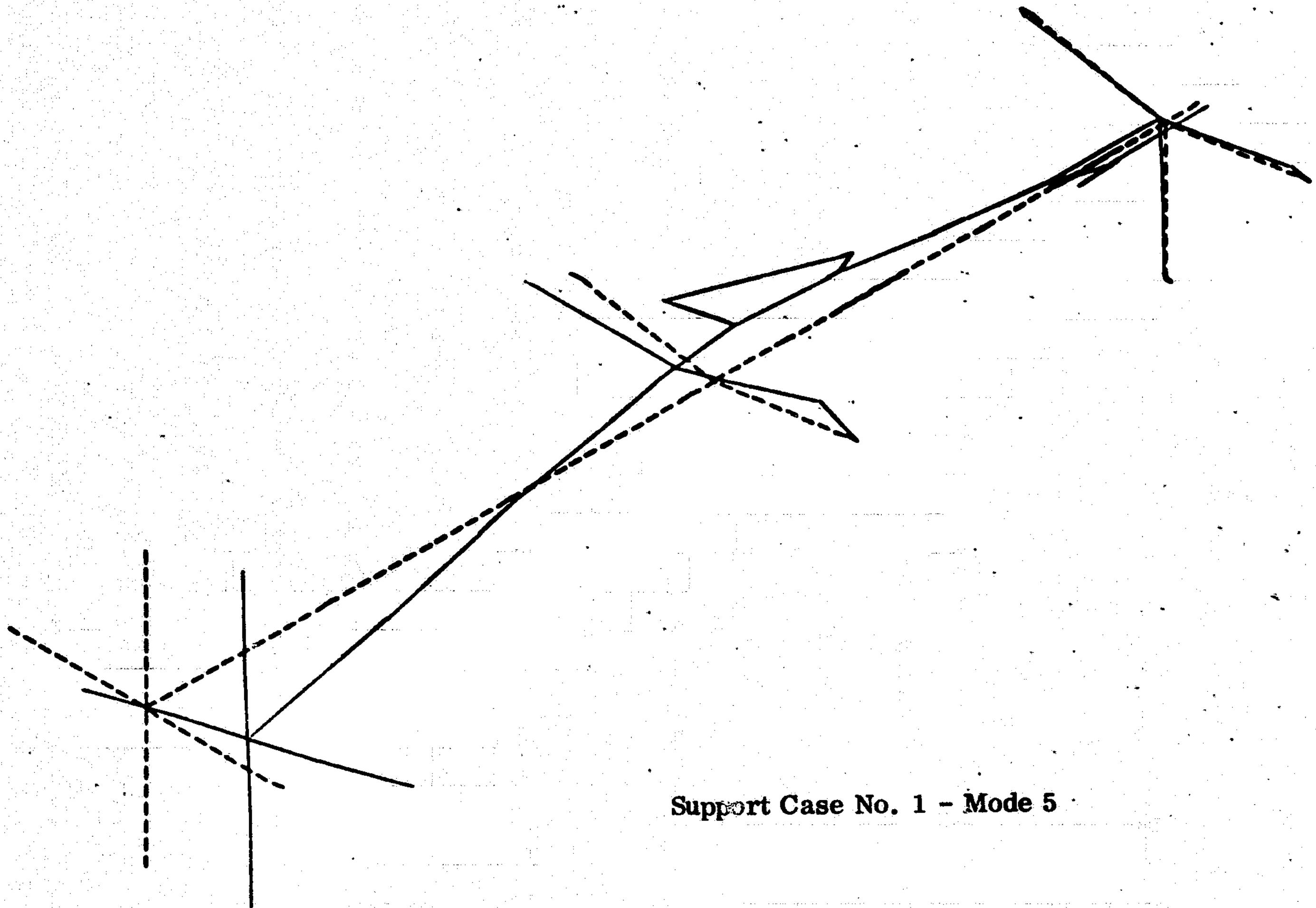


Support Case No. 1 - Mode 3



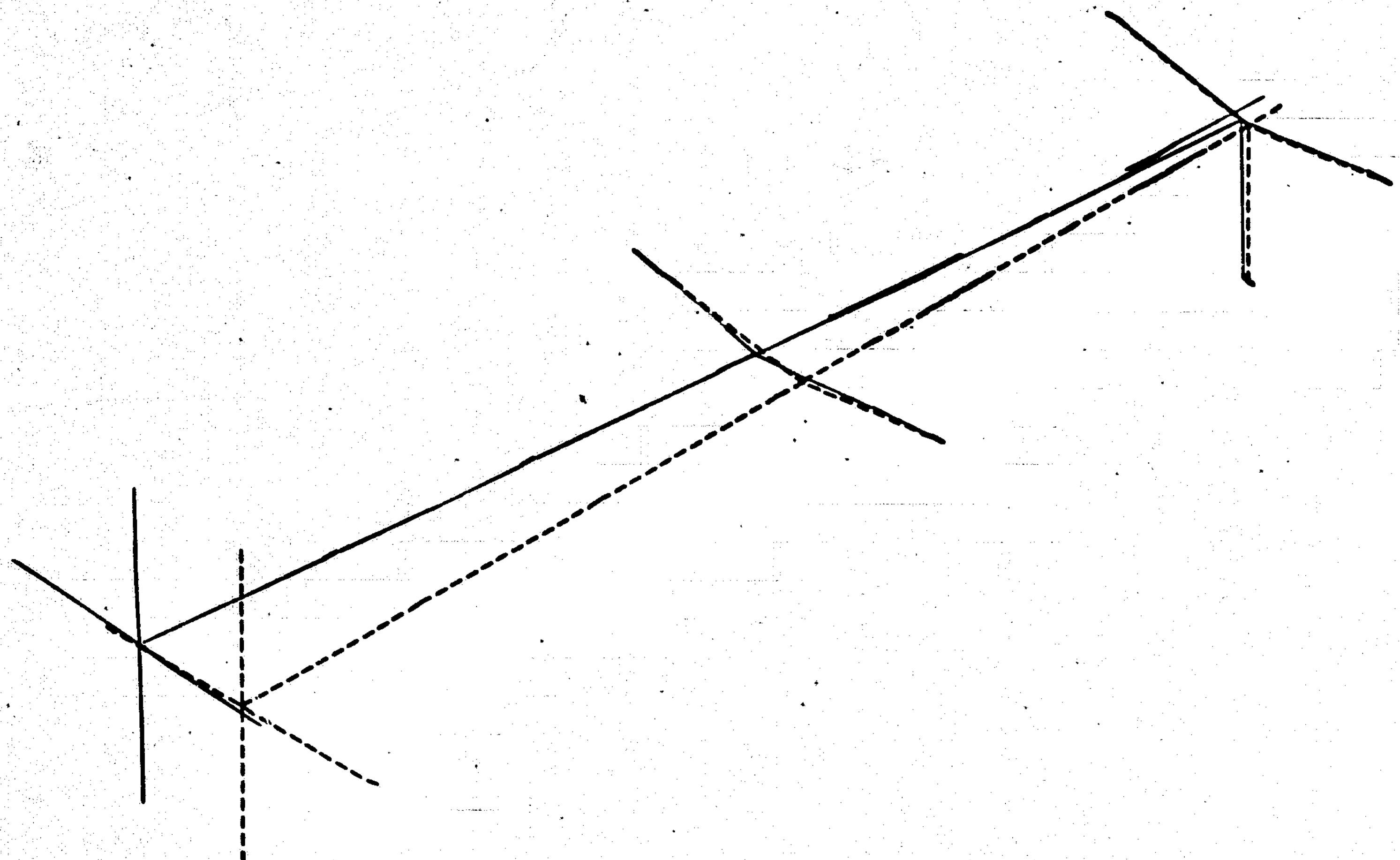
Support Case No. 1 - Mode 4

TUG NORMAL MODE ANALYSIS 12/03/74
UNDEFORMED
A5(11.5)



Support Case No. 1 - Mode 5

TUG NORMAL MODE ANALYSIS 12/05/74
UNDEFORMED
S1(3.36)

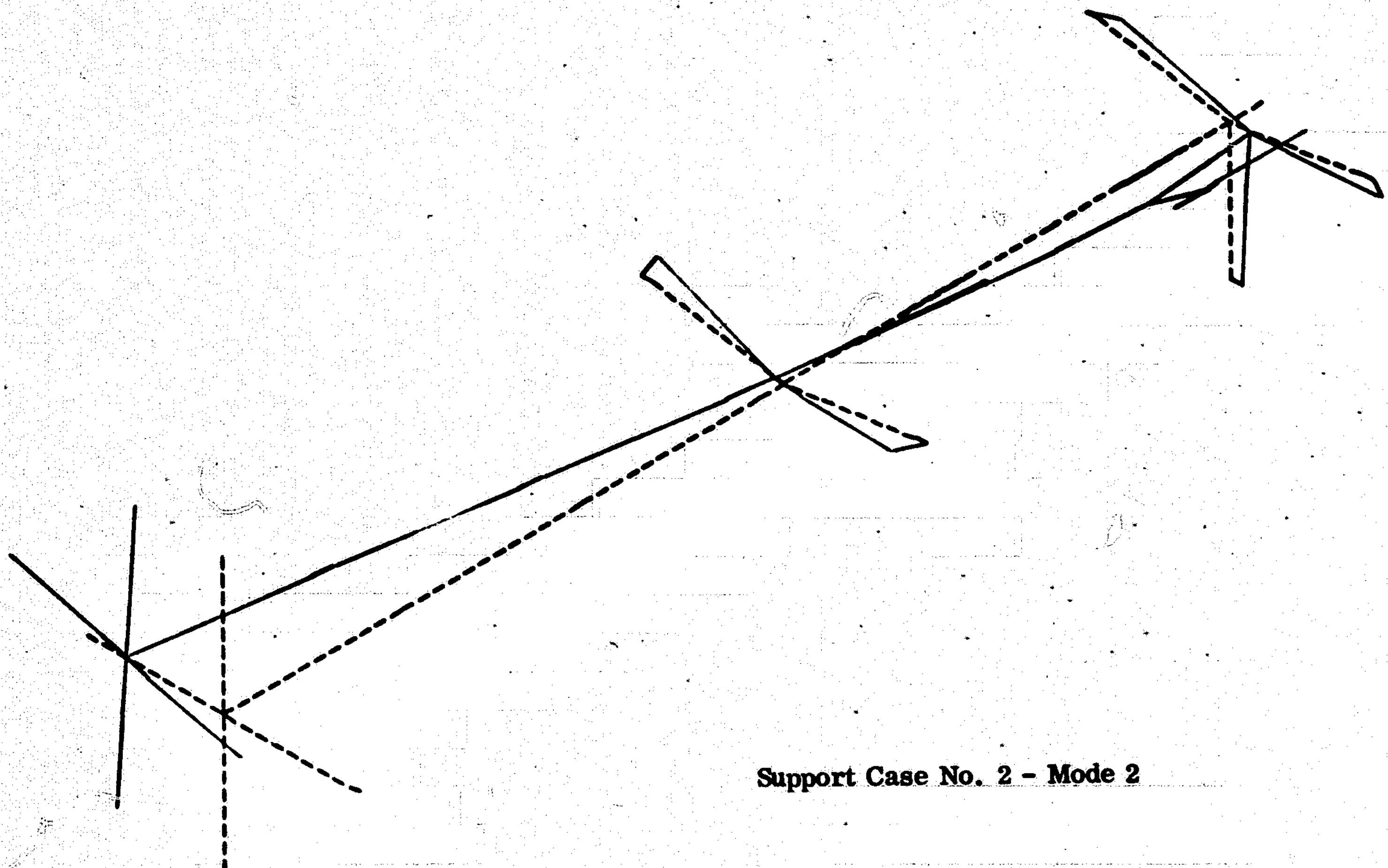


Support Case No. 2 - Mode 1

TUG NORMAL MODE ANALYSIS 12/05/74

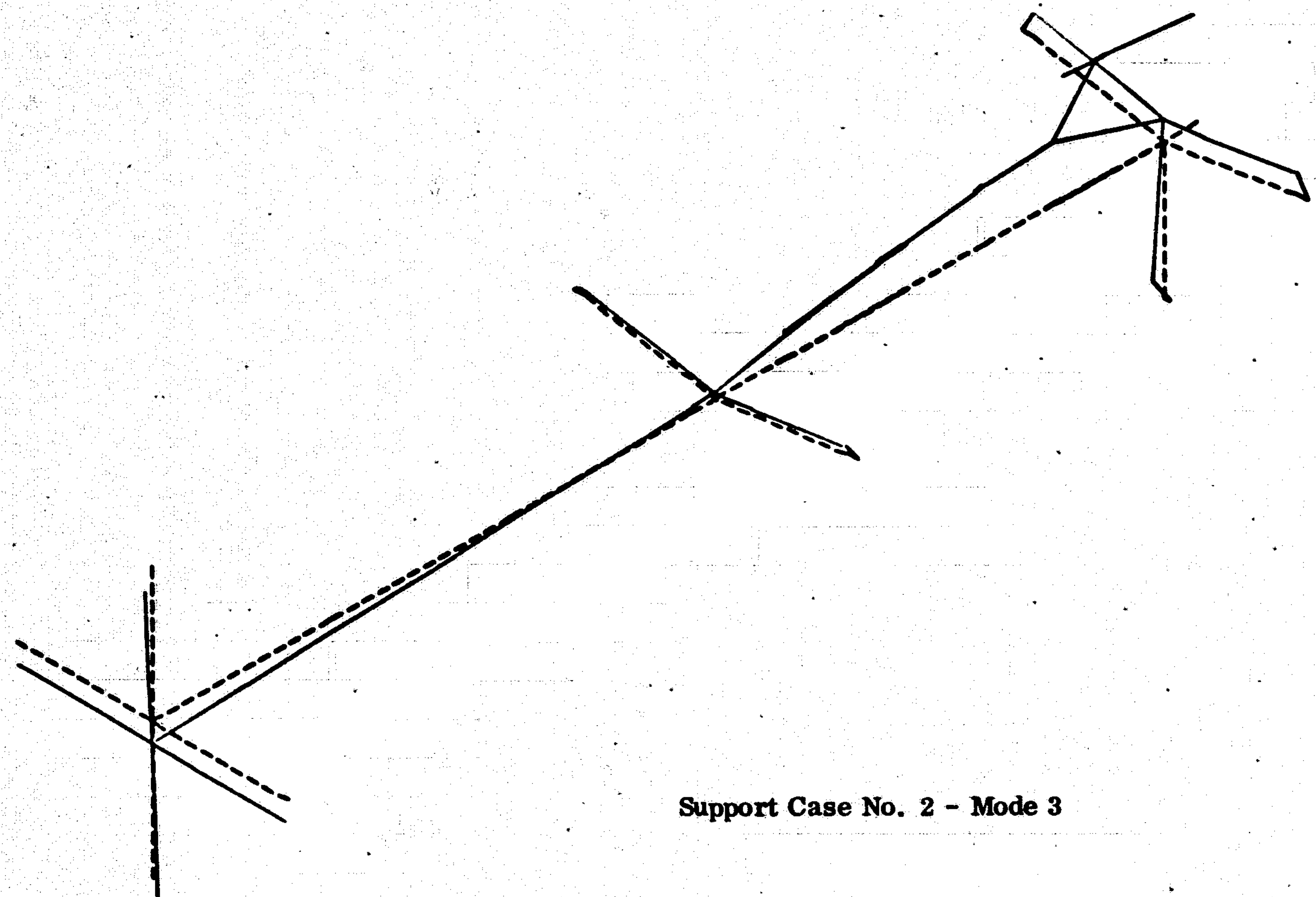
UNDEFORMED

S2(5.57)



Support Case No. 2 - Mode 2

TUG NORMAL MODE ANALYSIS 12/05/74
UNDEFORMED
S3(5.99)

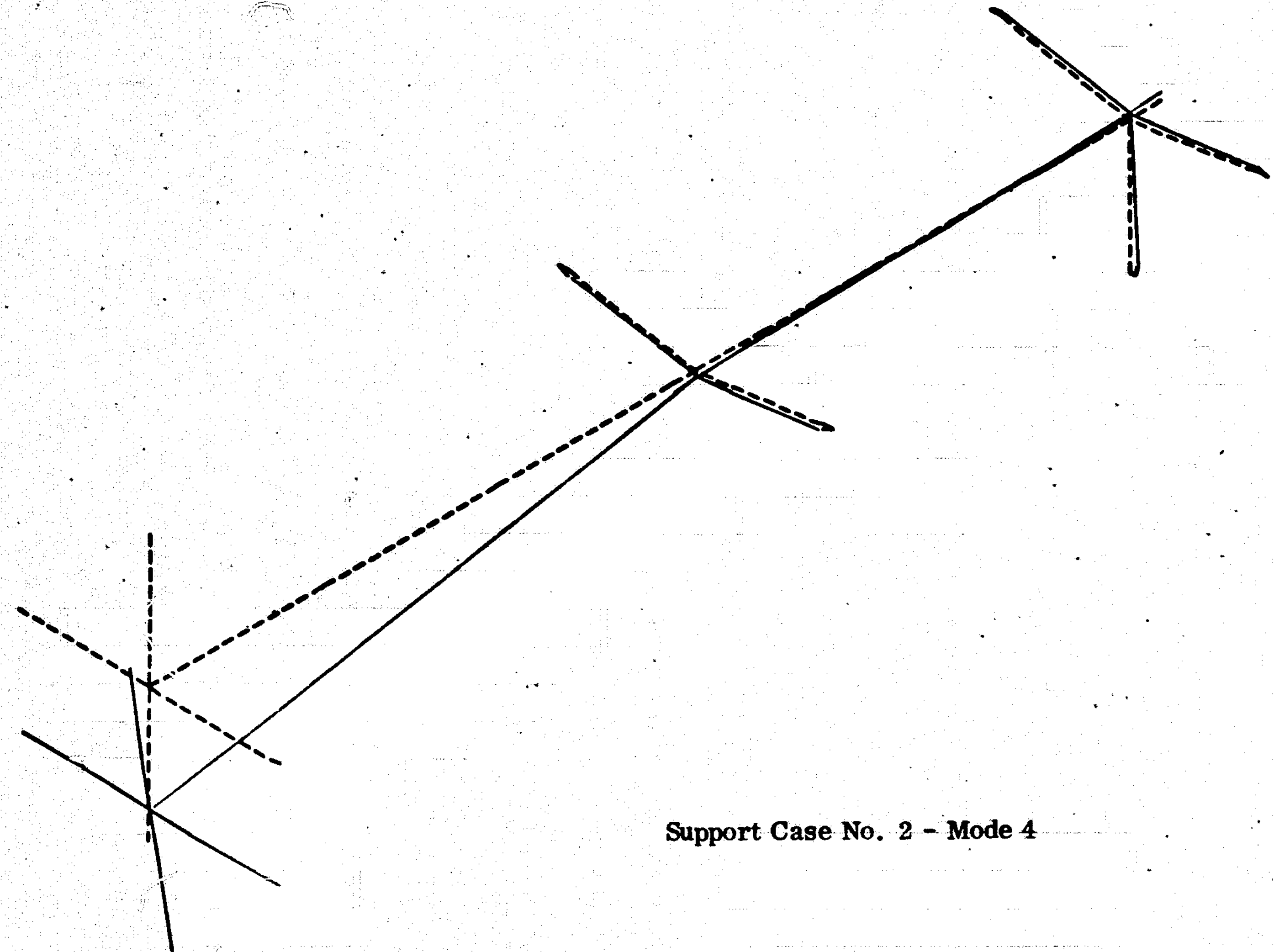


Support Case No. 2 - Mode 3

TUG NORMAL MODE ANALYSIS 12/05/74

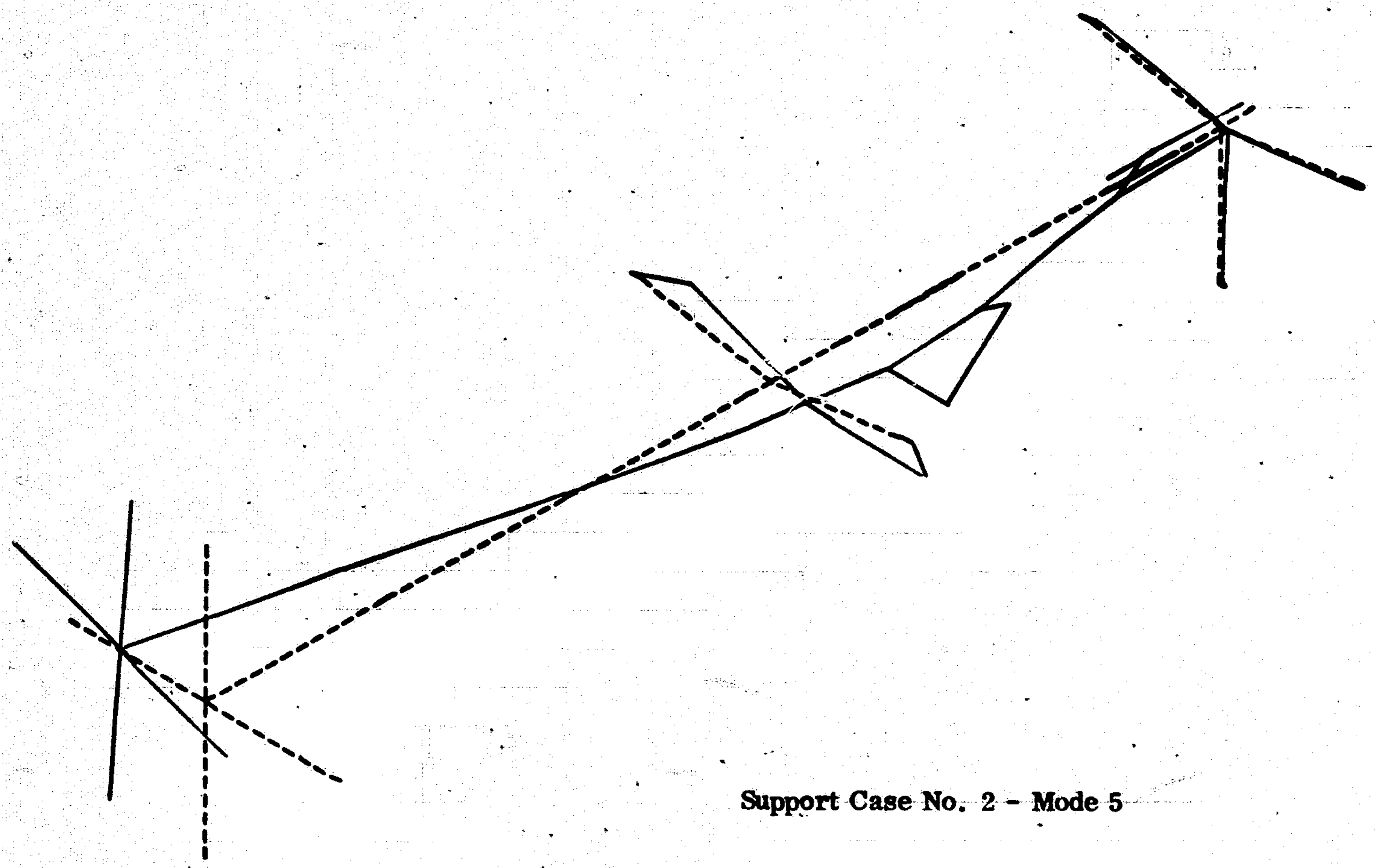
UNDEFORMED

S4(6.72)



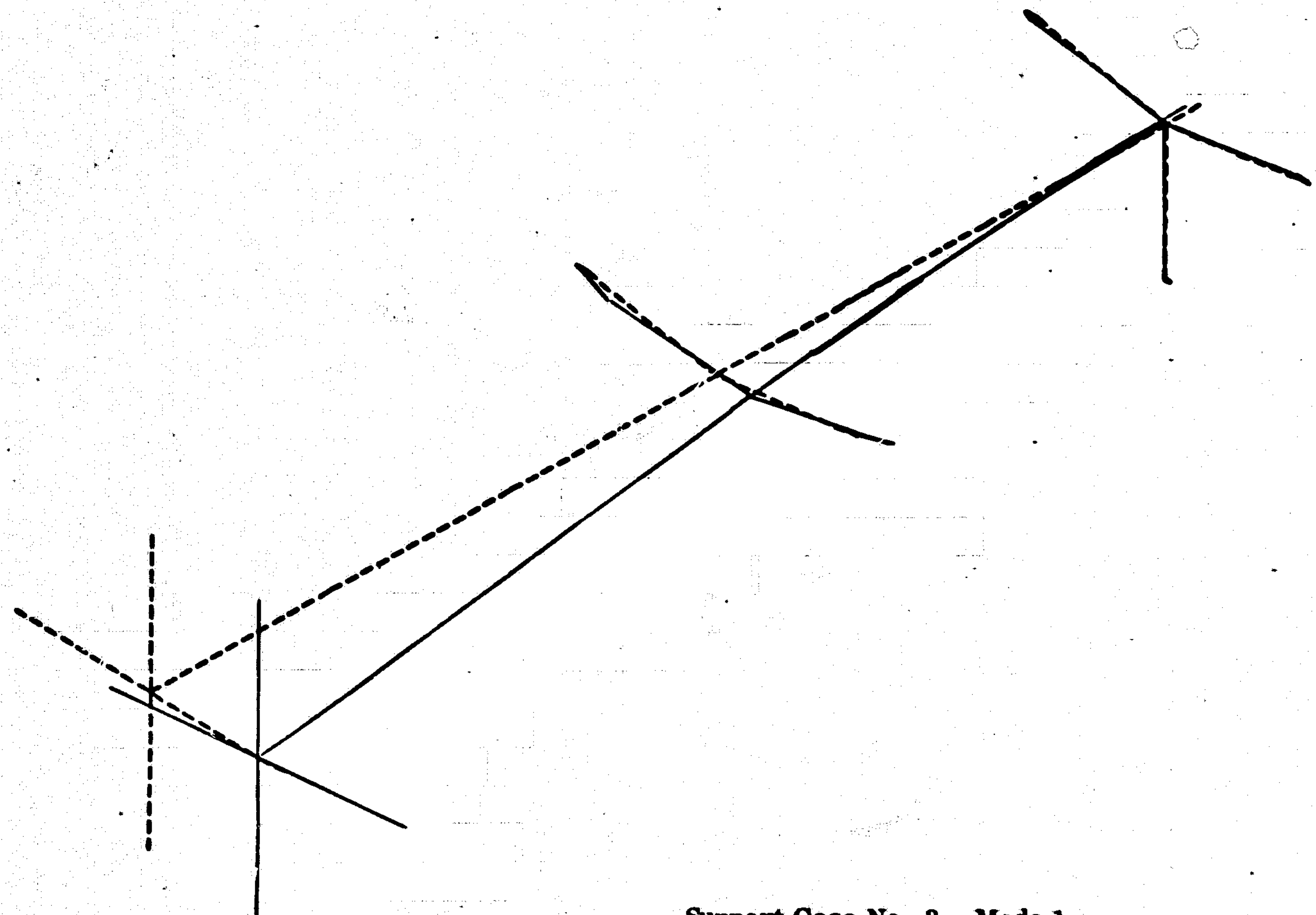
Support Case No. 2 - Mode 4

T U S   N O R M A L   M O D E   A N A L Y S I S   12/05/74
UNDEFORMED
SS(11.5)



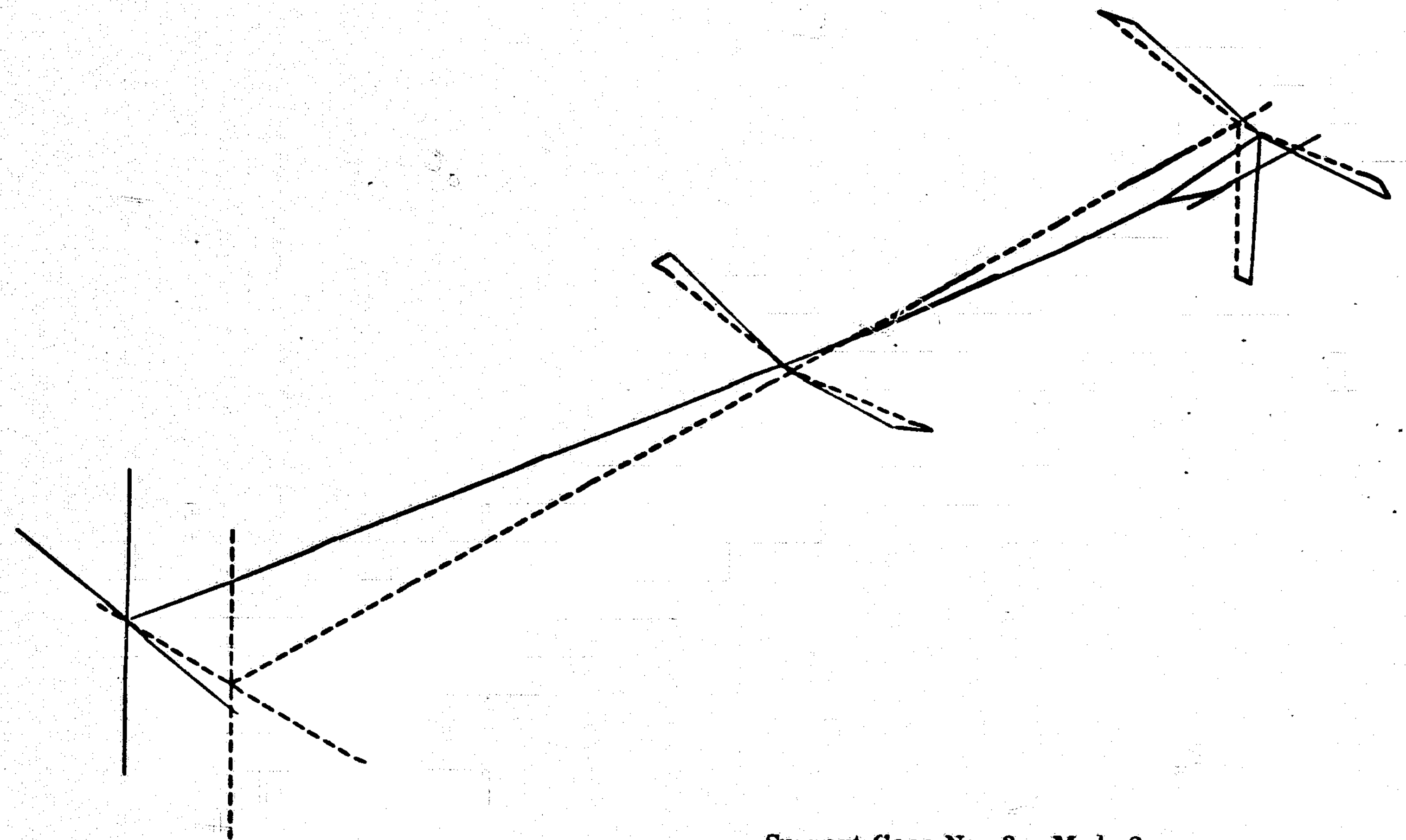
Support Case No. 2 - Mode 5

TUG NORMAL MODE ANALYSIS 12/04/74
UNDEFORMED
S8(3.39)



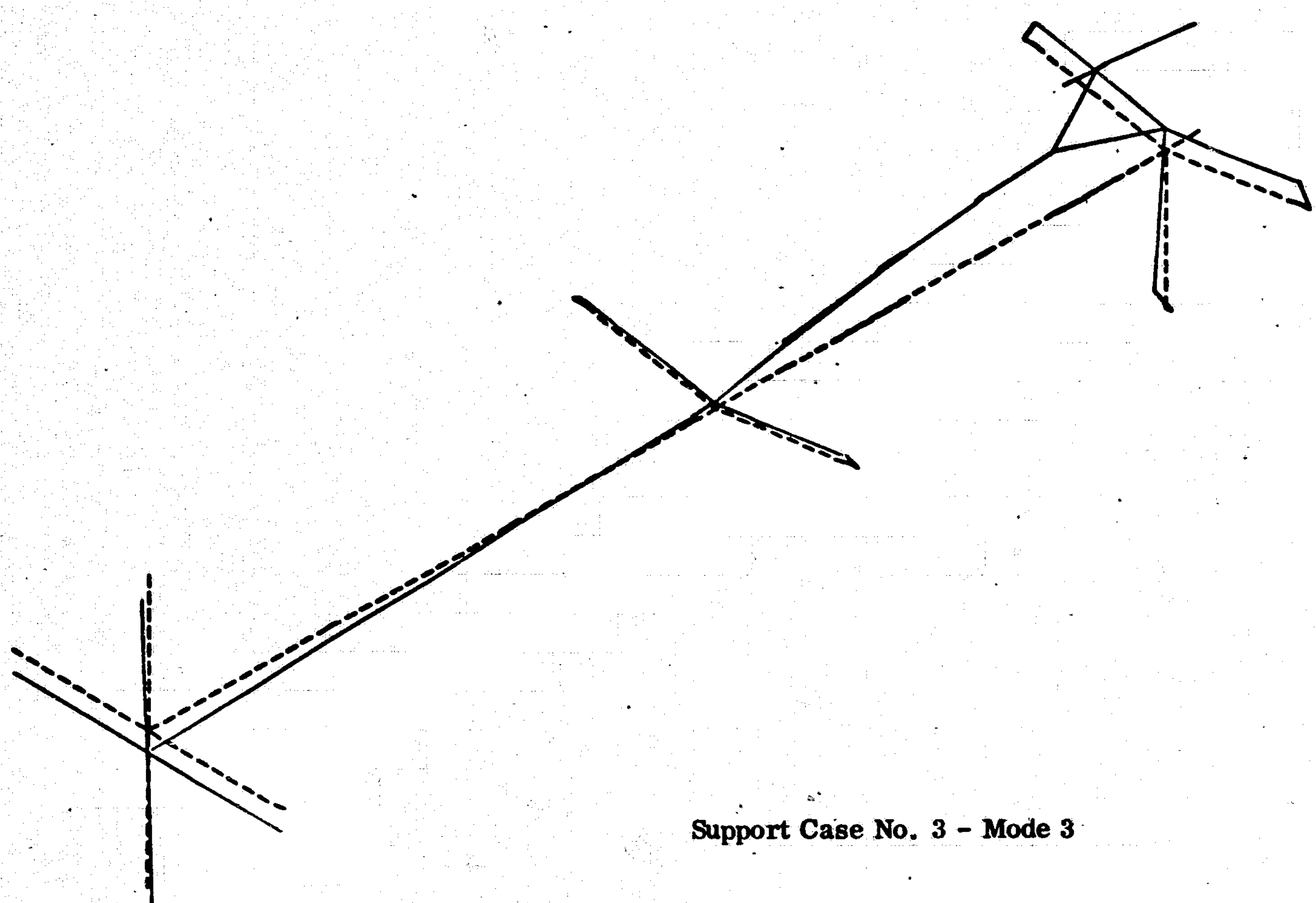
Support Case No. 3 - Mode 1

T U G N O R M A L M O D E A N A L Y S I S 12/04/74
UNDEFORMED
S2(5.63)



Support Case No. 3 - Mode 2

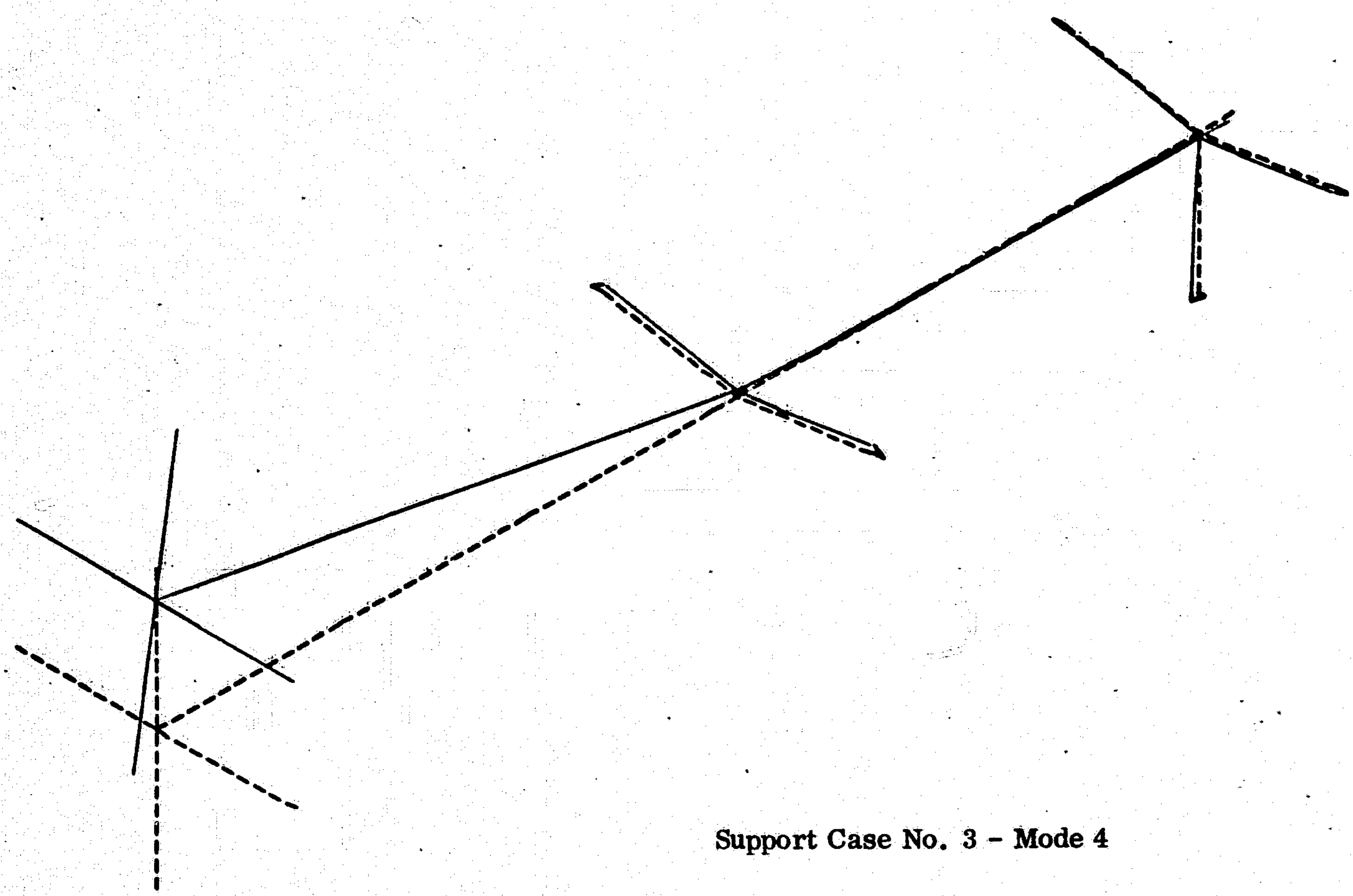
T U G   N O R M A L   M O D E   A N A L Y S I S   12/04/74
UNDEFORMED
S3(5.99)



Support Case No. 3 - Mode 3

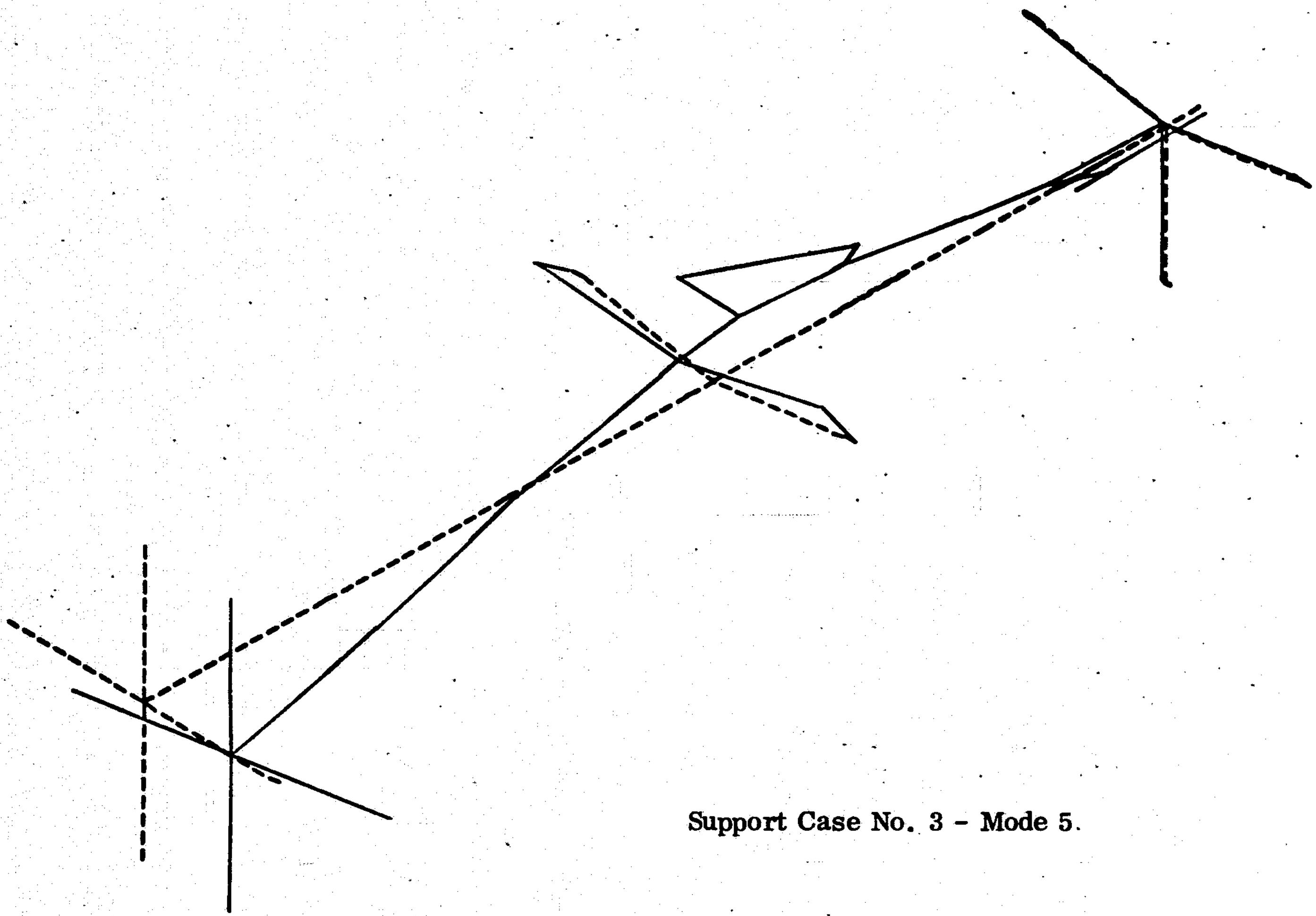
T U G N O R M A L M O D E A N A L Y S I S   12/04/74
UNDEFORMED
S4(6.72)

C-3.



Support Case No. 3 - Mode 4

TUG NORMAL MODE ANALYSIS 12/04/74
UNDEFORMED
S3(11.5)

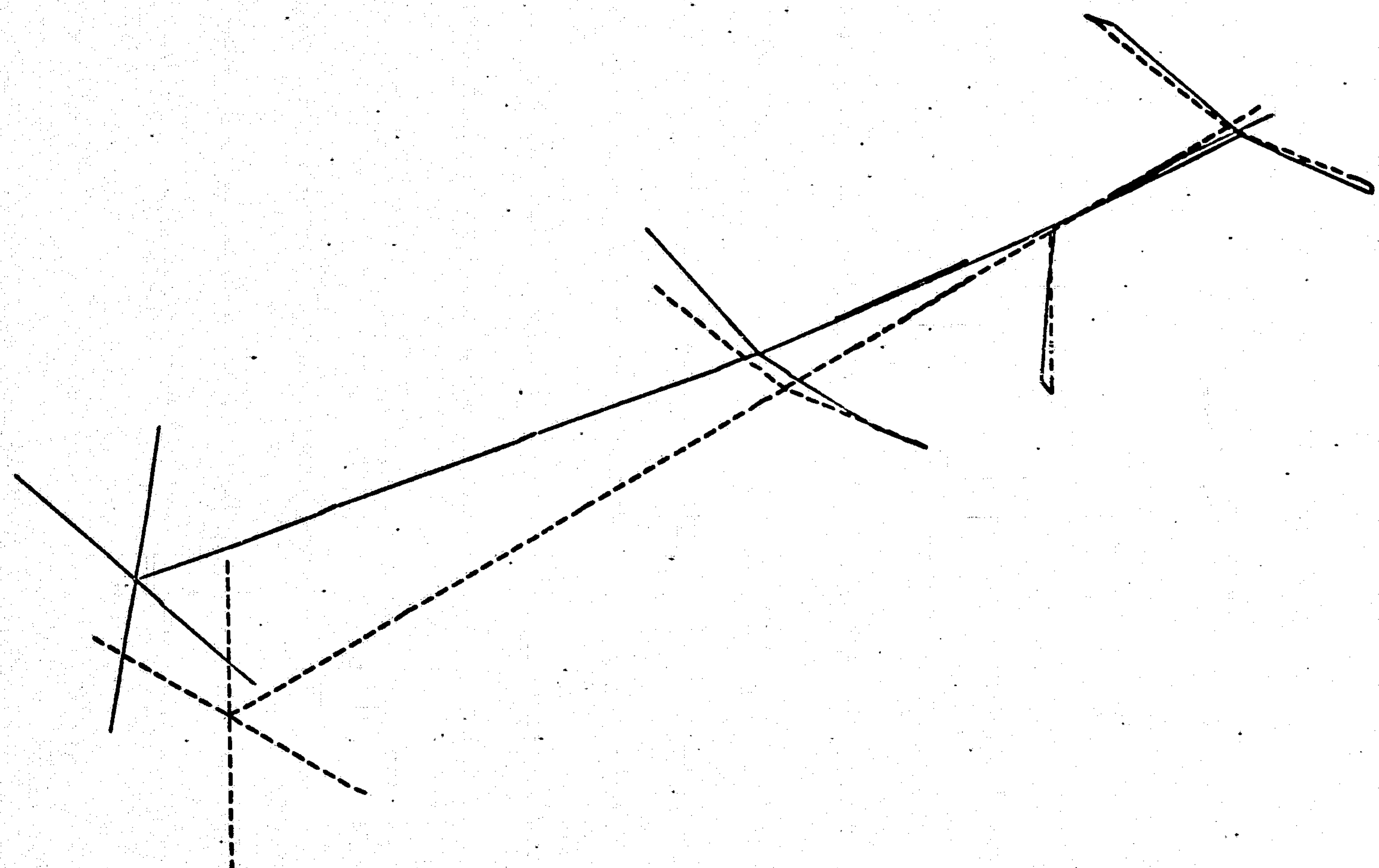


Support Case No. 3 - Mode 5.

TUG NORMAL MODE ANALYSIS 12/09/74

UNDEFORMED

A2(4.40)

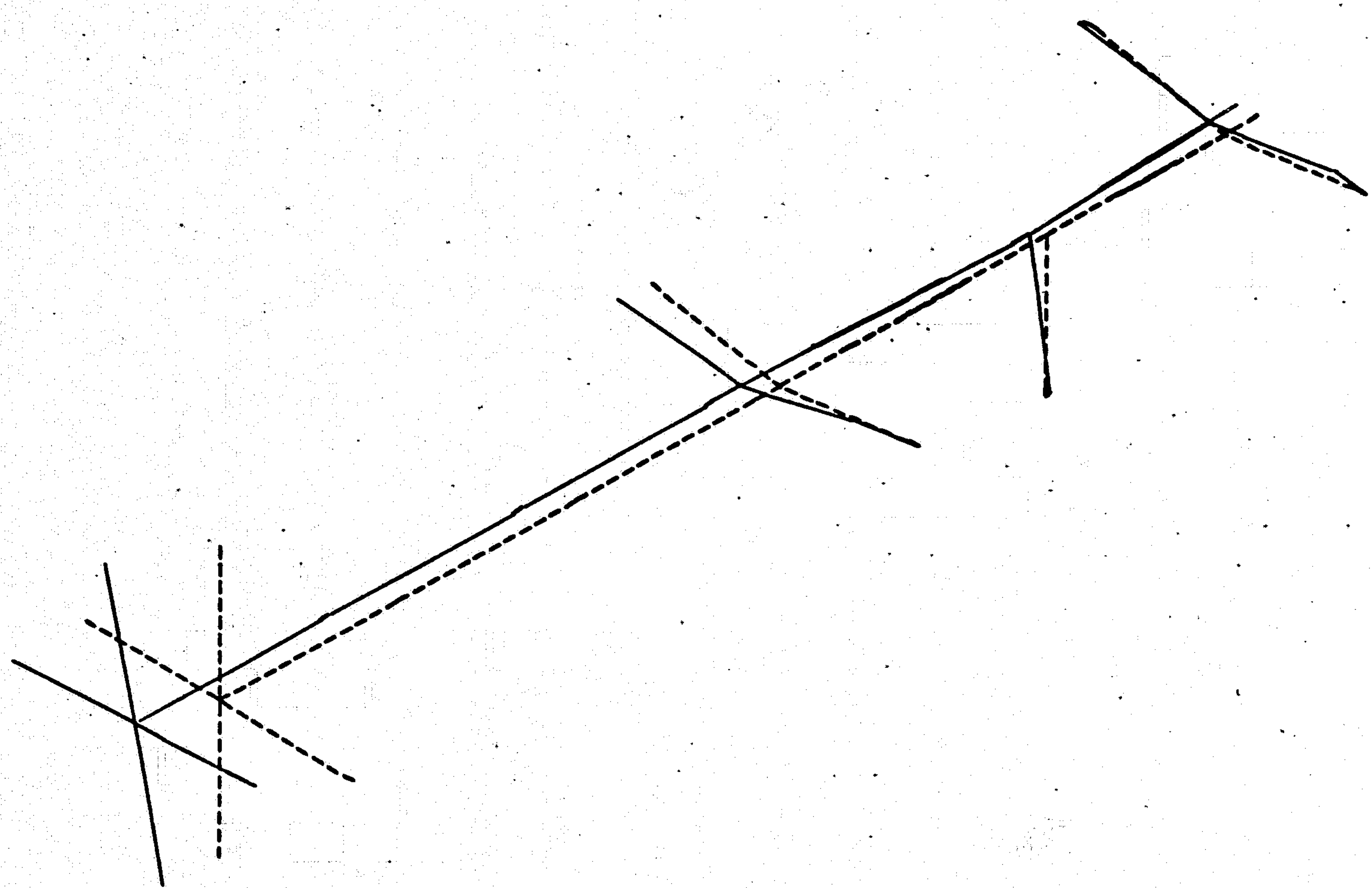


Support Case No. 4 - Mode 2

TUG NORMAL MODE ANALYSIS 12/09/74

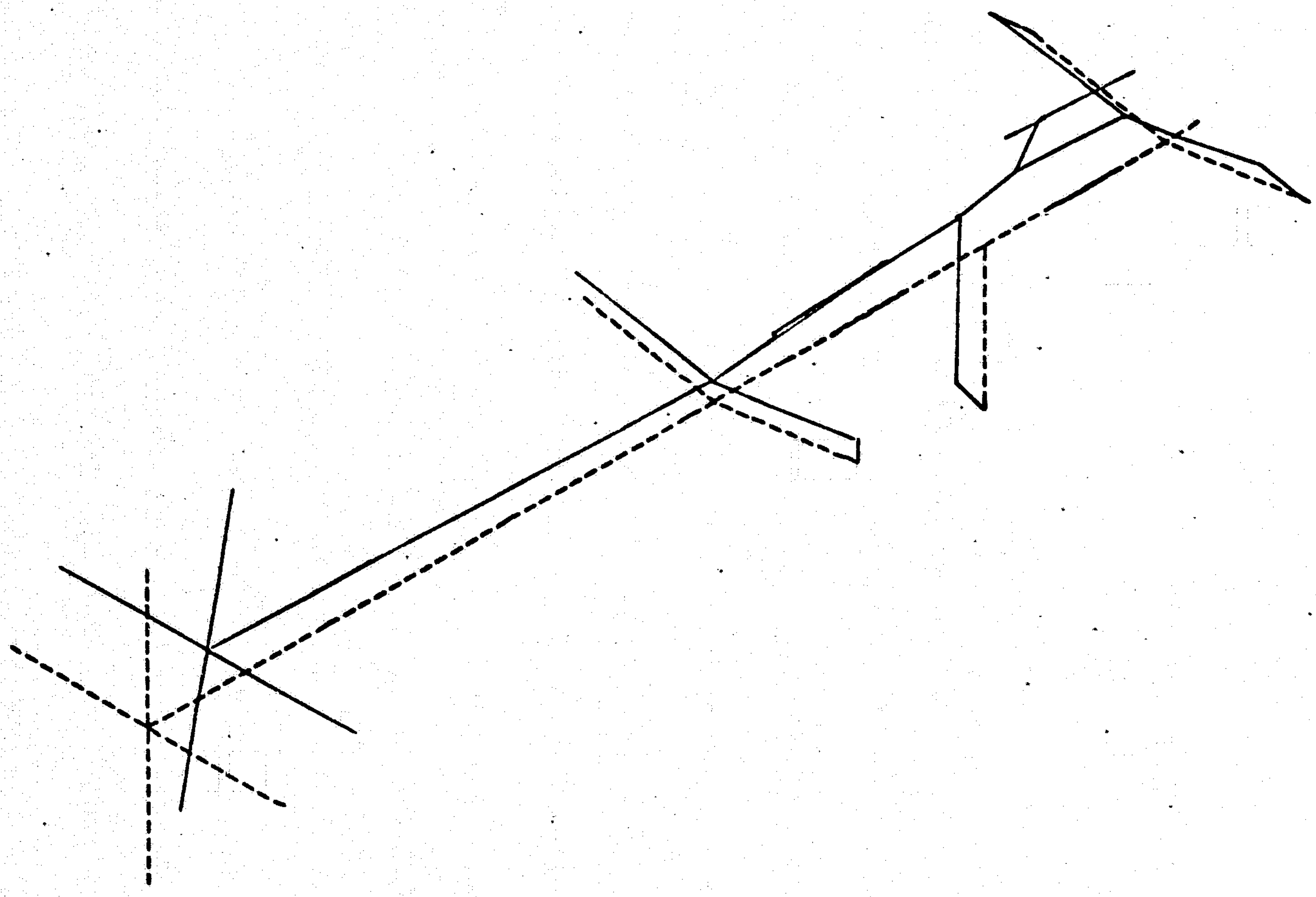
UNDEFORMED

A1(3.46)



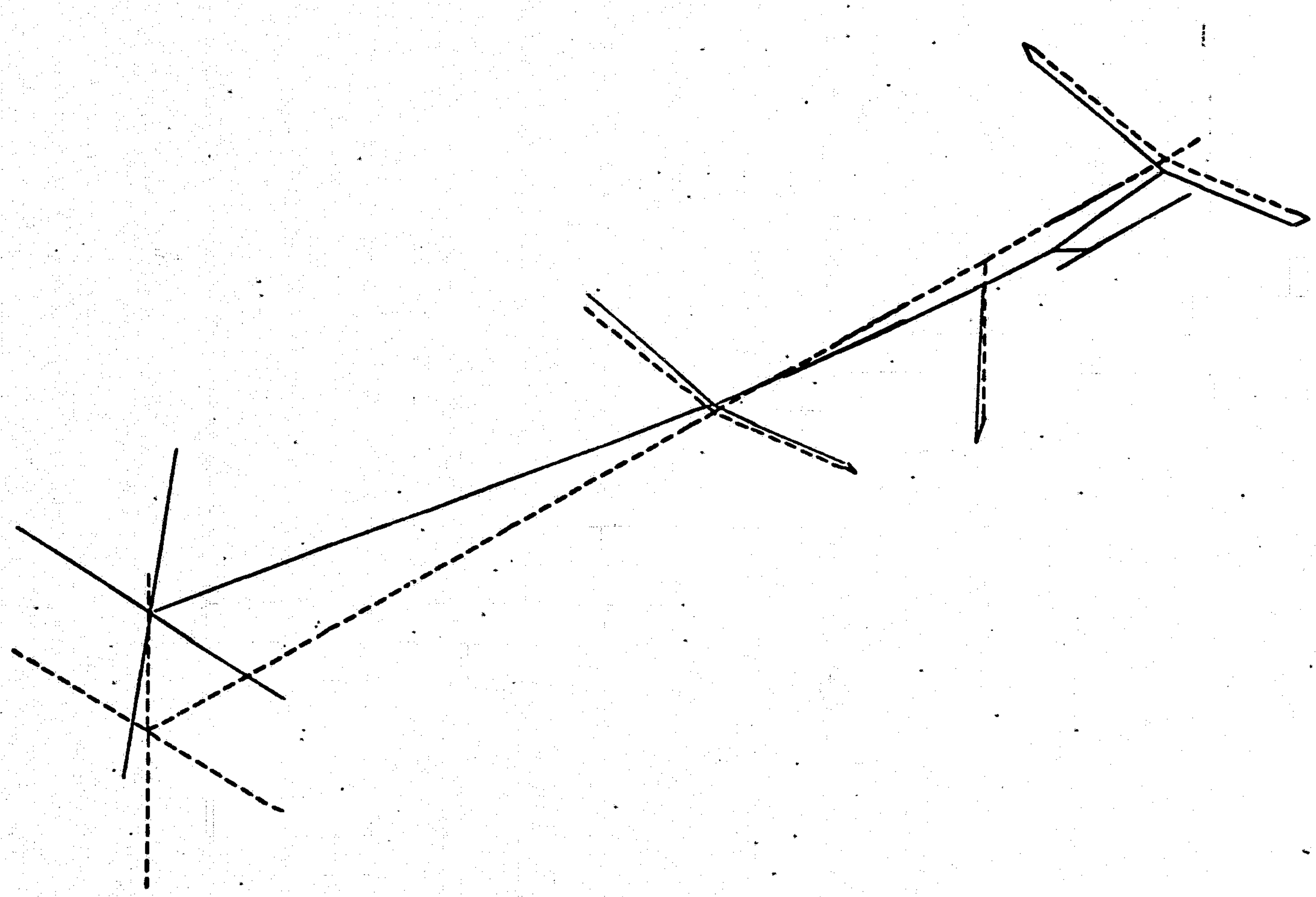
Support Case No. 4 - Mode 1

TUG NORMAL MODE ANALYSIS 12/09/74
UNDEFORMED
A3(5.38)



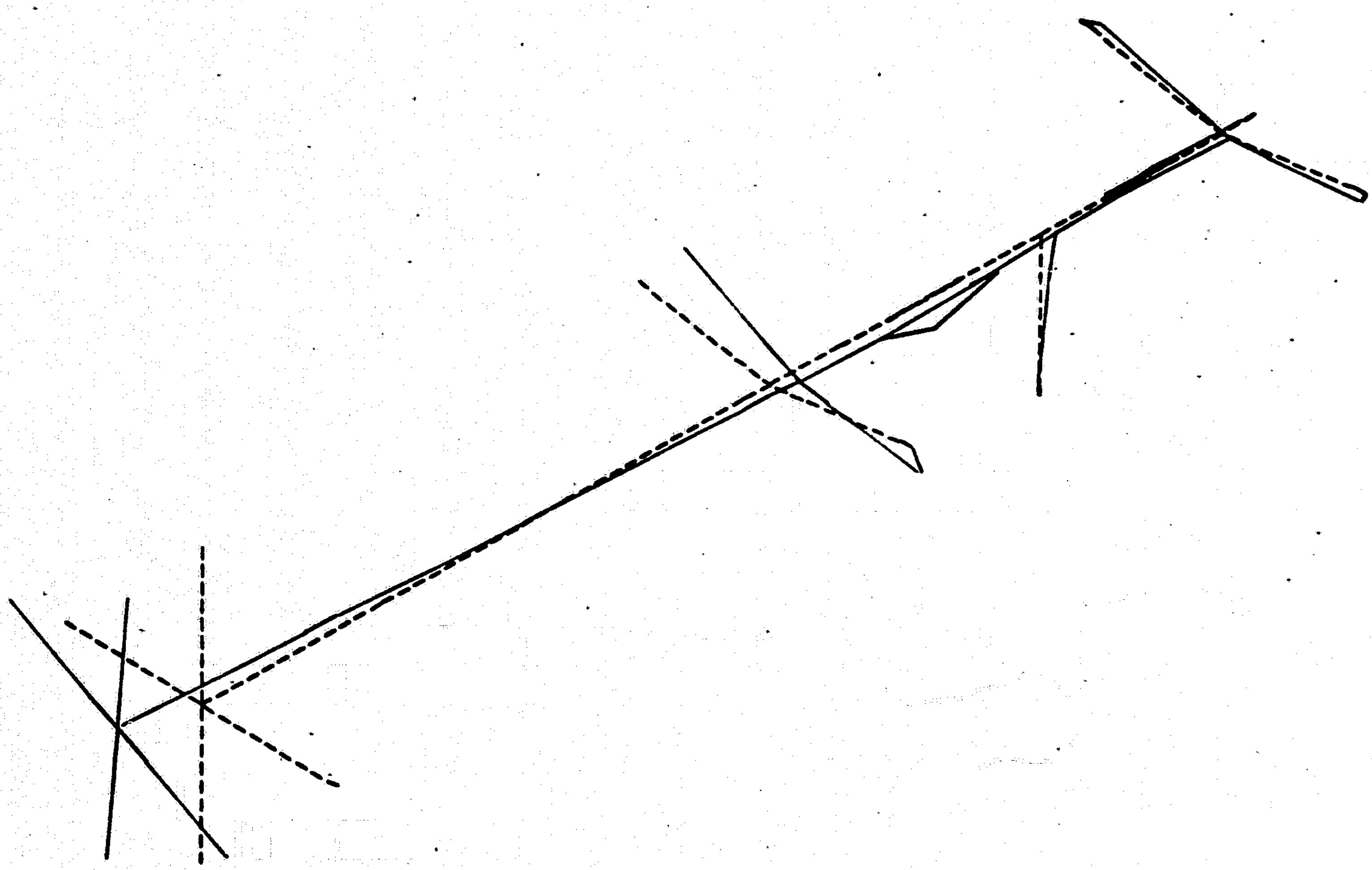
Support Case No. 4 - Mode 3

TUG NORMAL MODE ANALYSIS 12/09/74
UNDEFORMED
A4(6.11)



Support Case No. 4 - Mode 4

TUG NORMAL MODE ANALYSIS 12/09/74
UNDEFORMED
A5(11.6)

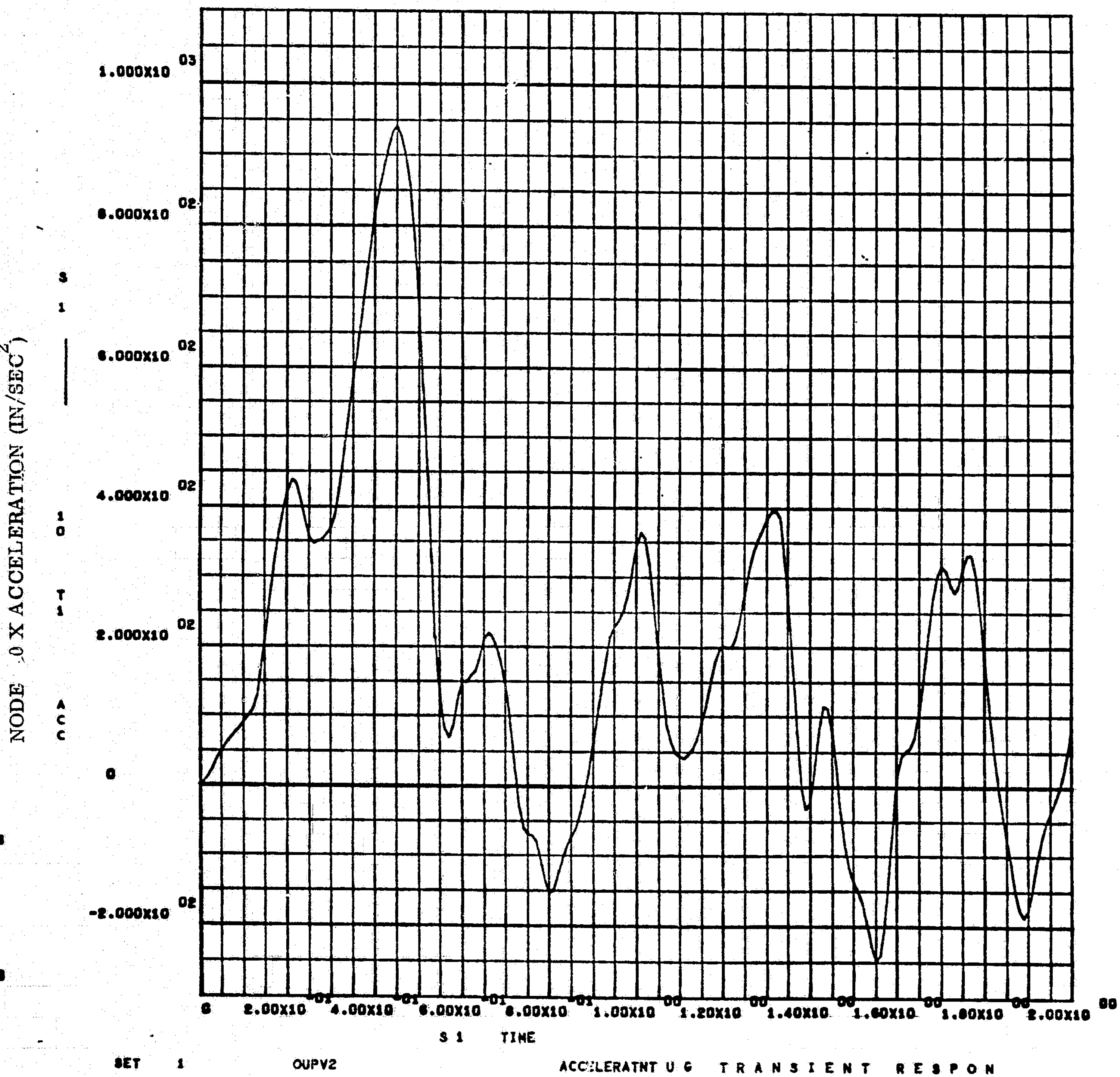


Support Case No. 4 - Mode 5

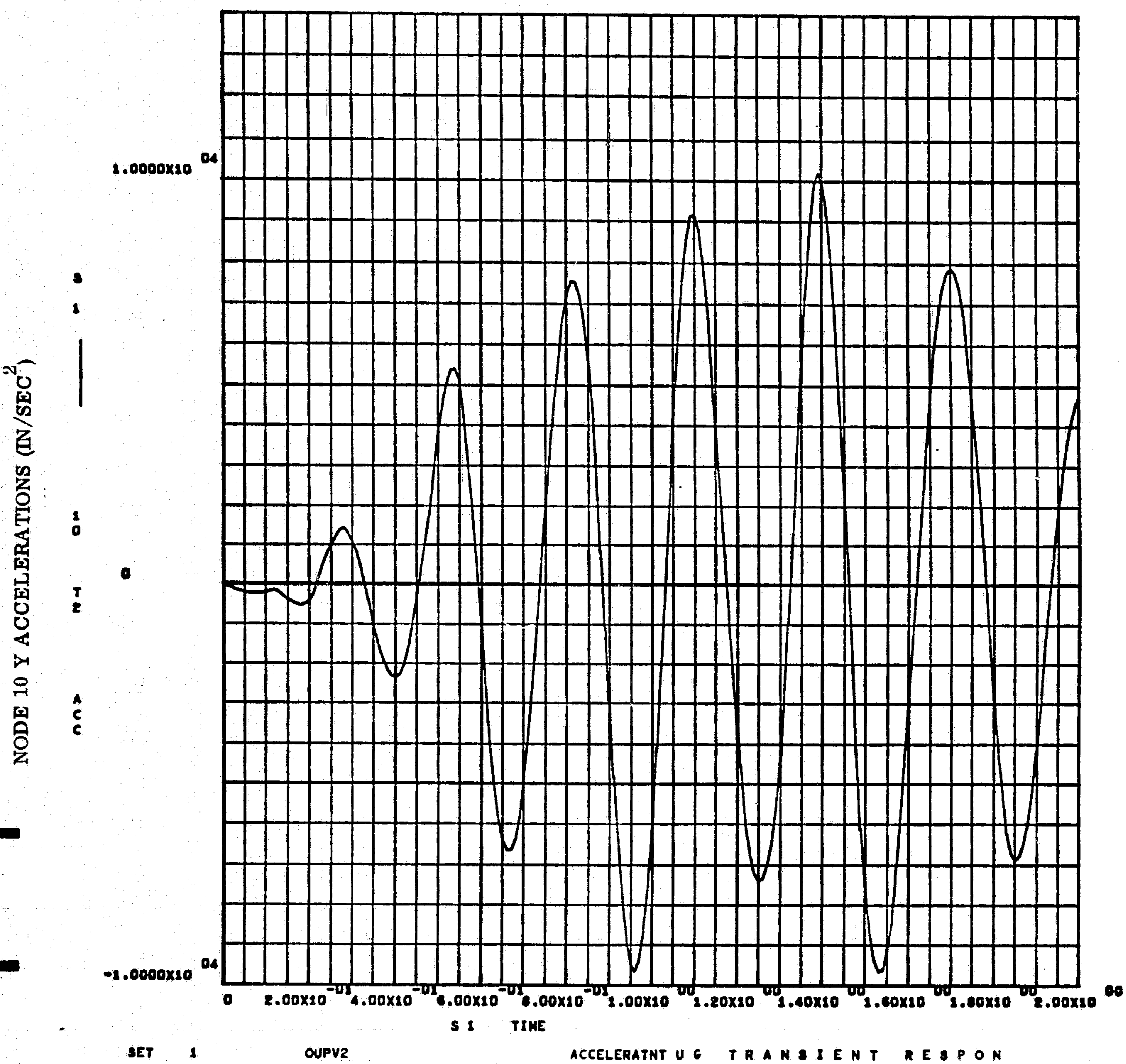
DYNAMIC LOADS ANALYSIS FOR TUG/SHUTTLE INTERFACE STUDY FOR THE SHUTTLE LIFT-OFF CONDITION

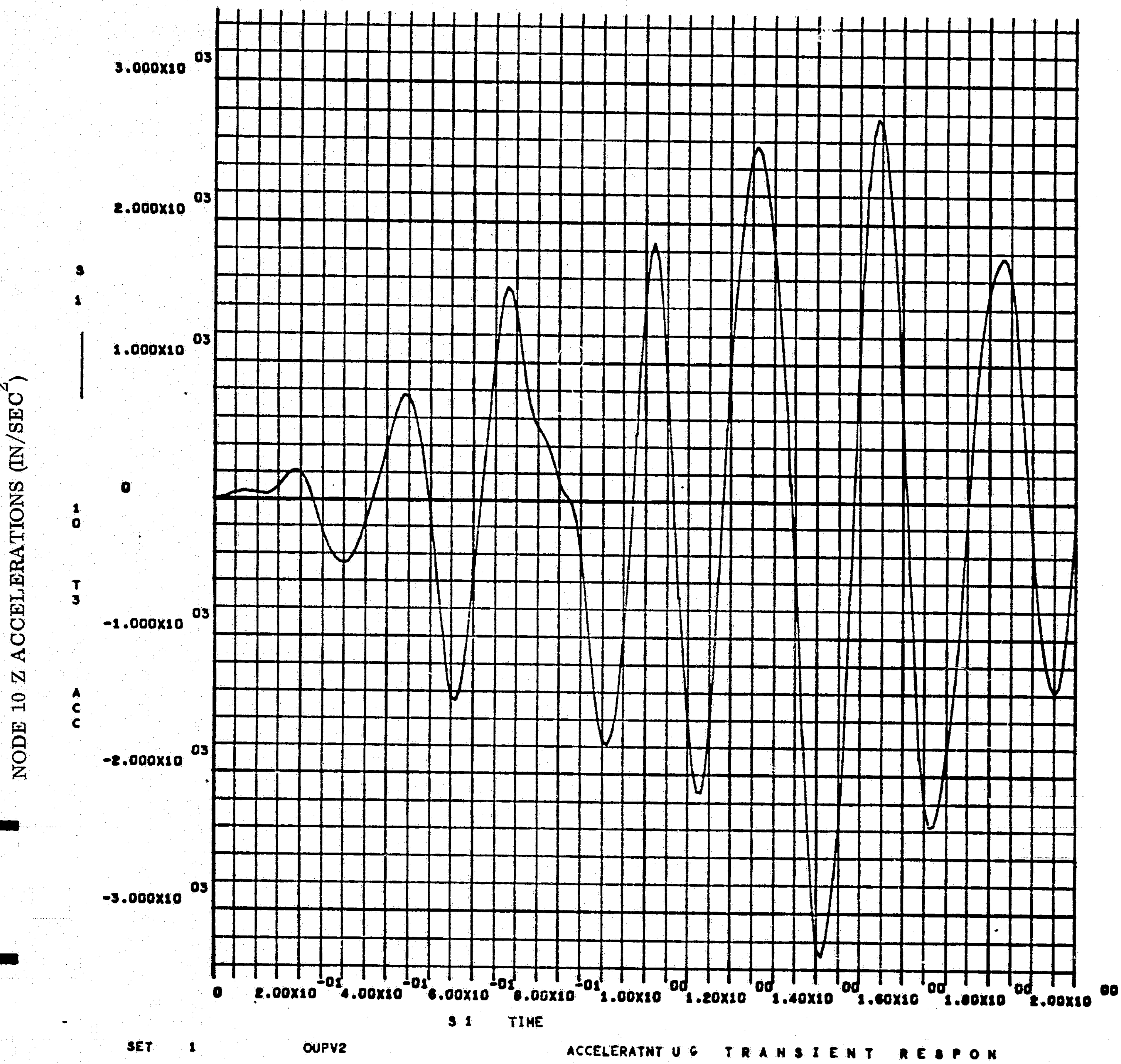
Enclosure b) Response time histories of Support Case No. 1 subjected to Shuttle lift-off transient.

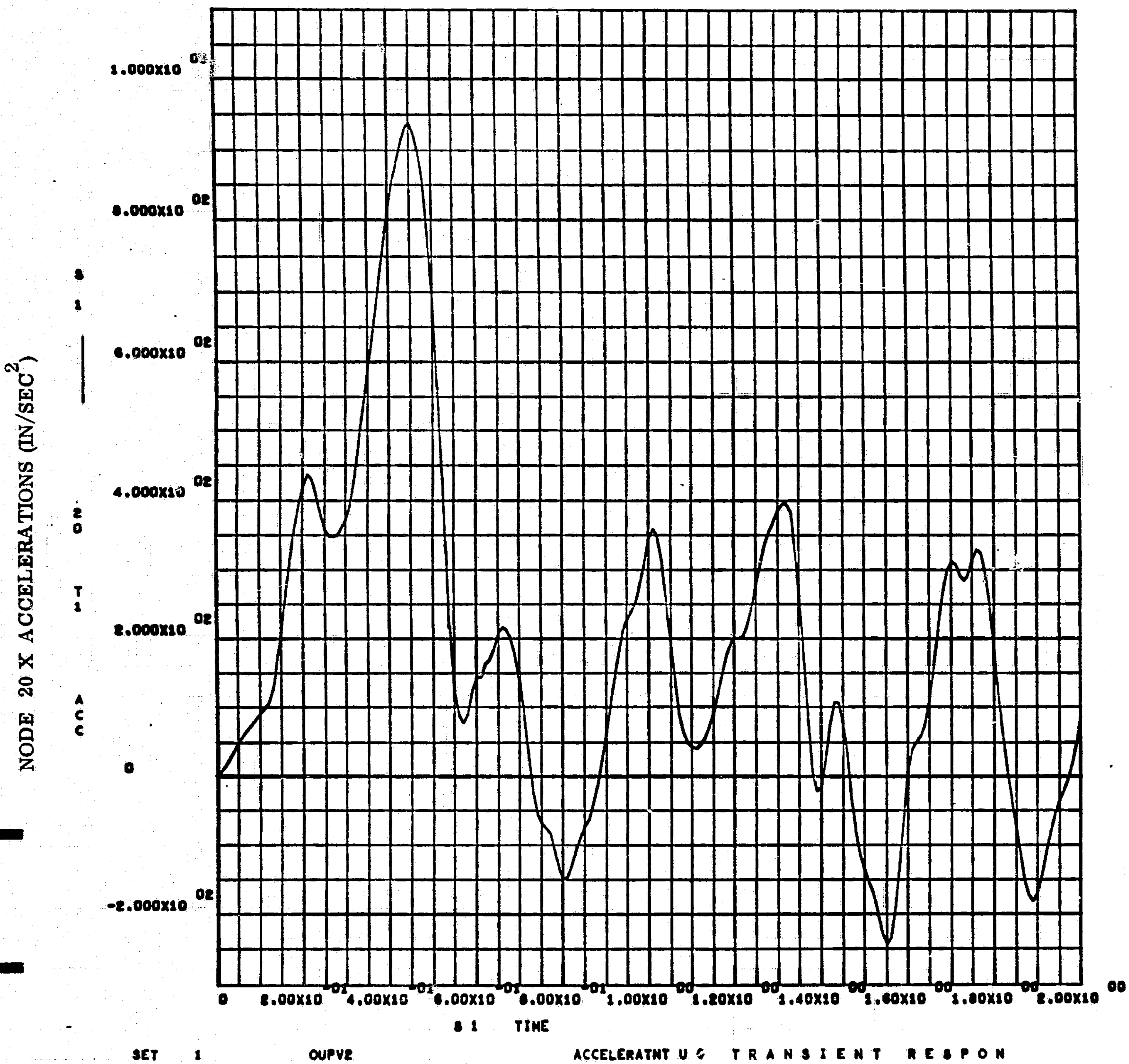
This enclosure presents the shuttle lift-off response time histories of support Case No. 1 as shown in Figure 1 of the text. The applied acceleration time histories are given in Figure 5. The node locations are presented in Figure 2. It should be noted that the displacements are relative to the orbiter and the X accelerations do not contain 1 g due to gravity.



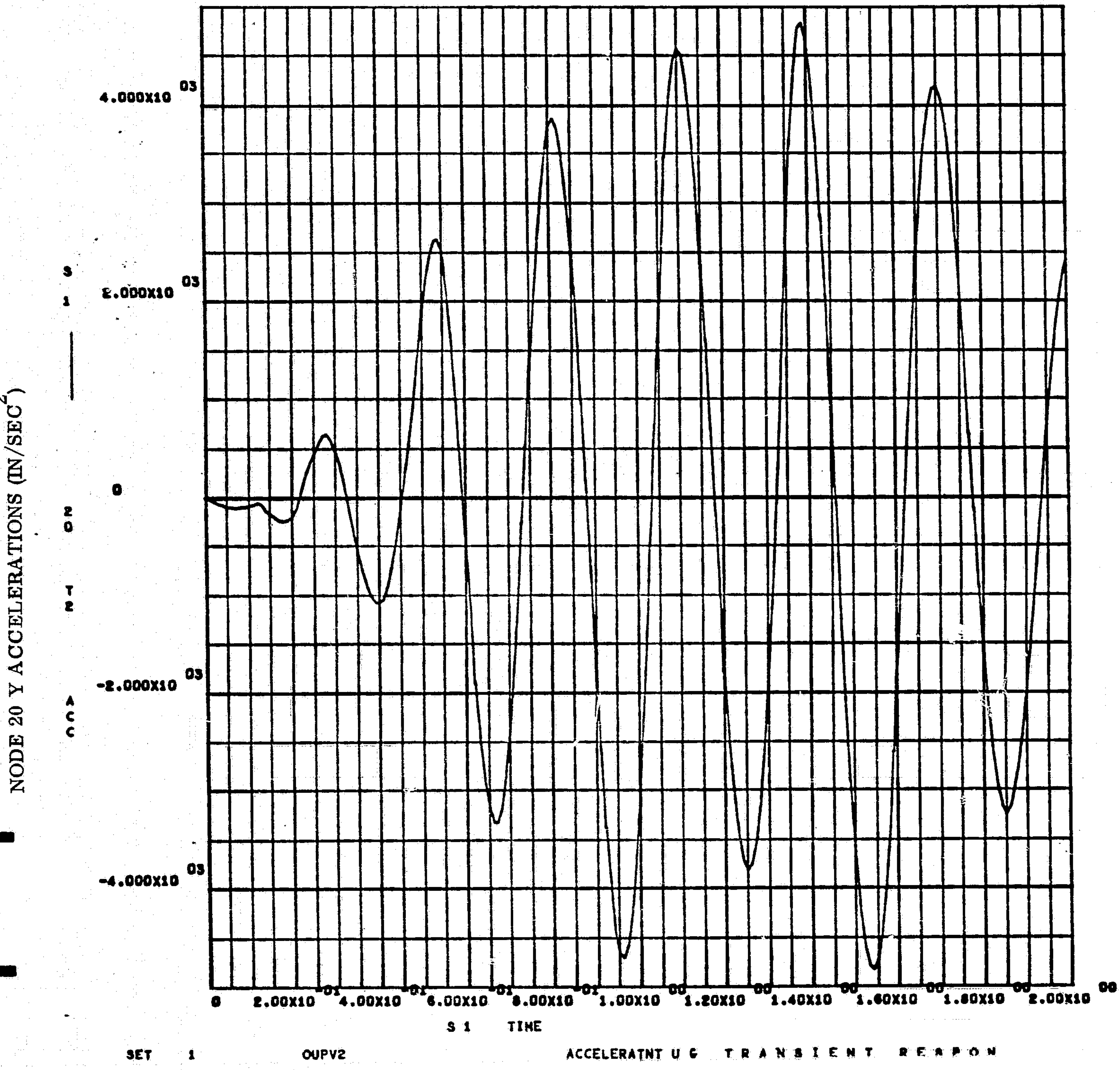
NODE .0 X ACCELERATION (IN/SEC^2)
S 1 10 T 1 ACC
1.000X10 03
8.000X10 02
6.000X10 02
4.000X10 02
2.000X10 02
0
-2.000X10 02
0 2.00X10 -01 4.00X10 -01 6.00X10 -01 8.00X10 -01 1.00X10 00 1.20X10 00 1.40X10 00 1.60X10 00 1.80X10 00 2.00X10 00
S 1 TIME
SET 1
OUPV2
ACC:LERATNT U G T R A N S I E N T R E S P O N

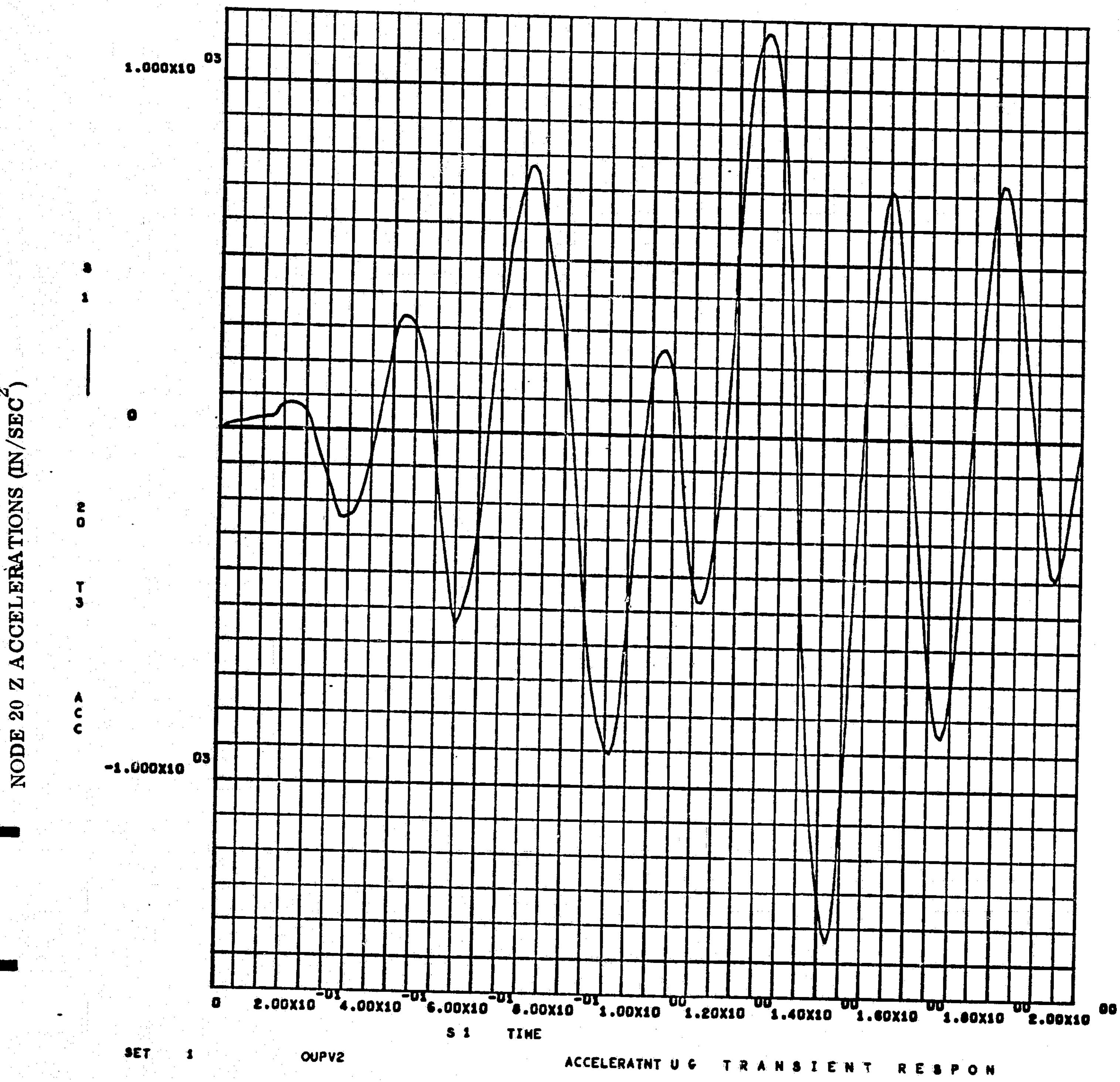

NODE 10 Y ACCELERATIONS (IN/SEC^2)
1.0000X10 04
0
-1.0000X10 04
S 1
1 0
T 2
A C C
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1
OUPV2
ACCELERATNT U G TRANSIENT RESPON


NODE 10 Z ACCELERATIONS (IN/SEC2)
S 1 ACC 10 T3
3.000X10 03
2.000X10 03
1.000X10 03
0
-1.000X10 03
-2.000X10 03
-3.000X10 03
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1
OUPV2
ACCELERATNT U G
T R A N S I E N T R E S P O N

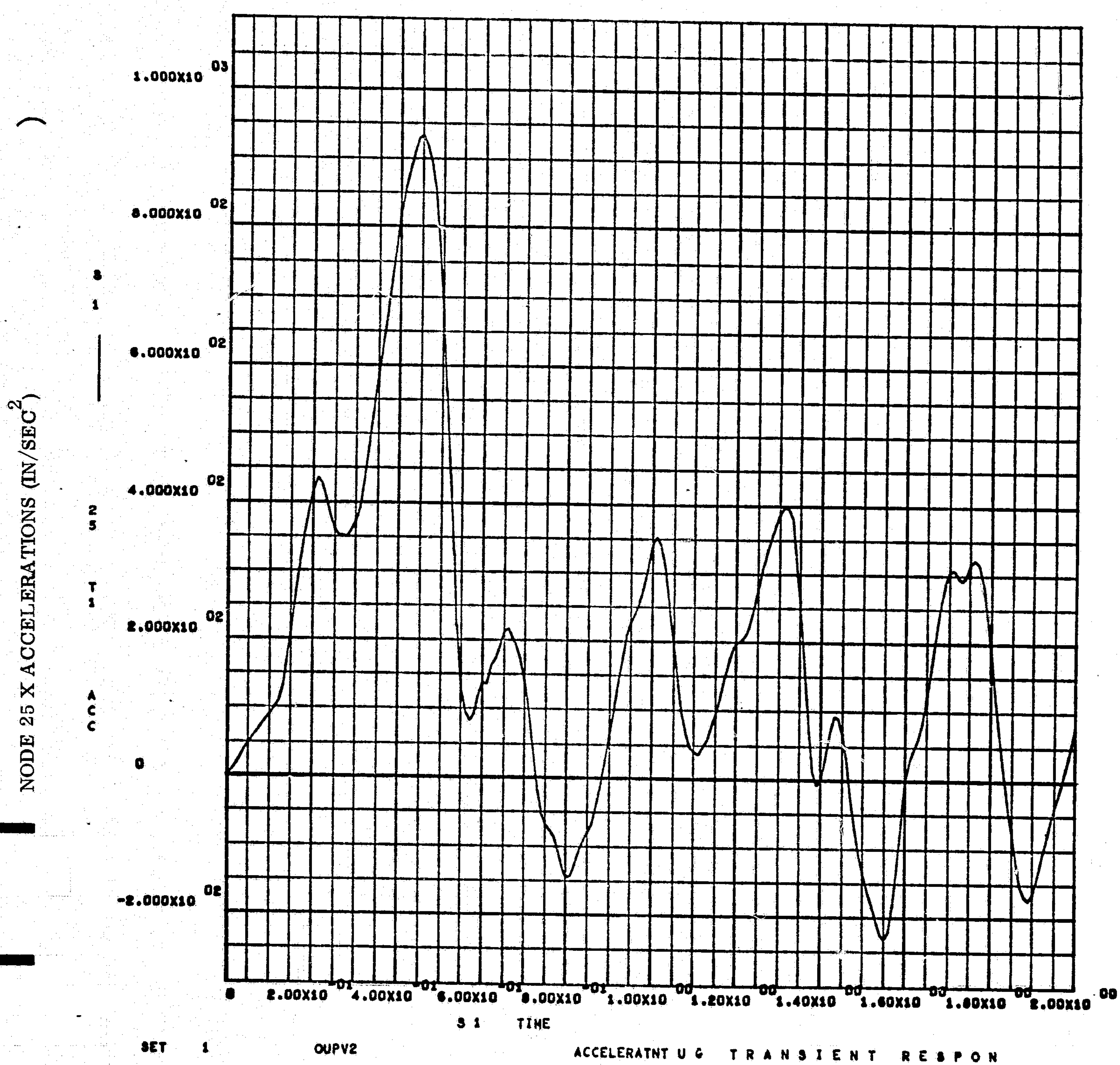


NODE 20 X ACCELERATIONS (IN/SEC²)
1.000X10 03
8.000X10 02
6.000X10 02
4.000X10 02
2.000X10 02
0
-2.000X10 02
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1 OUPV2 ACCELERATNT U C TRANSIENT RESPON

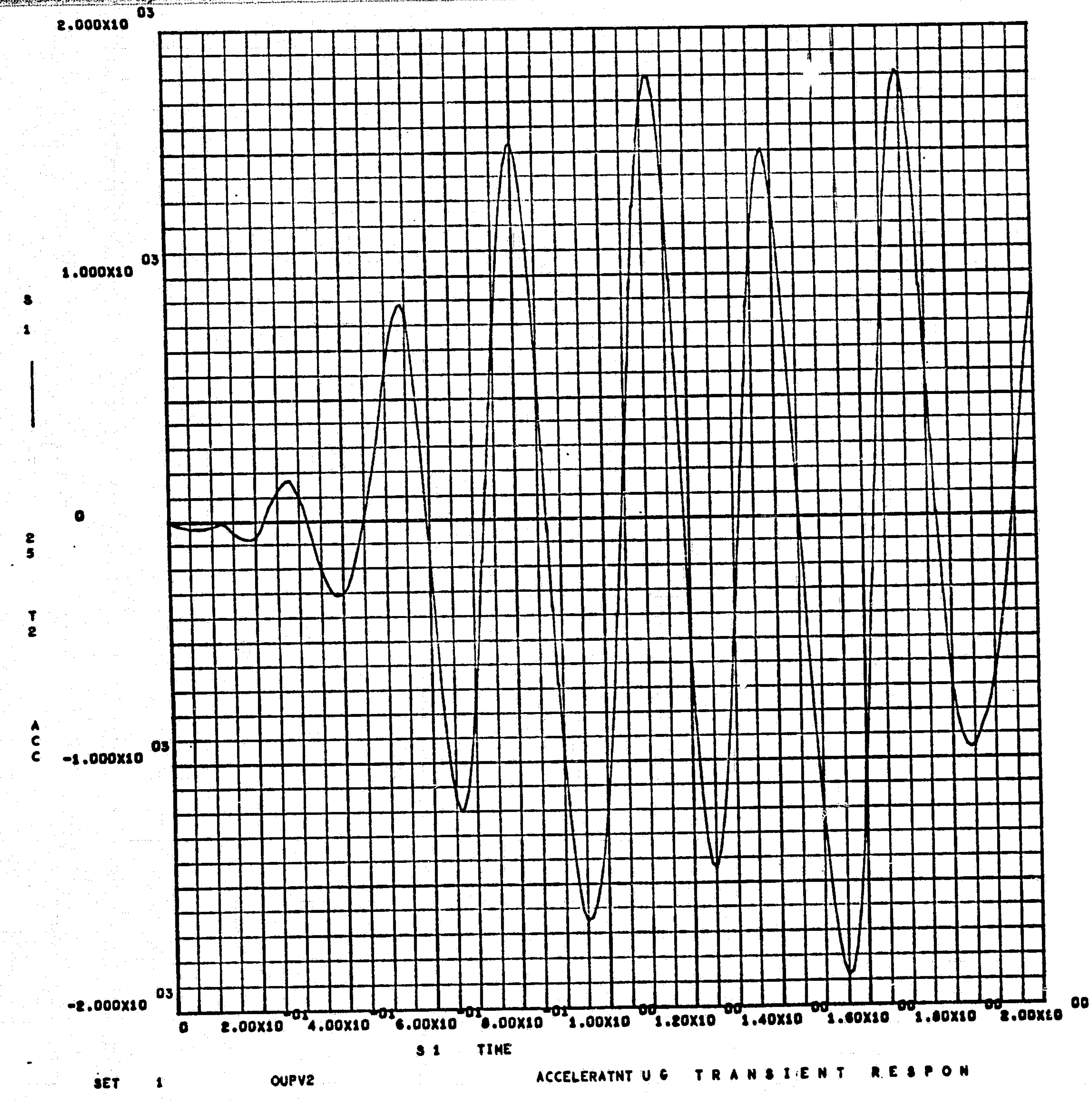

NODE 20 Y ACCELERATIONS (IN/SEC^2)
S1 20 T2 ACC
4.000X10 03
2.000X10 03
0
-2.000X10 03
-4.000X10 03
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1 OUPV2 ACCELERATNT U G T R A N S I E N T R E S P O N



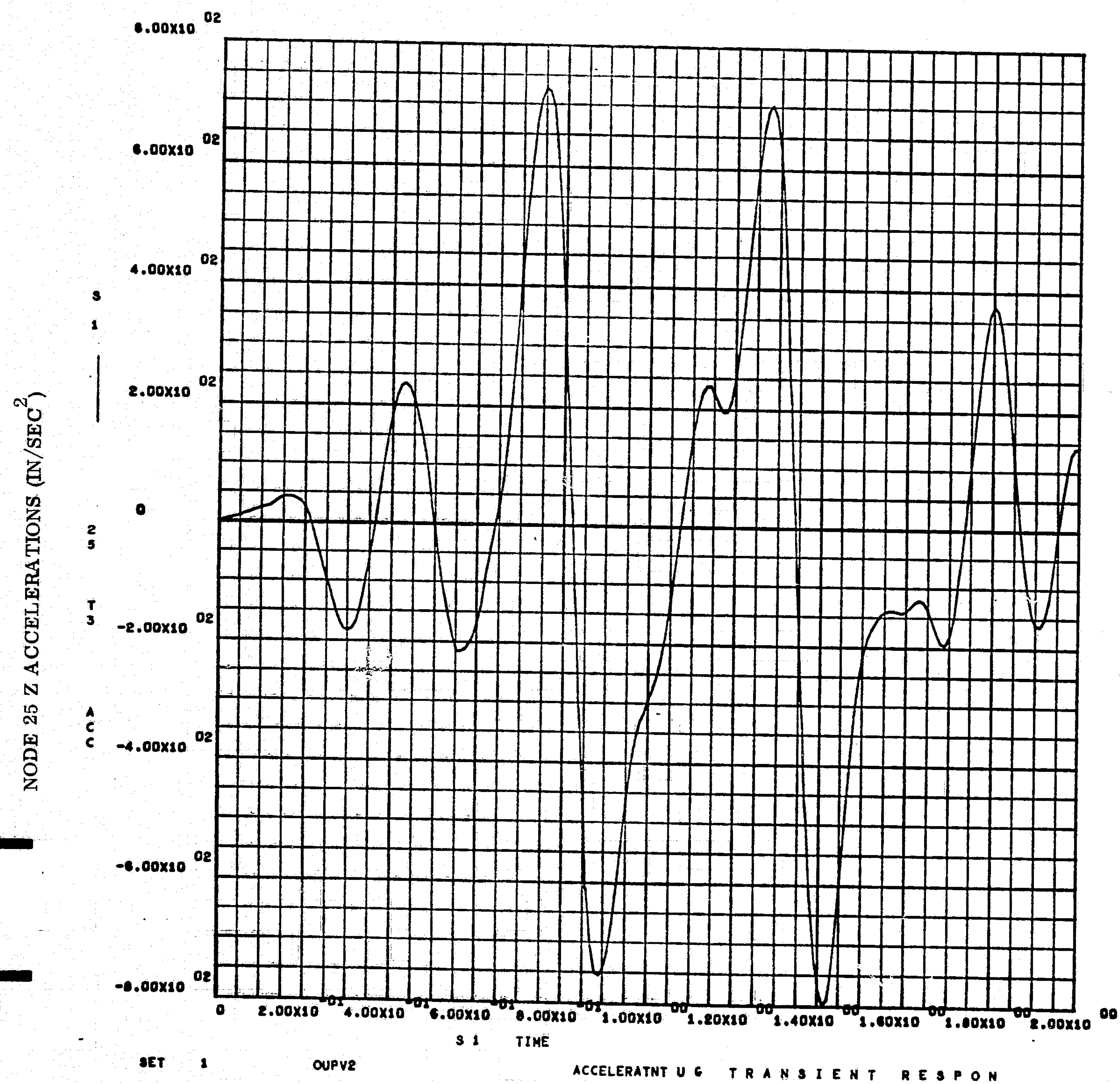
NODE 20 Z ACCELERATIONS (IN/SEC^2)
1.000X10 03
0
-1.000X10 03
S 1
20
T 3
ACC
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1
OUPV2
ACCELERATNT U G TRANSIENT RESPON

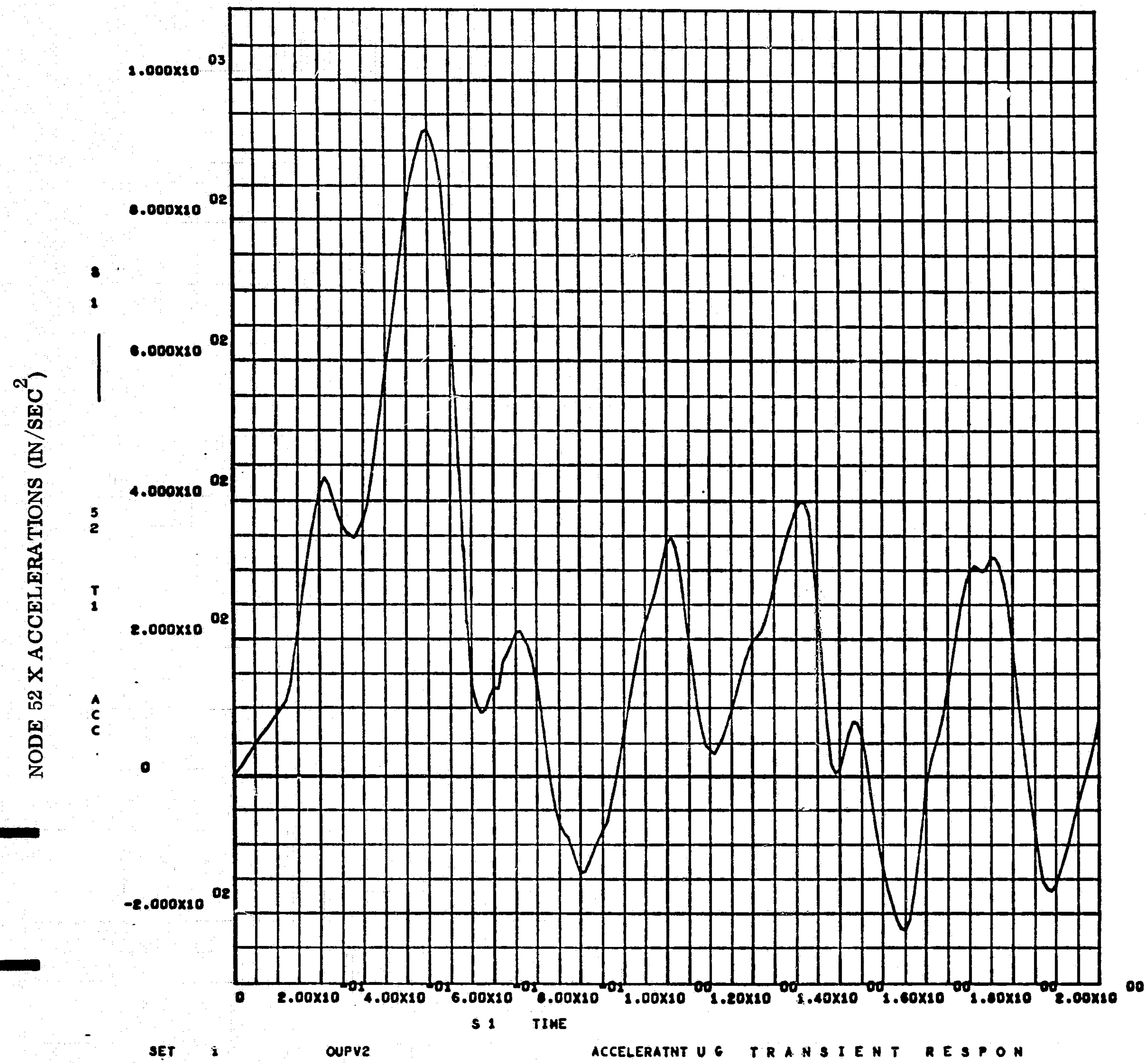


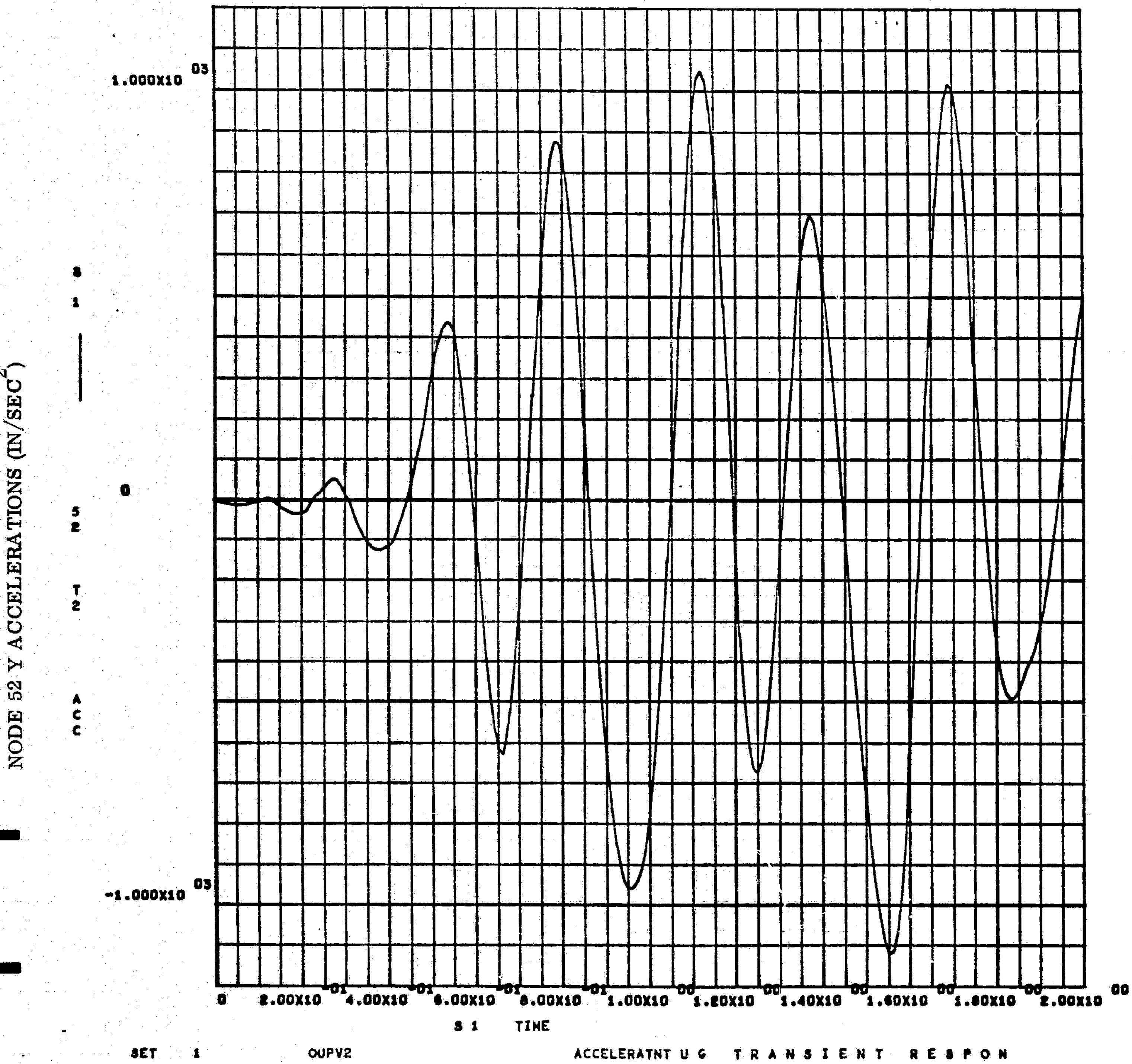
NODE 25 X ACCELERATIONS (IN/SEC^2)
1.000X10 03
8.000X10 02
6.000X10 02
4.000X10 02
2.000X10 02
0
-2.000X10 02
S 1 — 25 T 1 ACC
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1
OUPV2
ACCELERATNT U G TRANSIENT RESPON

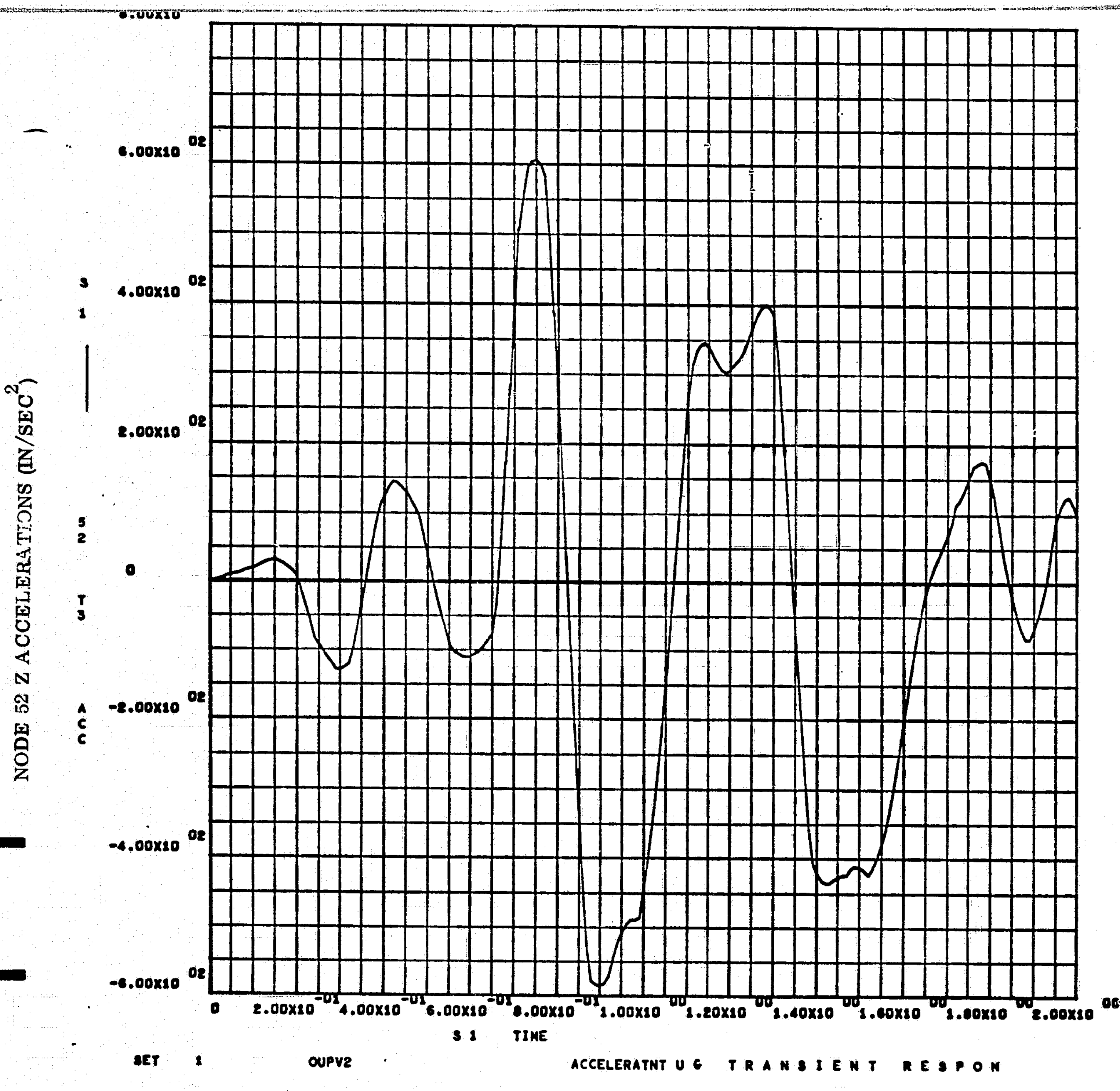


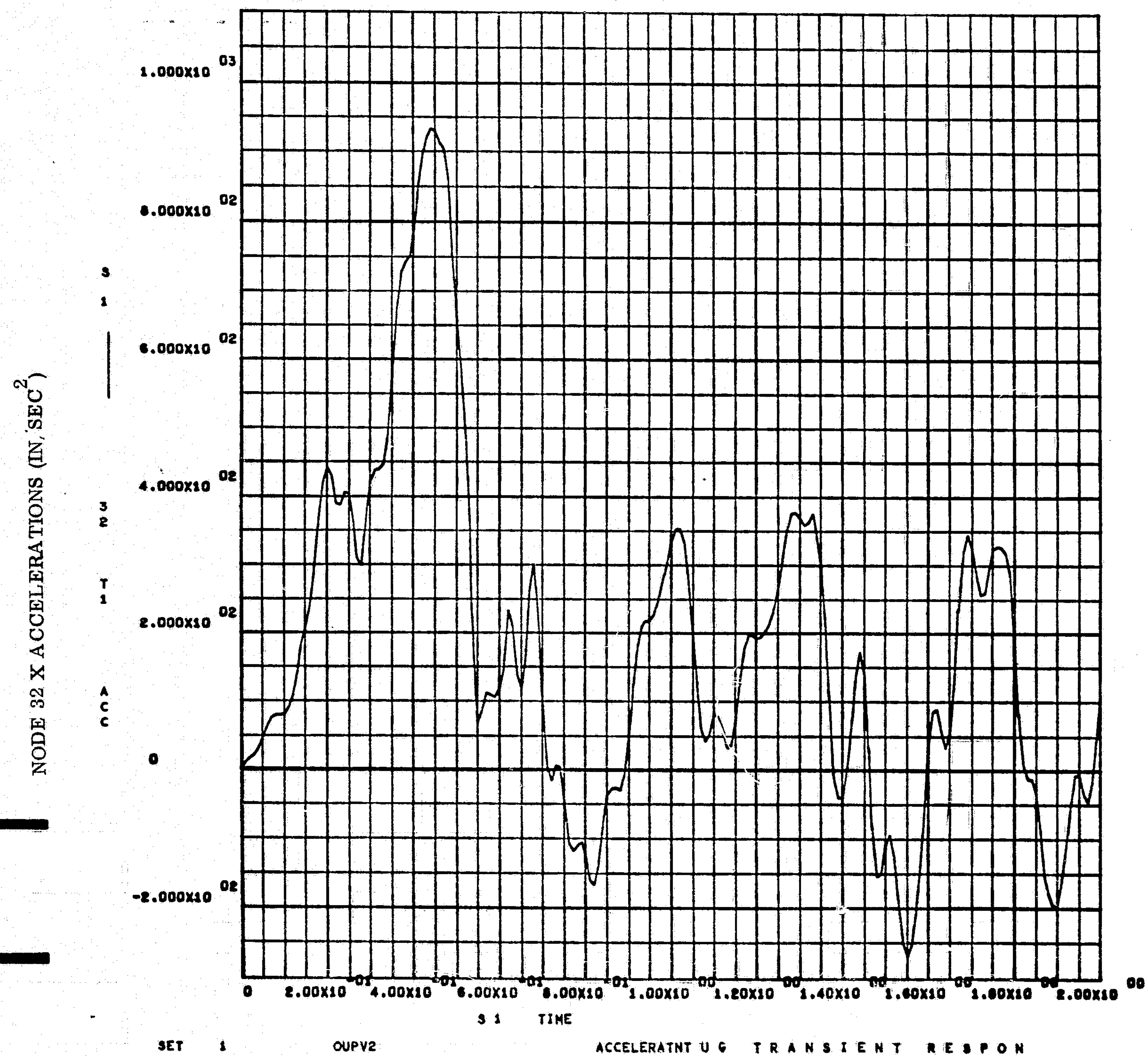
NODE 25 Y ACCELERATIONS (IN/SEC^2)

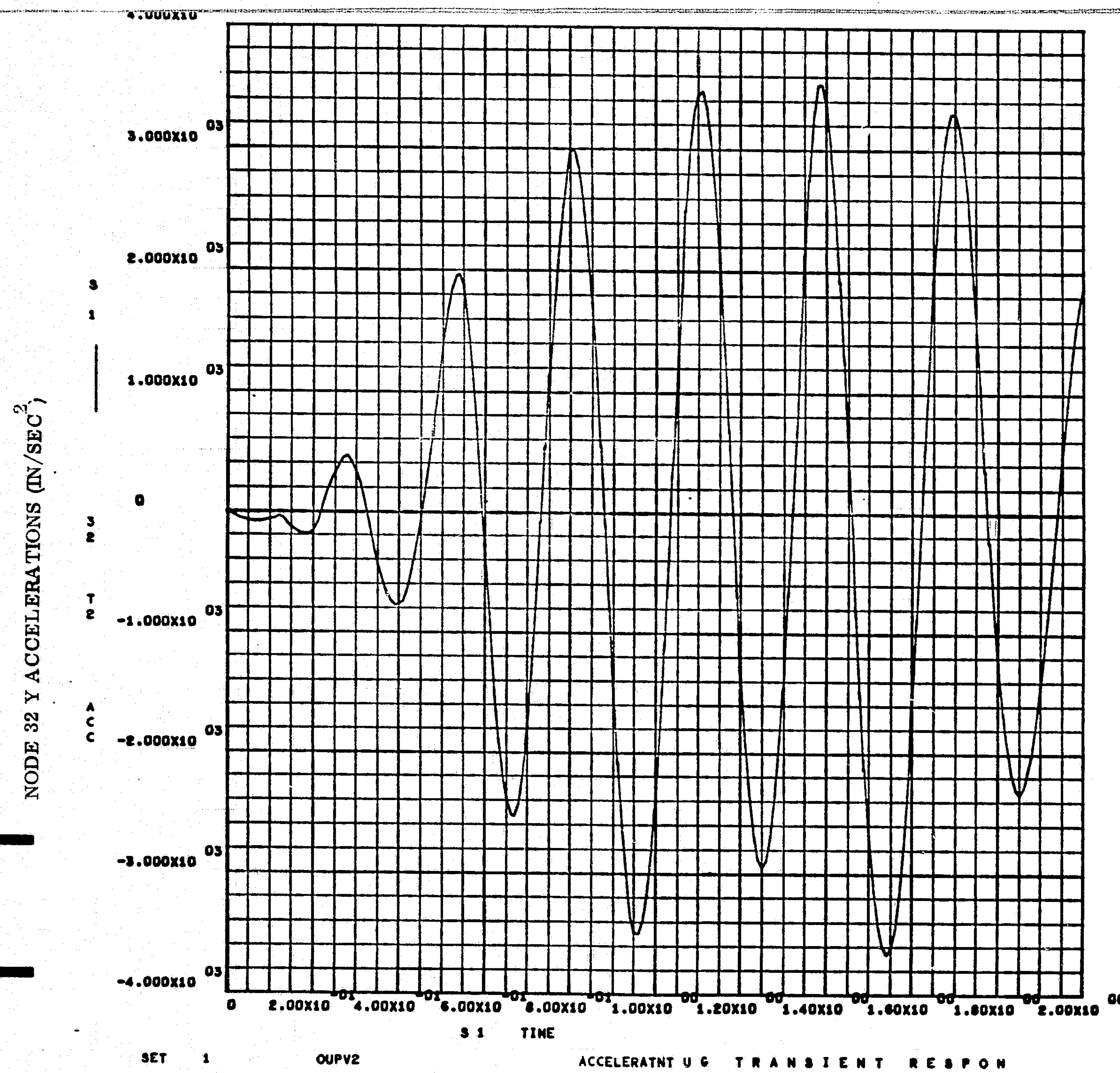

NODE 25 Z ACCELERATIONS (IN/SEC^2)
8.00X10 02
6.00X10 02
4.00X10 02
2.00X10 02
0
-2.00X10 02
-4.00X10 02
-6.00X10 02
-8.00X10 02
S 1 — 25 T 3 ACC
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1
OUPV2
ACCELERATNT U G TRANSIENT RESPON

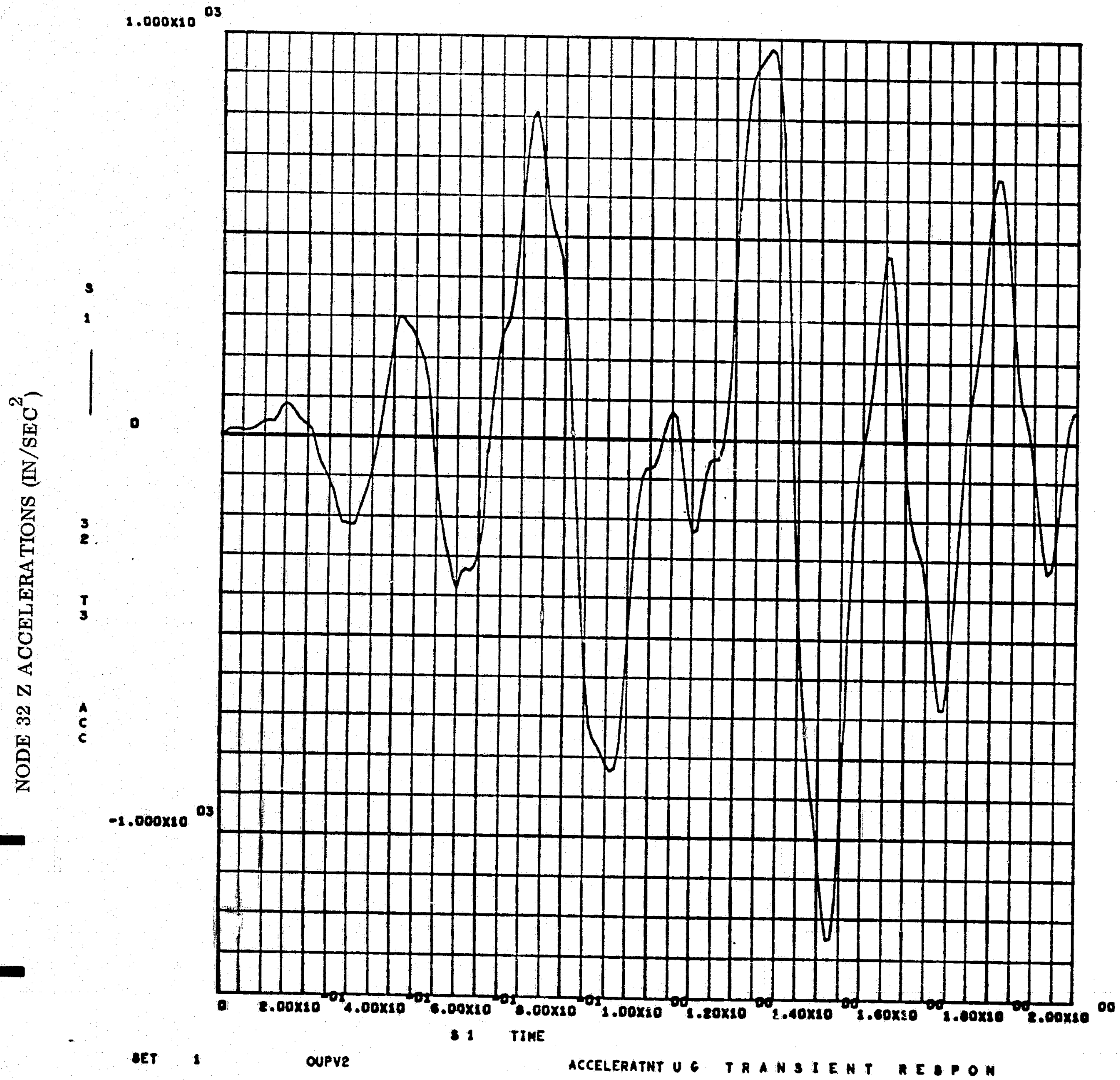

NODE 52 X ACCELERATIONS (IN/SEC^2)
1.000X10 03
8.000X10 02
6.000X10 02
4.000X10 02
2.000X10 02
0
-2.000X10 02
S 1
5 2
T 1
A C C
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1
OUPV2
ACCELERATNT U G TRANSIENT RESPON

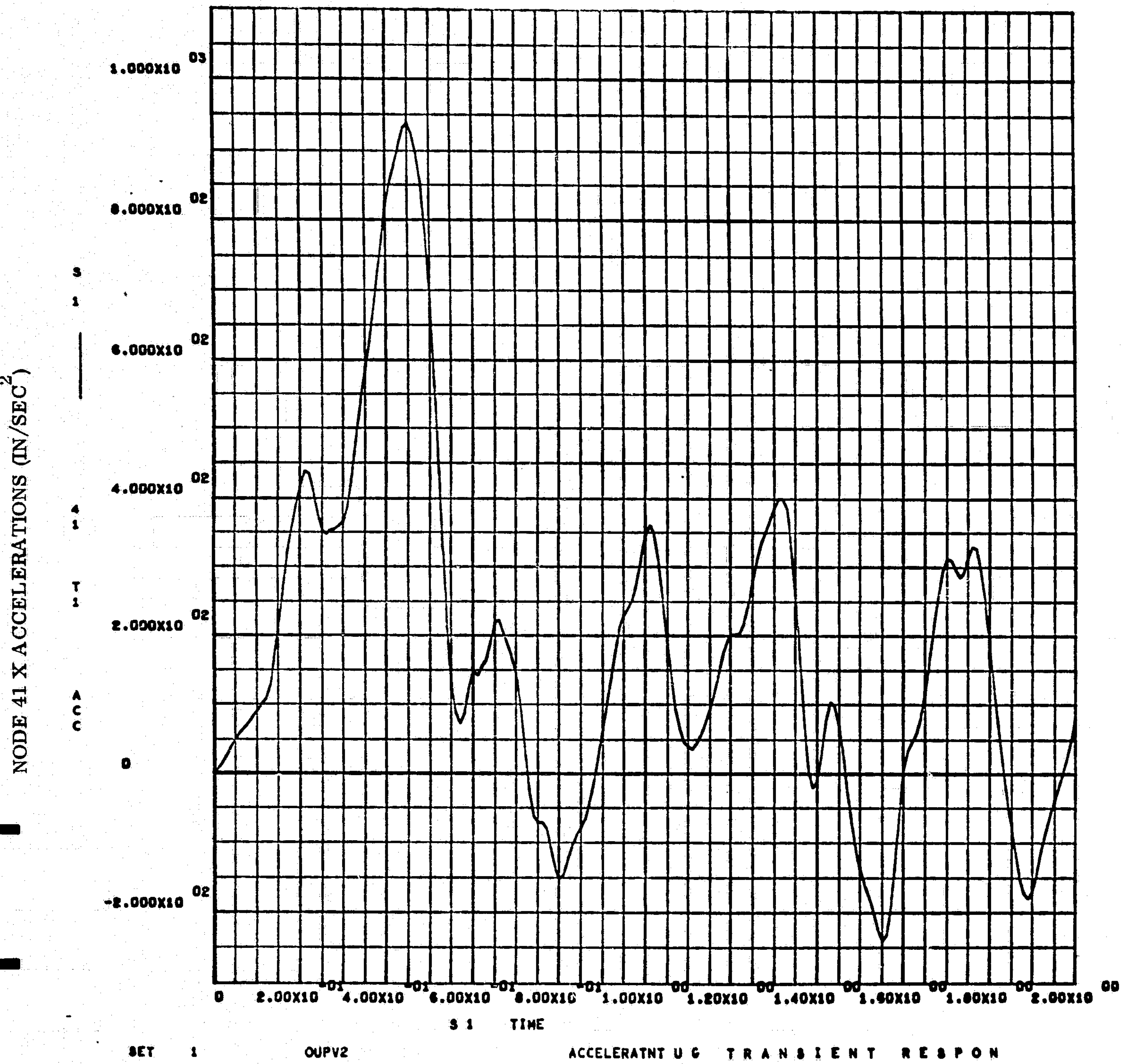

NODE 52 Y ACCELERATIONS (IN/SEC^2)
S 1 — 52 T 2 ACC
1.000X10 03
0
-1.000X10 03
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1
OUPV2
ACCELERATNT U G TRANSIENT RESPON


NODE 52 Z ACCELERATIONS (IN/SEC^2)
6.00X10 02
4.00X10 02
2.00X10 02
0
-2.00X10 02
-4.00X10 02
-6.00X10 02
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1
OUPV2
ACCELERATNT U G TRANSIENT RESPON

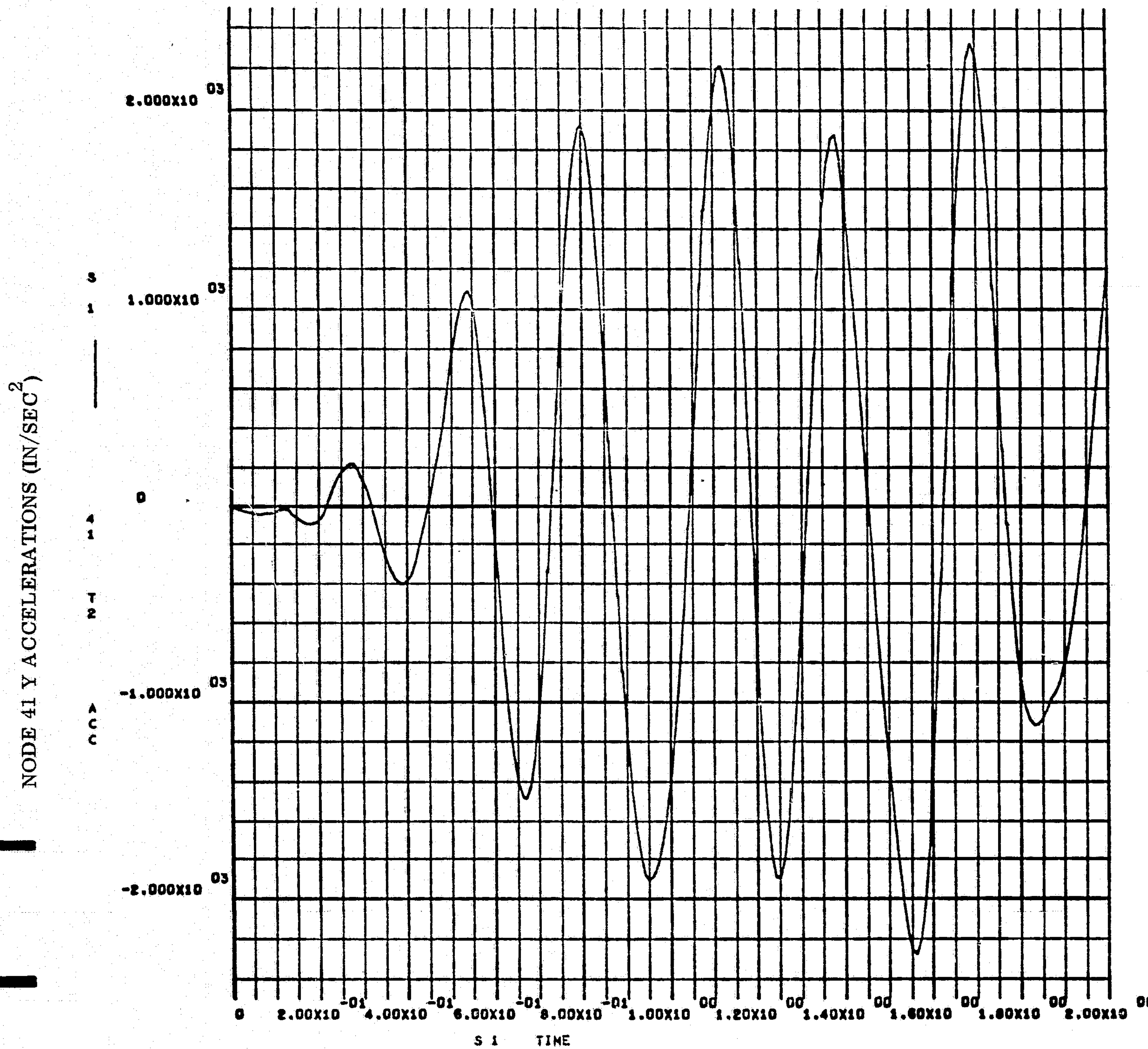

NODE 32 X ACCELERATIONS (IN/SEC^2)
S 1
32
T 1
ACC
1.000X10 03
8.000X10 02
6.000X10 02
4.000X10 02
2.000X10 02
0
-2.000X10 02
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1
OUPV2
ACCELERATNT U G TRANSIENT RESPON


NODE 32 Y ACCELERATIONS (IN/SEC^2)
S 1
32 T2 ACC
4.000X10 03
3.000X10 03
2.000X10 03
1.000X10 03
0
-1.000X10 03
-2.000X10 03
-3.000X10 03
-4.000X10 03
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1
OUPV2
ACCELERATNT U G TRANSIENT RESPON

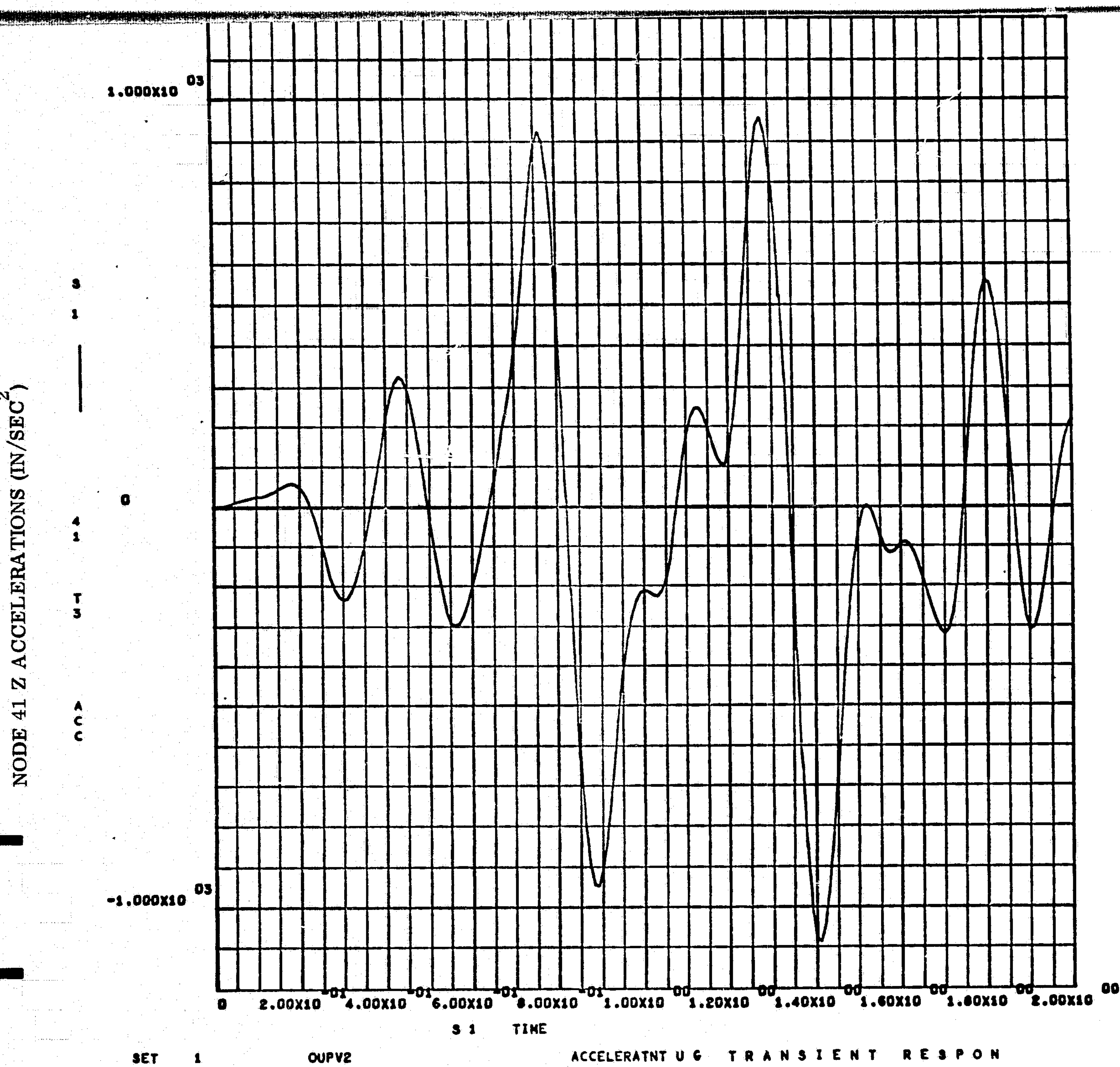

1.000X10 03
0
-1.000X10 03
S 1 — 0
3 2 T 3
A C C
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1
OUPV2
ACCELERATNT U G TRANSIENT RESPON
NODE 32 Z ACCELERATIONS (IN/SEC^2)



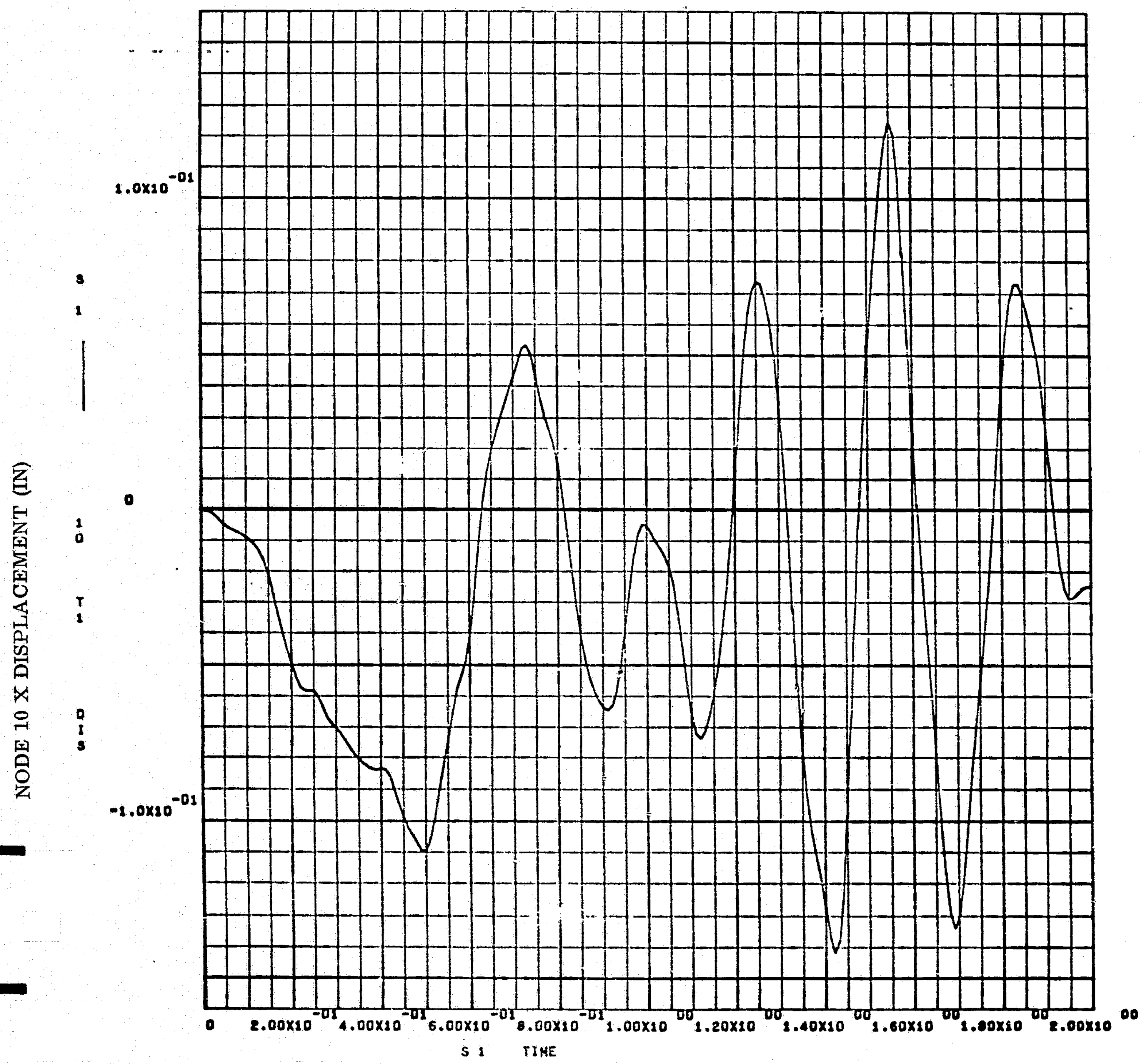
NODE 41 X ACCELERATIONS (IN/SEC²)
S 1 41 T 1 ACC
1.000X10 03
8.000X10 02
6.000X10 02
4.000X10 02
2.000X10 02
0
-2.000X10 02
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1
OUPV2
ACCELERATNT U G T R A N S I E N T R E S P O N

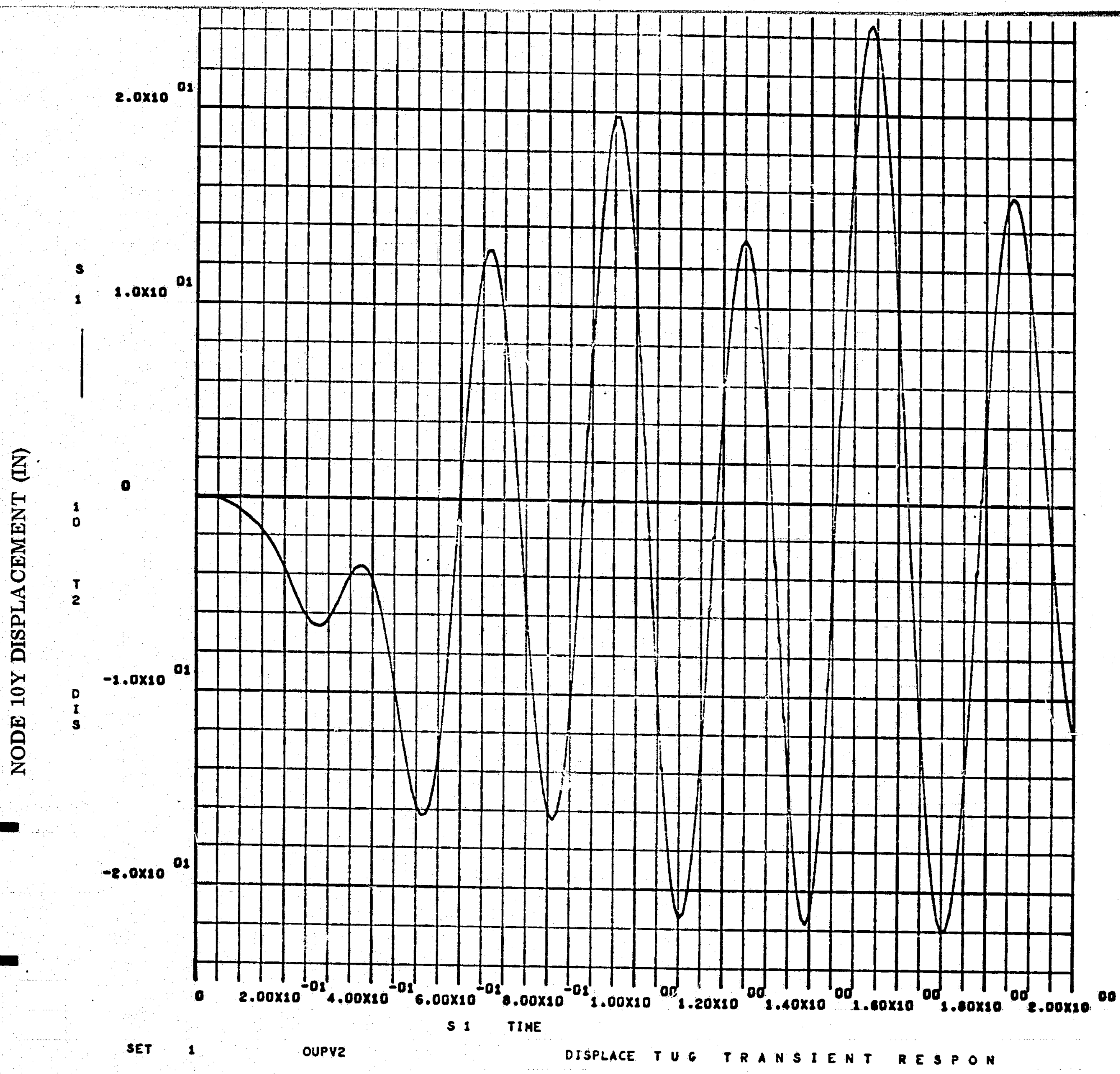


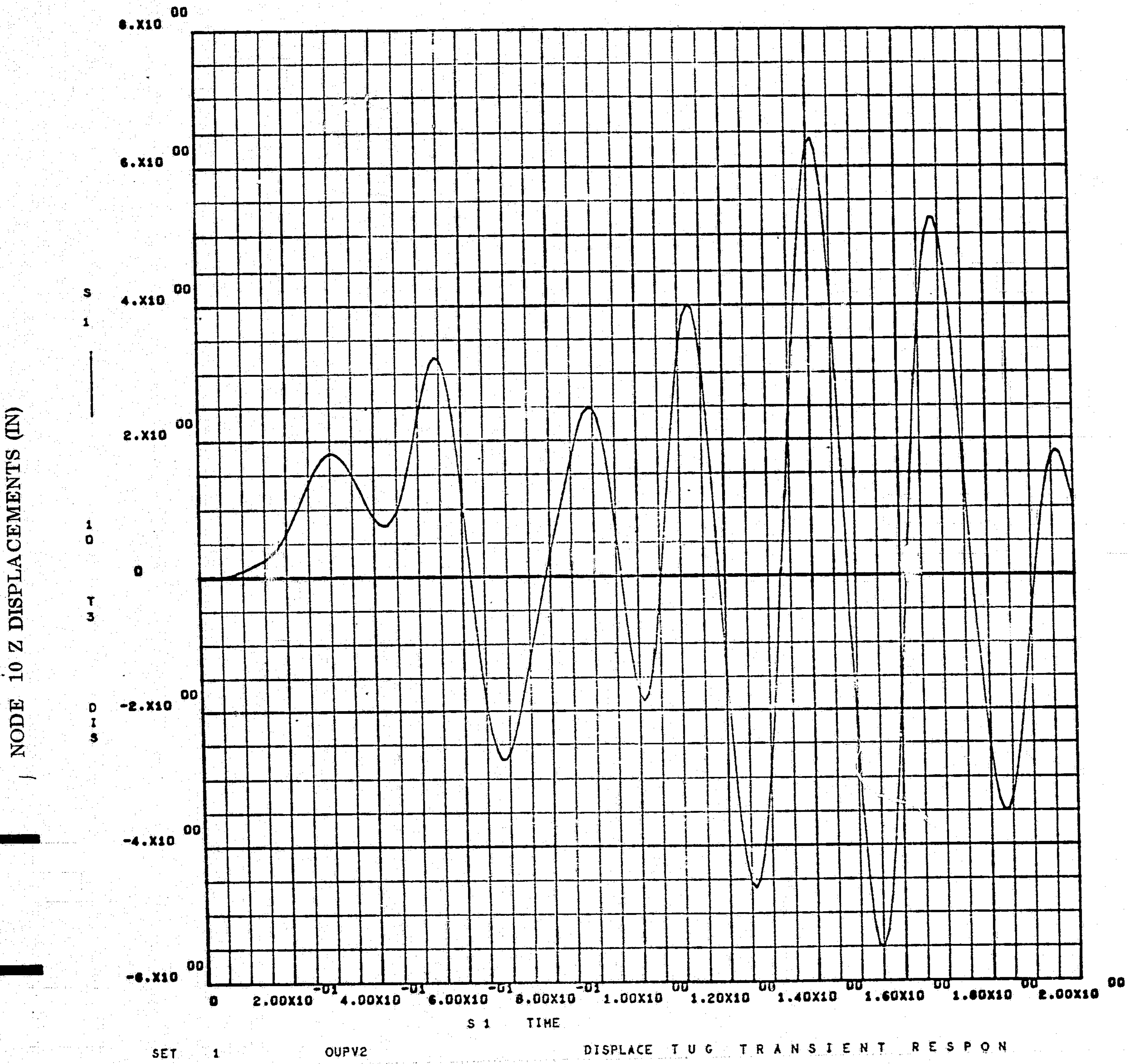
NODE 41 Y ACCELERATIONS (IN/SEC^2)
S 1 — 41 T 2 ACC
2.000X10 03
1.000X10 03
0
-1.000X10 03
-2.000X10 03
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME

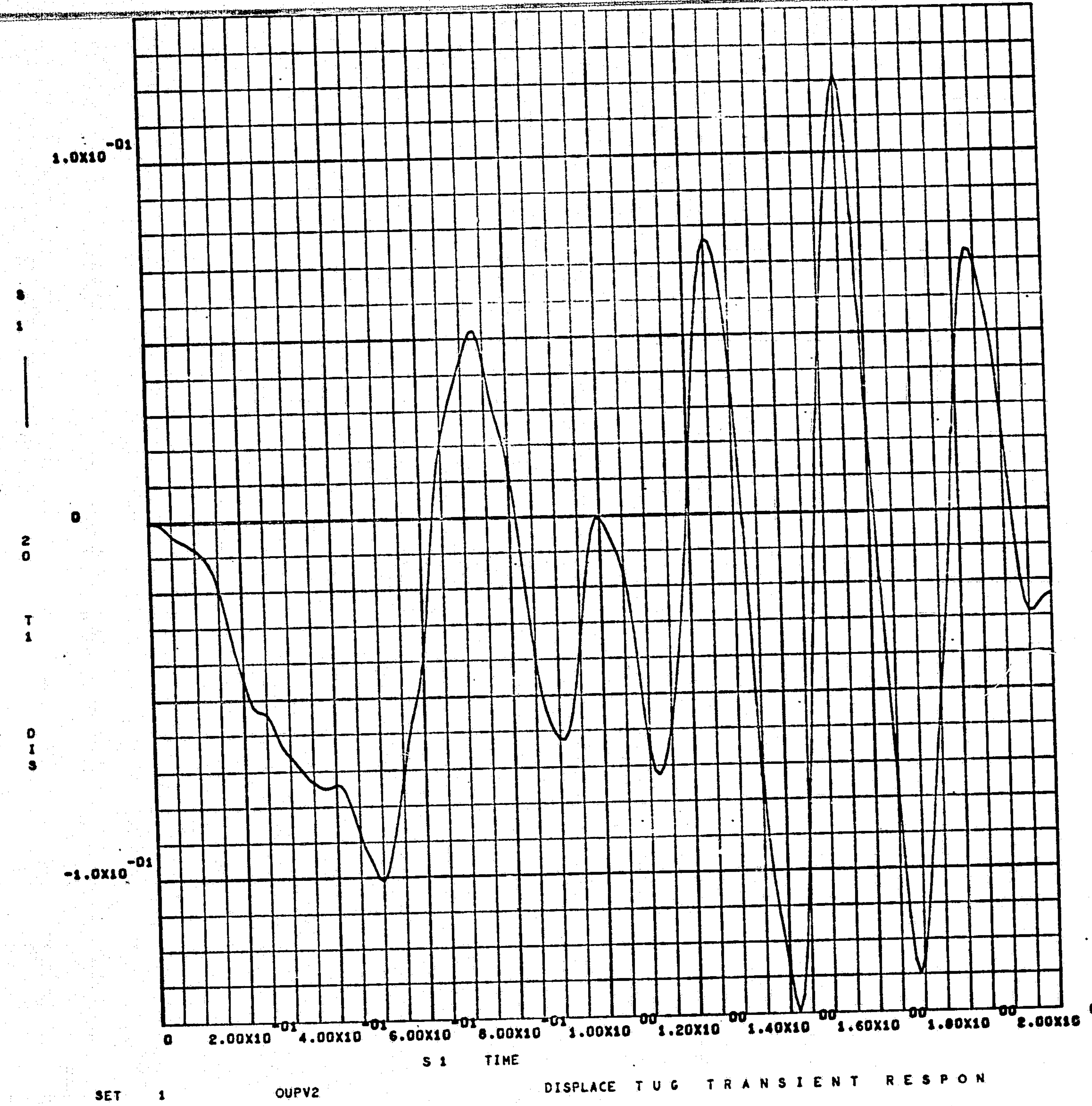


NODE 41 Z ACCELERATIONS (IN/SEC^2)
1.000X10 03
0
-1.000X10 03
S 1 — 4 1 T 3 ACC
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1
OUPV2
ACCELERATNT U G TRANSIENT RESPON

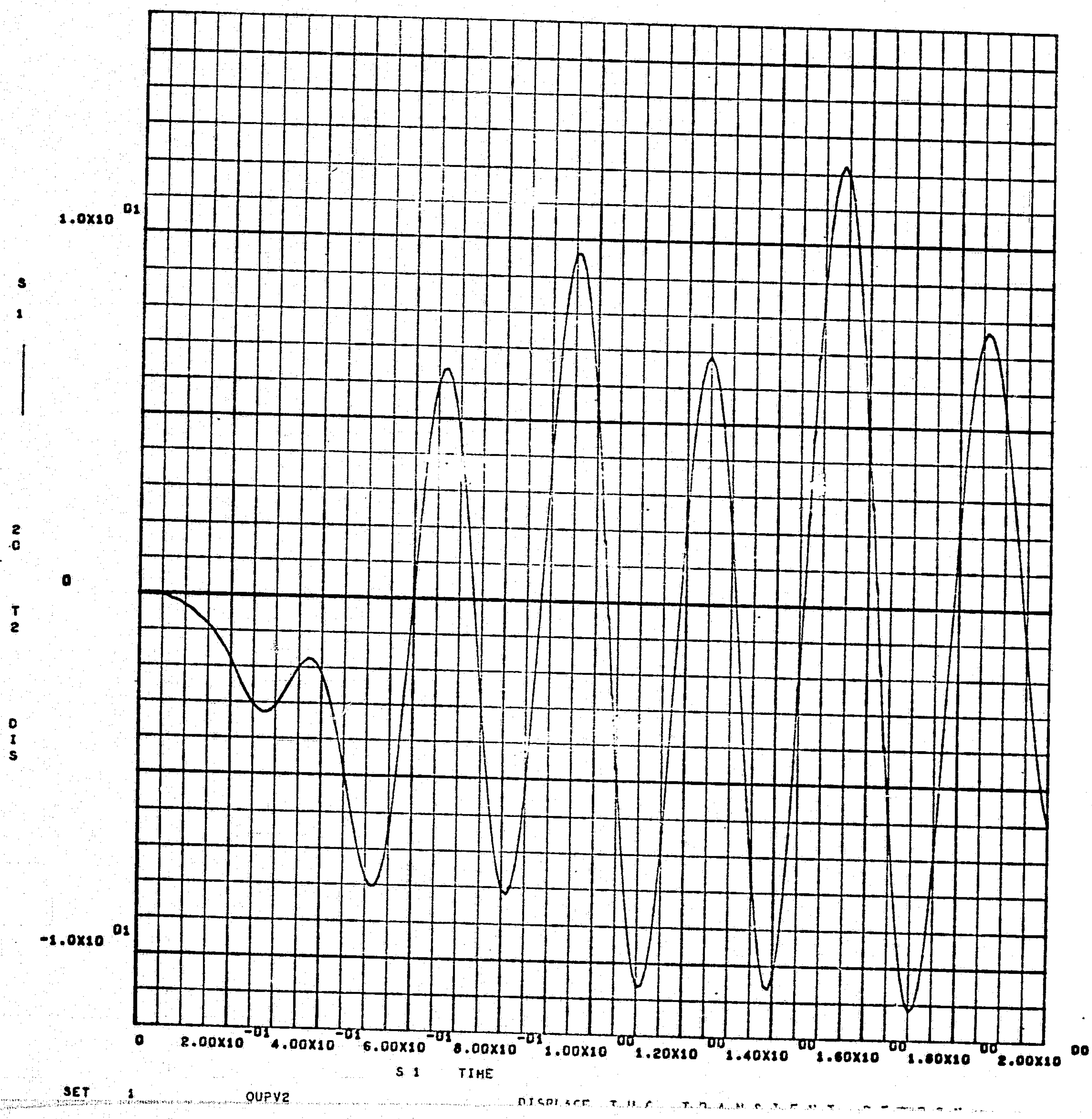

NODE 10 X DISPLACEMENT (IN)
S1 10 T1 QIS
1.0X10^-01
0
-1.0X10^-01
0
2.00X10^-01
4.00X10^-01
6.00X10^-01
8.00X10^-01
1.00X10^00
1.20X10^00
1.40X10^00
1.60X10^00
1.80X10^00
2.00X10^00
S 1 TIME


NODE 10Y DISPLACEMENT (IN)
S1 — 10 T2 DIS
2.0X10 01
1.0X10 01
0
-1.0X10 01
-2.0X10 01
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1
OUPV2
DISPLACE T U G T R A N S I E N T R E S P O N

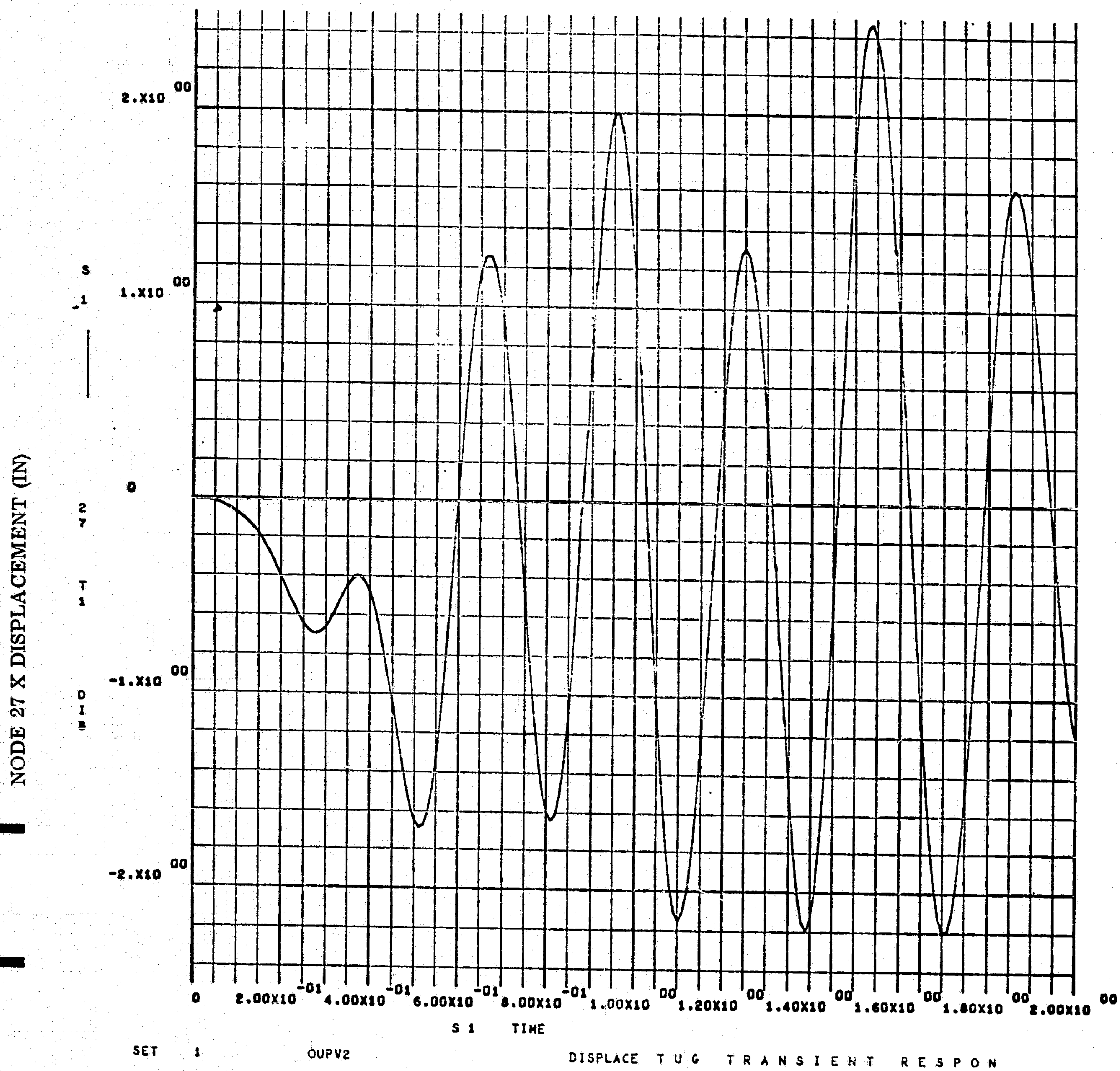

NODE 10 Z DISPLACEMENTS (IN)
S 1
10
T 3
DIS
8.X10 00
6.X10 00
4.X10 00
2.X10 00
0
-2.X10 00
-4.X10 00
-6.X10 00
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1
OUPV2
DISPLACE TUG TRANSIENT RESPON

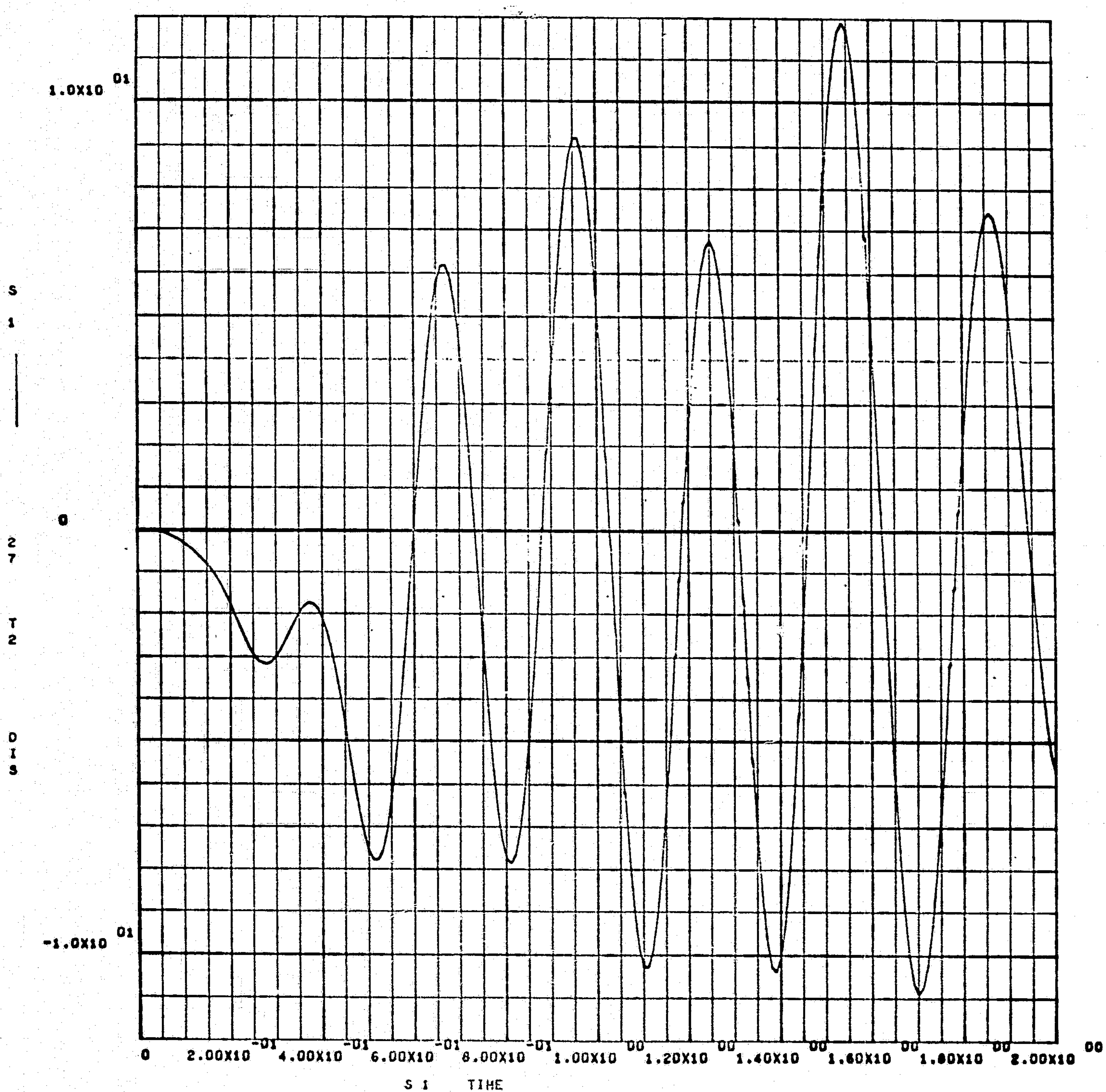


NODE 20 X DISPLACEMENT (IN)

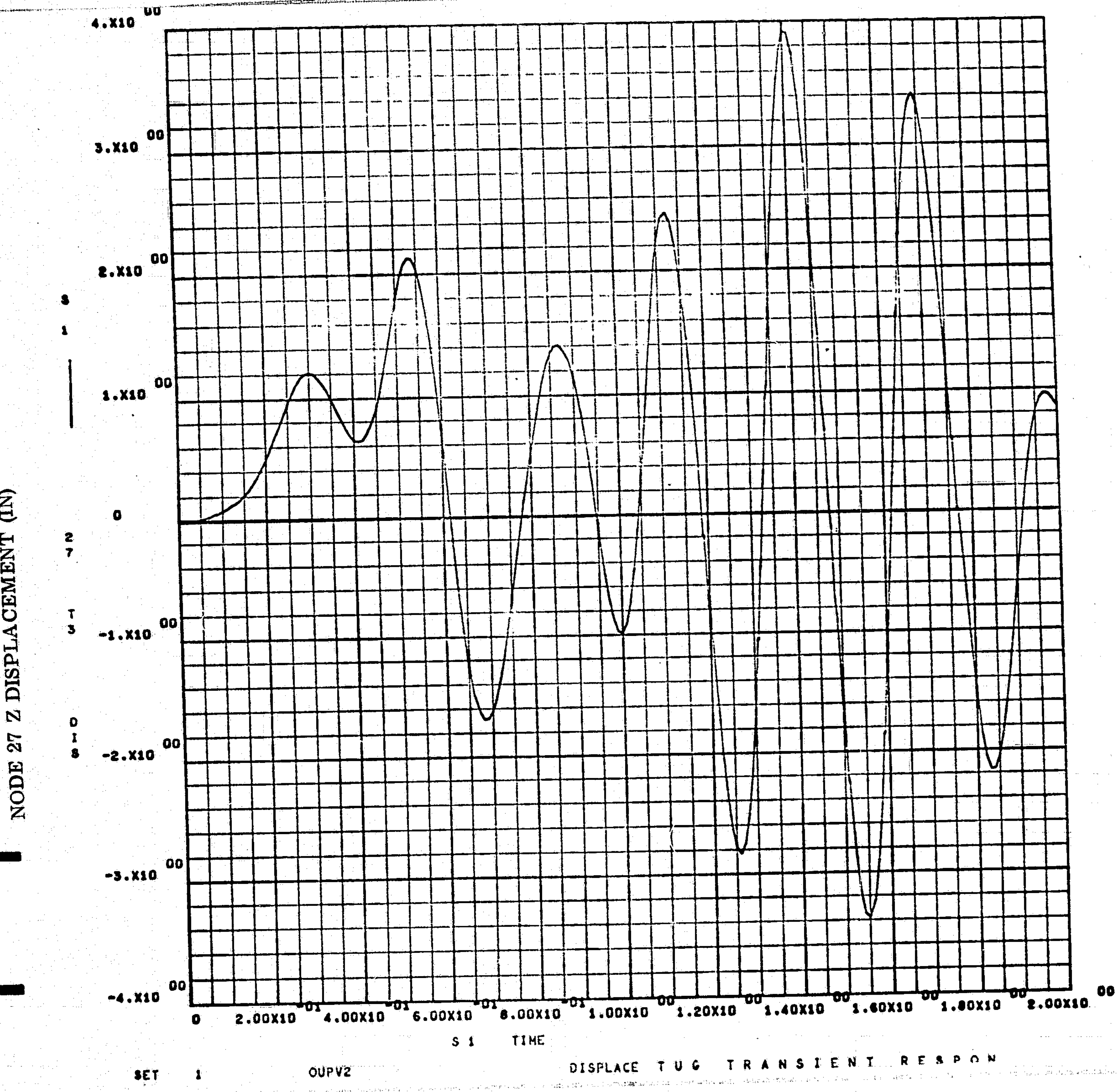


NODE 20 Y DISPLACEMENT (IN)


NODE 27 X DISPLACEMENT (IN)
S 1 27 T 1 DIR
2.X10 00
1.X10 00
0
-1.X10 00
-2.X10 00
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1
OUPV2
DISPLACE T U G T R A N S I E N T R E S P O N



NODE 27 Y DISPLACEMENT (IN)



NODE 27 Z DISPLACEMENT (IN)
S 1
27
T 3
D I S
4.X10 00
3.X10 00
2.X10 00
1.X10 00
0
-1.X10 00
-2.X10 00
-3.X10 00
-4.X10 00
0
2.00X10 -01
4.00X10 -01
6.00X10 -01
8.00X10 -01
1.00X10 00
1.20X10 00
1.40X10 00
1.60X10 00
1.80X10 00
2.00X10 00
S 1 TIME
SET 1
OUPV2
DISPLACE T U G T R A N S I E N T R E S P O N

APPENDIX C

TWO PHASE FLOW ANALYTICAL MODEL

Physical Model

Figure 1 shows a simplified physical model for dump of fluid from a pressurized tank through a duct with an exit to vacuum. Liquid is forced from the tank through the line to the exit by a combination of ullage pressure and elevation head pressure. As the liquid proceeds through the line at rate $\mathring{\omega}$, friction pressure losses reduce and increasing elevation head increased local pressure. If head pressure gradient is small (because of low vehicle acceleration, for example), at some point in the line (the transition point), the friction ΔP will cause the local static pressure to drop to the vapor pressure of the fluid and vaporization will begin. As the resulting two-phase fluid (liquid-gas mixture) proceeds further through the duct, further pressure losses progressively reduce pressure, causing further vaporization, increasing the relative quantity of gas in the flowing liquid (the vapor fraction). The vapor fraction continues to increase until the exit is reached. At the exit, the flow velocity of the fluid is the two-phase mixture sonic velocity.

Analytical Model Summary

The analytic model that simulates the physical model described above is also outlined in Figure C-1. This model is programmed for iterative solution on the Hewlett-Packard programmable calculator. The iteration procedure used is as follows:

(1) The location of the two-phase transition point is assumed and input in terms of the ΣK_L, L_L and h (summation of loss coefficients, length, and height to liquid surface) at the point.

(2) Liquid flowrate $\mathring{\omega}$ is calculated assuming that the pressure loss ΔP_L to the transition point is such that the static pressure P equals the fluid vapor pressure P_V, properly accounting for elevation head pressure.

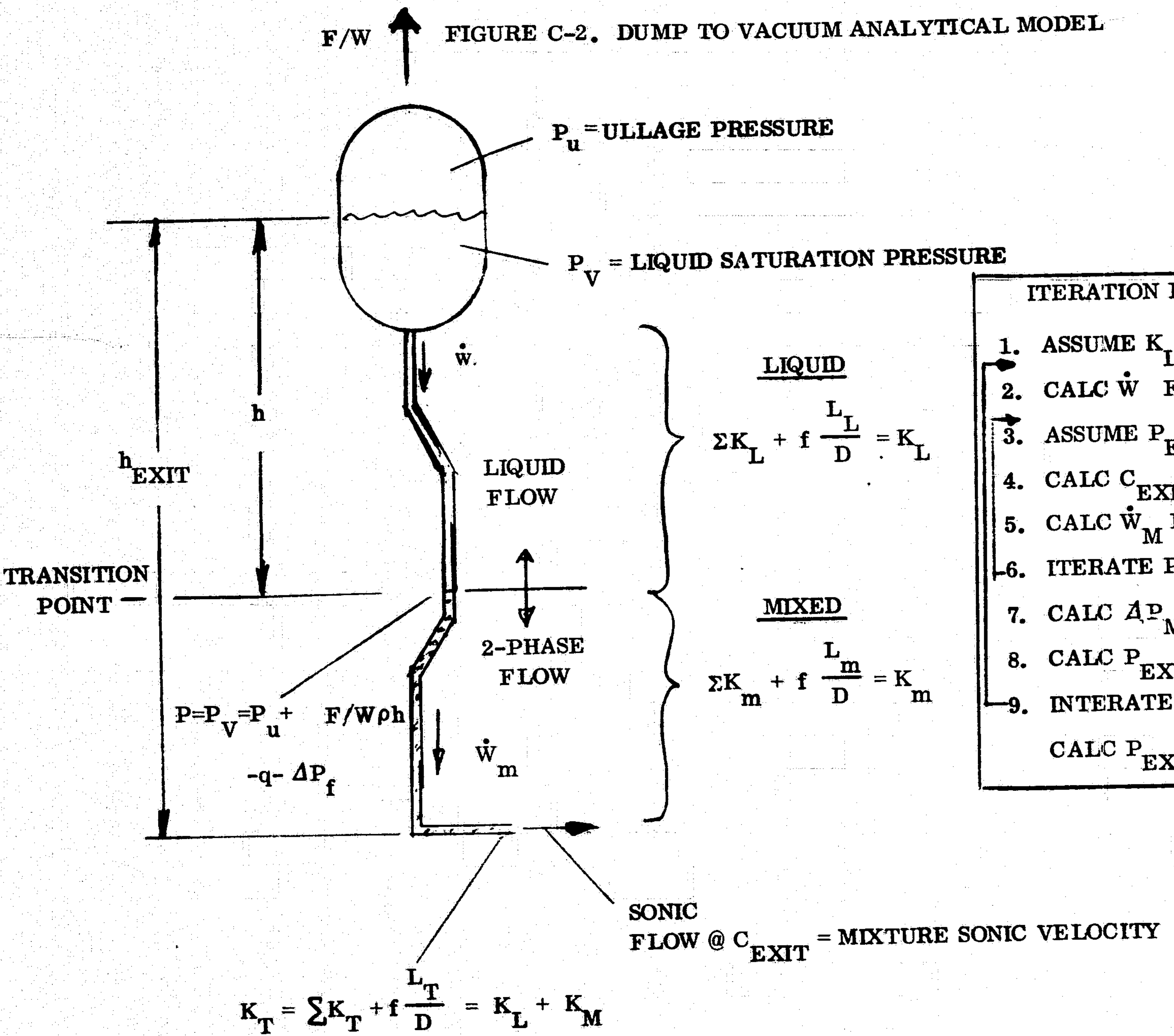
(3) An exit pressure P_{EXIT} less than P_V is assumed.

(4) Exit sonic velocity C_{exit} and exit mixture density ρ_{exit} are calculated for the assumed P_{exit}.

(5) Exit flowrate $\mathring{\omega}_m$ is calculated for the assumed C_{exit}, ρ_{exit}, and exit area.

(6) If the calculated $\mathring{\omega}_m$ does not match the $\mathring{\omega}$ calculated (which it will not not at the first iteration), then P_{exit} is iterated (back to step 3) using the Newton-Rapson technique until a match is obtained.

FIGURE C-2. DUMP TO VACUUM ANALYTICAL MODEL



ITERATION PROCEDURE

1. ASSUME K_L (& h)
2. CALC $\dot{W}$ FOR $P = P_V$
3. ASSUME P_{EXIT}
4. CALC C_{EXIT}
5. CALC $\dot{W}_M$ FOR C_{EXIT}, ρ_{EXIT}
6. ITERATE P_{EXIT} UNTIL $\dot{W}_M = \dot{W}$
7. CALC ΔP_M
8. CALC P_{EXIT}
9. INTERATE K_L UNTIL CALC P_{EXIT} = ASSUMED P_{EXIT}

(7) The pressure drop ΔP_m from transition point to exit is calculated for the solution values of $\mathring{\omega}_m$, ρ_{exit}, C_{exit}, etc.

(8) An exit pressure compatible with ΔP_L, ΔP_m, head pressure at exit, P_u, etc., is calculated, and compared with the iterated value of P_{exit} determined above in the step 3-6 iteration loop. Calculated and assumed values of P_{exit} will not match at the first iteration.

(9) Location of the transition point is iterated (back to step 1) until a match is obtained between the calculated and assumed (iterated) values of P_{exit}. A Newton-Raphson iteration with K_L the independent and (assumed P_{exit}) - (calculated P_{exit}) the dependent variable.

(10) When the assumed and calculated values of P_{exit} match, an internally consistent solution to the model (all flowrates, pressures, ΔPs, etc., are compatible), and the solution is printed out.

Analytical Model Equation and Block Diagram

A block diagram of the basic computer model including all major equations (except those involved in calculating mixture conditions at the exit) is given in Figure C-2. All equations are derivations of the accepted fluid mechanics relationship and involve no assumptions down to the numbered block 5. Implicit in this equation is the assumption that $\Delta P_m = K_m \; q_{avg}$, and that the average q is 1/2 $(q_m + q_L)$ where q_m is the mixture dynamic pressure at the exit (neglecting any possible area restriction at the exit). The last term in equation 5 $(1/C_d^2)$ corrects static pressure for an exit restriction of area = C_d (duct area).

Equation 6 contains the assumption that the difference in elevation head pressure between the transition point and the exit can be calculated by (ρ_{avg}) $(h_{exit} - h)$ F/W where ρ_{avg} is $(\rho_L + \rho_{EXIT})/2$. No other assumptions are made in the basic program derivation.

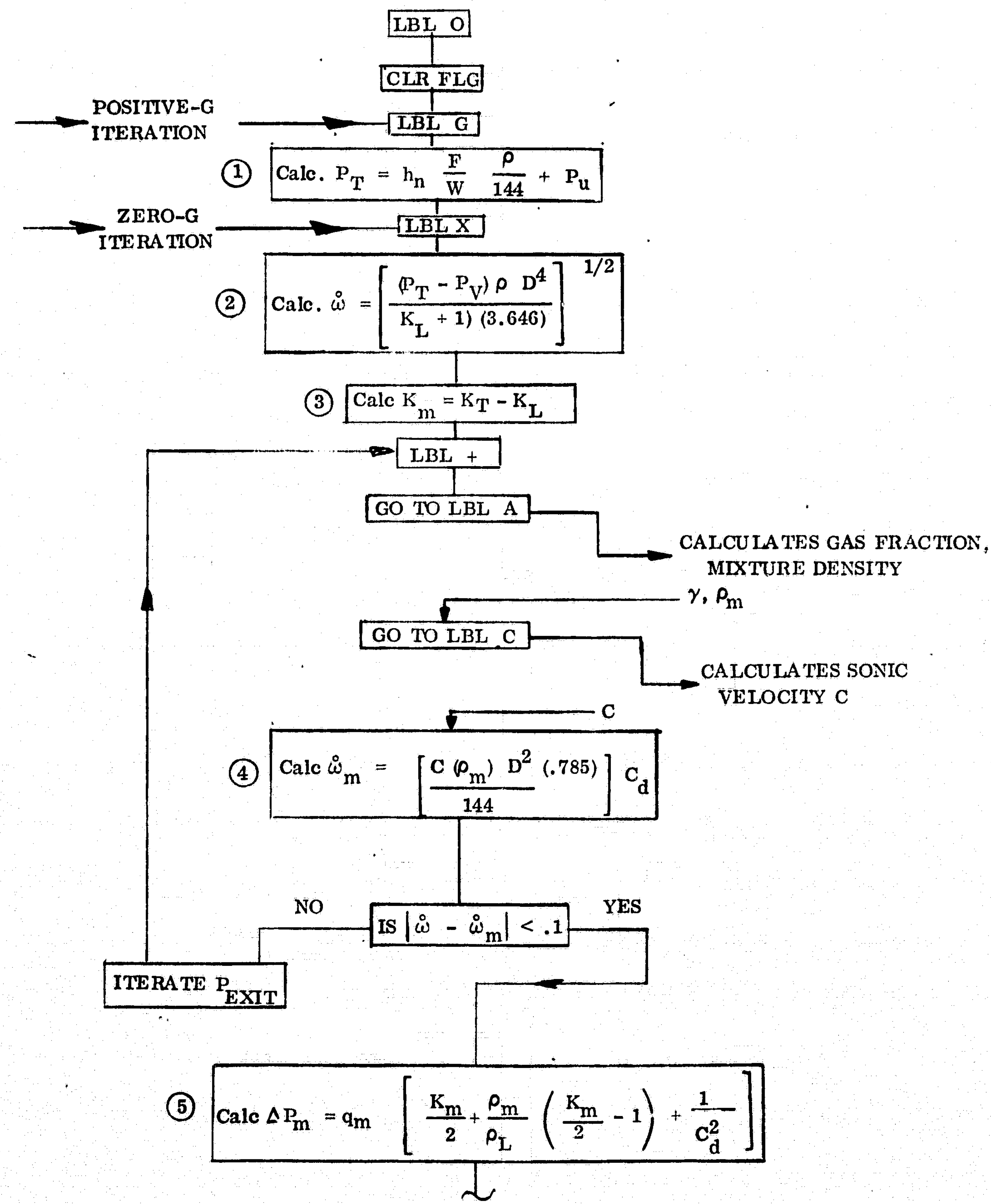
Mixture Exit Condition

The major area involving assumptions not generally recognized in the industry is the calculation of the exit mixture condition, including density, vapor fraction, and sonic velocity at the assumed exit pressure. For calculating mixture vapor fraction, density, and temperature, the technique derived in Reference 1 was used. In this technique, an isentropic expansion from the saturated liquid condition into the two-phase region is assumed. Initial and final saturation pressures and corresponding temperature, density, and entropy data are obtained from published NBS data tables. The mixture vapor-to-liquid ratio (V_v/V_ℓ) called "cavitation B factor" B is calculated from

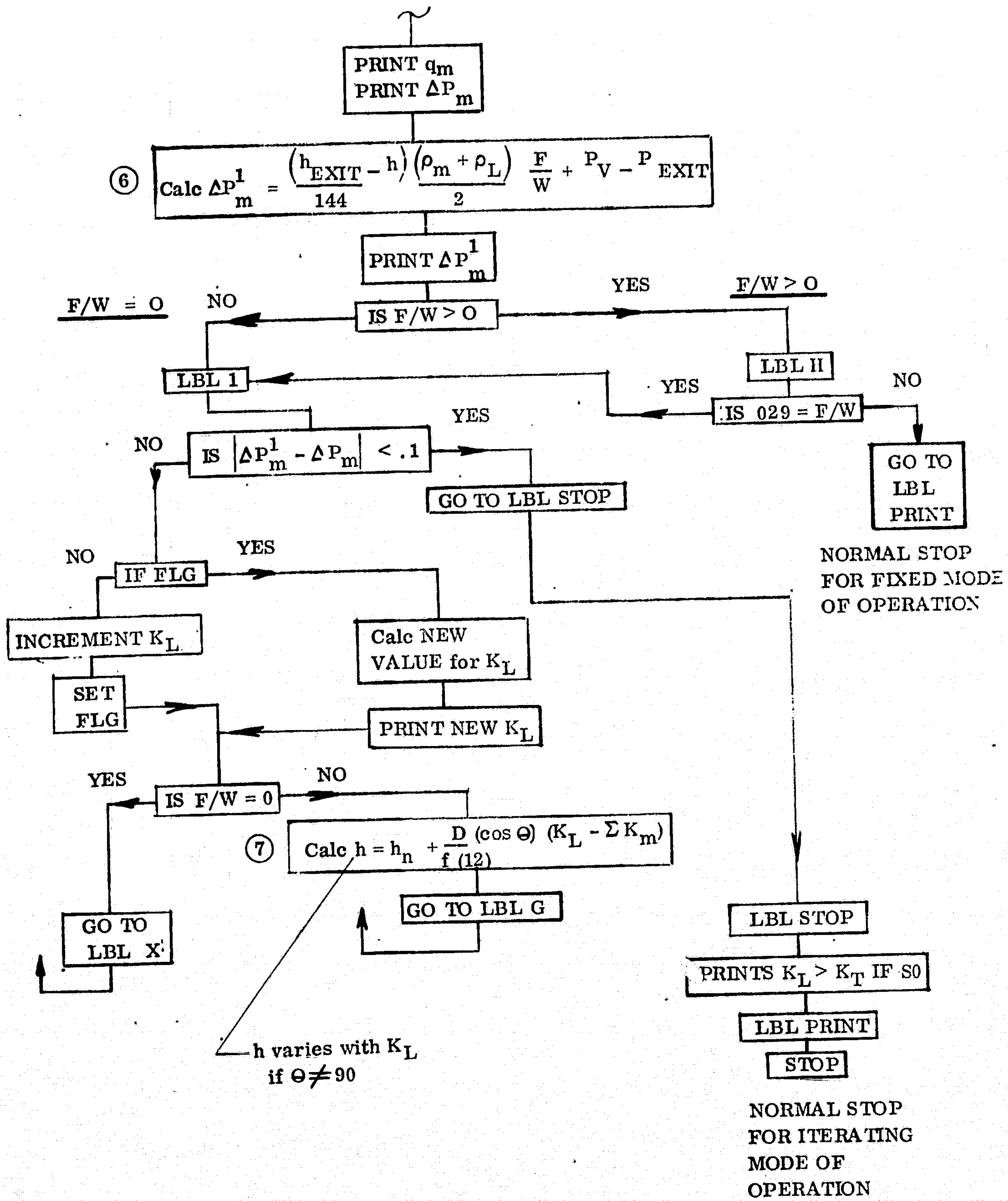
$$B = \frac{V_v}{V_\ell} = \frac{\rho_{\ell_2}}{\rho_{v_2}} \left(\frac{S_{\ell_2} - S_{\ell_2}}{S_{v_2} - S_{\ell_1}} \right)$$

FIGURE C-2

DUMP TO VACUUM BLOCK DIAGRAM



DUMP TO VACUUM BLOCK DIAGRAM (Continued)



DUMP TO VACUUM BLOCK DIAGRAM (Continued)

OPTIONAL CALCULATION FOR K_T^*

LBL K

(8) $$K_T = \left[\Sigma K_1 + f \frac{L_1}{D_1}\right]\left(\frac{D_1}{D}\right)^4 + f \frac{(L - L_1)}{D} + \Sigma K - \Sigma K_1$$

STOP

GO TO LBL O

*EFFECTIVE K_T FOR DUMP LINES WITH LARGE DIAMETER D_1 UPSTREAM, SMALLER DIAMETER D DOWNSTREAM.

where ρ is specific weight (density), S is entrophy, and the subscripts denote phase (liquid or vapor) and point (initial and final). Mixture density and vapor fraction (quality) can be calculated from B and the fluid properties.

Calculation of the proper mixture acoustic velocity is the area of most apparent uncertainty currently in the industry. The different "acoustic velocities" currently recognized are as follows:

(1) equilibrium - a further pressure drop in a two-phase mixture will cause vaporization as well as an expansion of existing vapor.

(2) Constant quality - no vaporization occurs, only an expansion of the existing vapor. There are "isothermal gas" and "isentropic gas" models for constant quality acoustic velocity.

The model for acoustic velocity incorporated into the program is capable of calculating velocity based on any of the above assumptions. Equations used were taken from Reference 2 and will not be repeated here. Typical curves of mixture sonic velocity vs gas fraction for O_2 and H_2 are given in Figure C-3 and C-4. Initial conditions for the saturated liquid before expansion into the two-phase region are given, but pressures and temperature vary along the curves as the gas fraction varies. It was decided to use the equilibrium assumption for H_2 because experiments documented in Reference 3, "Investigation of Two-Phase Hydrogen Flow in Pump Inlet Line," showed that this is the best simulation for passages of high length/diameter ratio. The constant quality isentropic assumption was used for LO_2 because the equilibrium assumption apparently gives erroneous low velocities at the near zero gas fraction. Acoustic velocities there are about 10 ft/sec, about one-half the normal flow velocity for liquid O_2 lines.

Summary of Major Assumptions

Major assumptions made in development of the two-phase model, discussed above in the model narrative description, are as follows:

(1) At the dump line exit, the two-phase mixture flows at the mixture acoustic velocity.

(2) Mixture acoustic velocities are calculated assuming equilibrium expansion for H_2, constant quality isentropic expansion for O_2.

(3) Pressure loss in the two-phase duct section can be calculated using the arithmetic average of transition point and exit dynamic pressure.

(4) Head pressure between the transition point and the exit can be calculated using the arithmetic average of the mixture densities at the two points.

Program Operation

An input/output printout for a typical run of the two-phase program is given

FIGURE C-3. TYPICAL TWO-PHASE H_2 SONIC VELOCITY VS GAS FRACTION

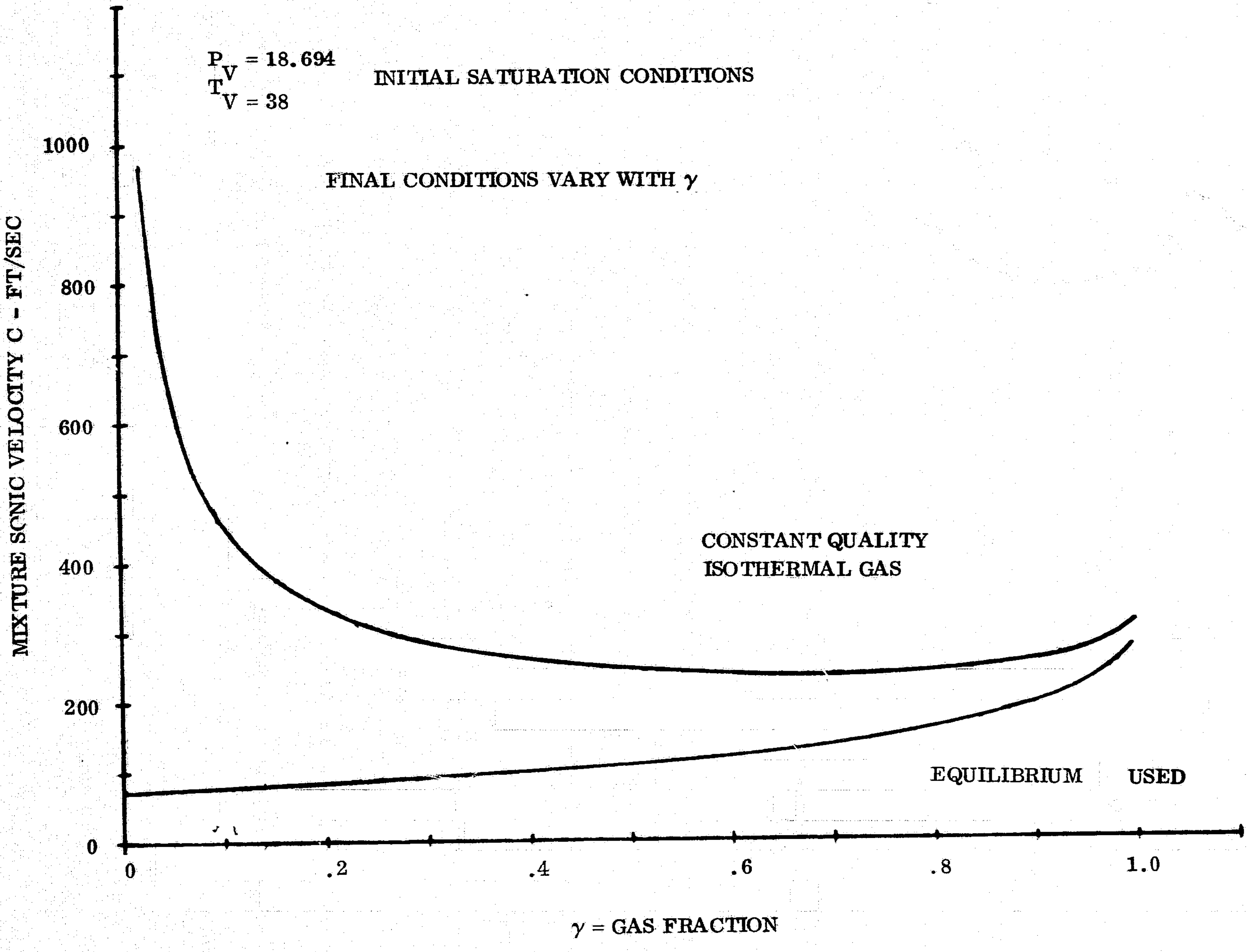
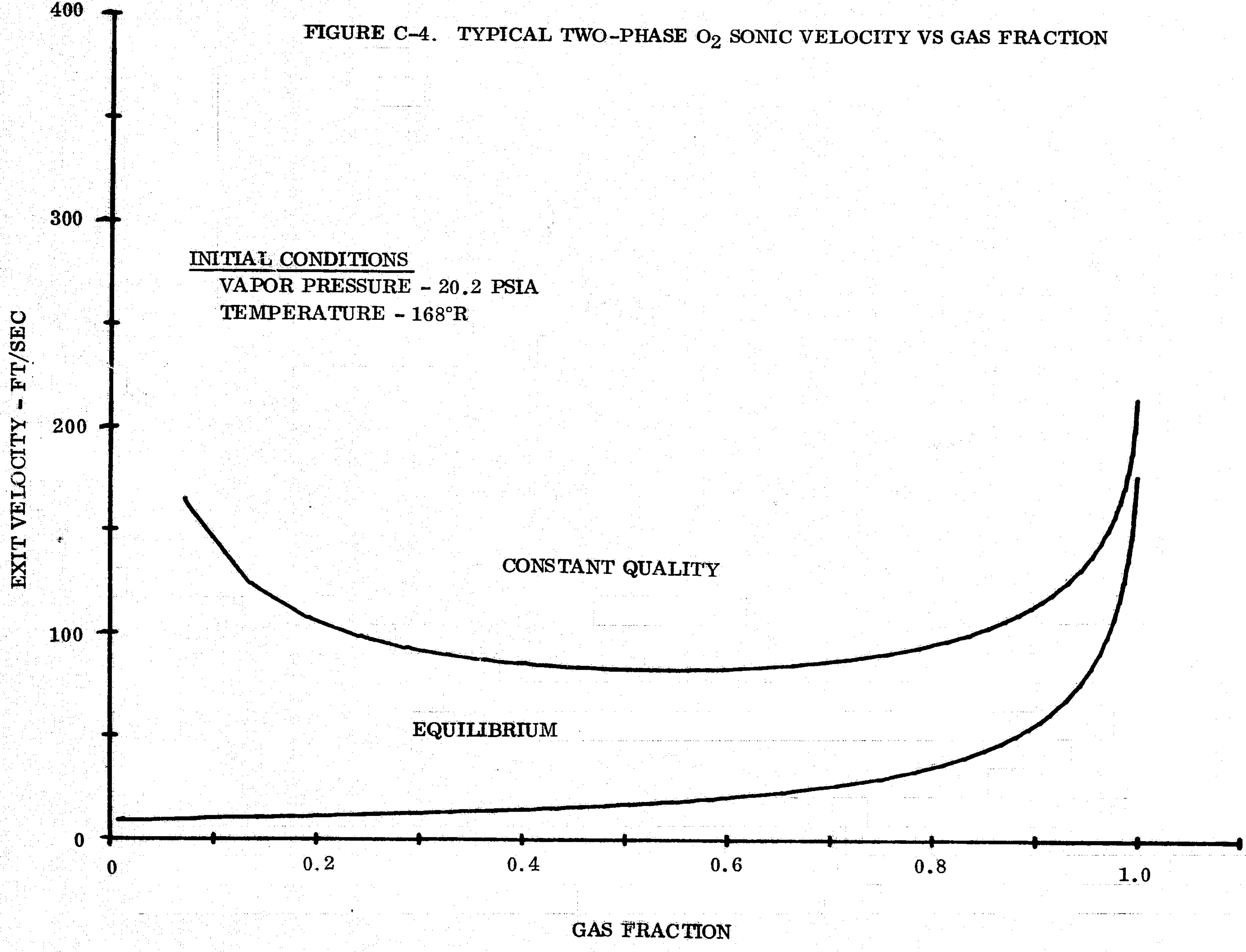


FIGURE C-4. TYPICAL TWO-PHASE O_2 SONIC VELOCITY VS GAS FRACTION



in Table C-1. This identifies all of the input required and the standard output data printed. An actual configuration analyzed (Baseline Tug LH_2 System) is shown in Figure C-5.

Operational Limitations of the Program

(1) The program model assumes that there is no choking upstream of exit or the two-phase transition point iterated in the program. This is not necessarily the case, because at low pressures and low fluid heights in the tank, the upper end of the duct may choke at a lower flow. This was the case for the Interface Study Baseline Tug LO_2 dump system. A larger diameter was required at the tank outlet than at the exit. If choking at any location is suspected, it can be checked as follows:

(a) Run the program for the entire system (tank to exit) and determine dump flowrate.

(b) Input the ΣK_L and h at the suspect point, and run the program in the fixed mode, provided for this purpose. This determines ω_L with pressure at the suspect point equal to vapor pressure, the choking point. If the flowrate so determined is greater than that determined in (a), the suspect point does not choke.

If choking is found upstream of the two-phase transition point, the solution from (a) is invalid. Capability is built into the program to simulate a step change in duct diameter at any point above the two-phase transition point. Diameter can be increased in the vicinity of the tank outlet so that the flowrate obtained in (b) is above flowrate from (a) and valid solutions can be obtained.

(2) With the simplified model built into the program, the iteration of the transition point is valid only for a straight dump line inclined at some arbitrary input angle to the acceleration vector. The reason is that the height h and therefore the elevation head pressure at the iterated point is calculated as a linear function of the iterated value of the total loss coefficient, the actual independent variable in the iteration. Therefore, the program will not properly iterate across components, around bends, etc., if the acceleration is anything other than zero. However, a valid solution can be obtained for a complex configuration such as shown in Figure C-5 in the following manner:

(a) Guess at the approximate location of the transition point.

(b) If the point is in a straight duct section, input ΣK and h at the upstream end of the section as the starting point, input the actual inclination angle of the duct, and let the program iterate to solution. If the solution ΣK and h fall within the straight section as assumed, the solution is valid.

TABLE 1. INPUT-OUTPUT RECORD

Mixture Dynamic Pressure, psi q_m	2.233197
ΔP in Two-Phase Section ΔP_m^1	3.486136
$P_v + F/W\,\rho\,(h_{EXIT_o} - h) - P_{EXIT}\ \Delta P_m$	3.446471
Flow Rate lb/sec, $\dot{\omega}$	23.987395
Gas Fraction at Exit, γ	0.494019
Mixture Sonic Velocity F/sec C	94.841451
P_{EXIT} psia	12.387364
Total $\Sigma K + f\frac{L}{D} = K_t$	2.993333 I
Liquid Section $\Sigma K + f\frac{L}{D} = K_L$	1.570880
Mixed Phase Section $\Sigma K + f\frac{L}{D} = K_m$	1.422453
Liquid Density, lb/ft^3 ρ_L	4.406147 I
Duct Dia. in., D	4.500000 I
Pressure at Transition Point, psia P	18.485078
Liquid Saturation Press., psia, P_v	15.500000 I
Exit Pressure, psia, P_{EXIT}	12.387364
Liquid Saturation Temp. °R, T_v	36.809115 I
Iterating Factor	0.200000 I
Thrust Weight, F/W	2.500000 I
Head at Exit, Ft, h_{EXIT}	12.083333 I
Head at Transition Point, ft, h	6.341248
Ullage Pressure, psia, P_u	18.000000 I
Iteration Code	2.500000 I*
$\Sigma K + f\,L/D$ at n, ΣK_n	1.496667 I
Slope of Duct Below h_n deg., θ	55.345431 I
Friction Factor, f	0.052824 I
Head at Reference Point, ft - h_n	6.041667 I
Exit Coef. of Discharge, C_d	1.000000 I
Dia. of Upstream Duct Section, in. D_1	4.500000 I
ΣK for Upstream Duct Section, ΣK_1	1.600000 I
Length for Upstream Duct Section, in. L_1	195.000000 I
ΣK for Entire Duct, ΣK	2.200000 I
Length for Entire Duct, in., L	255.000000 I

I - Input
* Input value equal to F/W places program in iterating mode.
Any other input gives fixed mode.

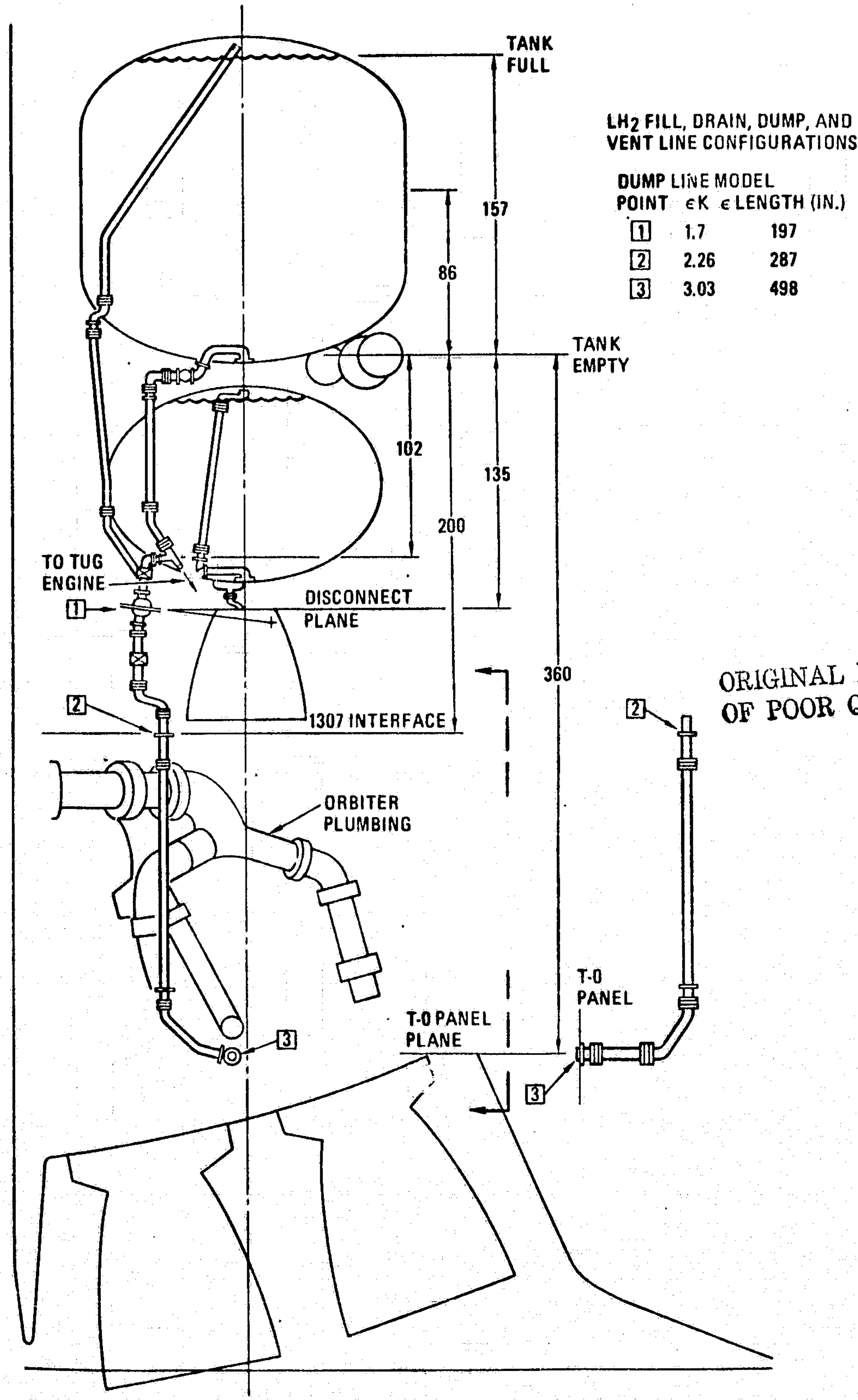


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Figure C-5. LH_2 Fill, Drain, Dump and Vent Line Configurations

(c) If the point is within a component, input ΣK and h at the upstream end of the component as the starting point, input 90° inclination to hold elevation h constant during iteration, and let the program iterate to solution. If the solution ΣK falls within the component, the solution is valid.

A second approach of slightly lower accuracy, but considerably easier in application is to linerarize the duct system by making it equivalent to an inclinded straight duct without components, i.e., of linear ΣK. This is done by (1) inputing an artificial inclination angle which gives compatible values of h and L; e.g., at the exit, $h = h_{exit}$ and $L - L_{exit}$; and (2) inputting an artificial value of f^1 for friction factor f which gives

$$\frac{f^1 L}{D} = \Sigma K + \frac{f L}{D}$$ at the exit.

If better accuracy is required, the linearization technique can be used to determine the starting point for iteration for the more exact technique described above.

<u>Observations based on analysis of Tug Abort Dump Lines</u>

A large number of runs were made in the course of the various analyses for this study and a parallel study, "Centaur IUS Systems Study." Some observation based on experience from these analyses are as follows:

(1) <u>Transition</u> - Assume a system as shown in Figure C-5. At a sufficiently low combination of tank pressure and vehicle acceleration (F/W) the transition point will be located well up the duct from the exit. As tank pressure or F/W is progressively increased, the transition point will move progressively closer to the exit unti at a sufficiently high pressure/ F/W combination, the transition point reaches the exit. At this point flow in the duct is no longer two-phase but pure liquid.

For the LH_2 systems analyzed, the transition point is generally in the first 25 to 50 percent of the duct length. For example, from a tank pressure minus vapor pressure ($P_u - P_v$) range of 0.8 to 6.0 psi, transition ranges from 2 to 68 percent of length for a typical case at zero-g. For the LO_2 systems analyzed, the transition is at the exit (i.e., no two-phase flow) for F/W above approximately 0.5. Figures C-6 and -7 gives flowrate and exit conditions for a typical system of low $P_u - P_v$ for a range of F/W that gives both all liquid and two-phase flow.

(2) The variable of most influence on flowrate is ($P_u - P_v$) for H_2 and F/W for LO_2.

(3) The difference between flowrates at high F/W and low F/W is reduced for high values of ($P_u - P_v$). An example for a typical LO_2 system is as follows:

FIGURE C-6. LO_2 TRANSITION - TWO-PHASE TO LIQUID

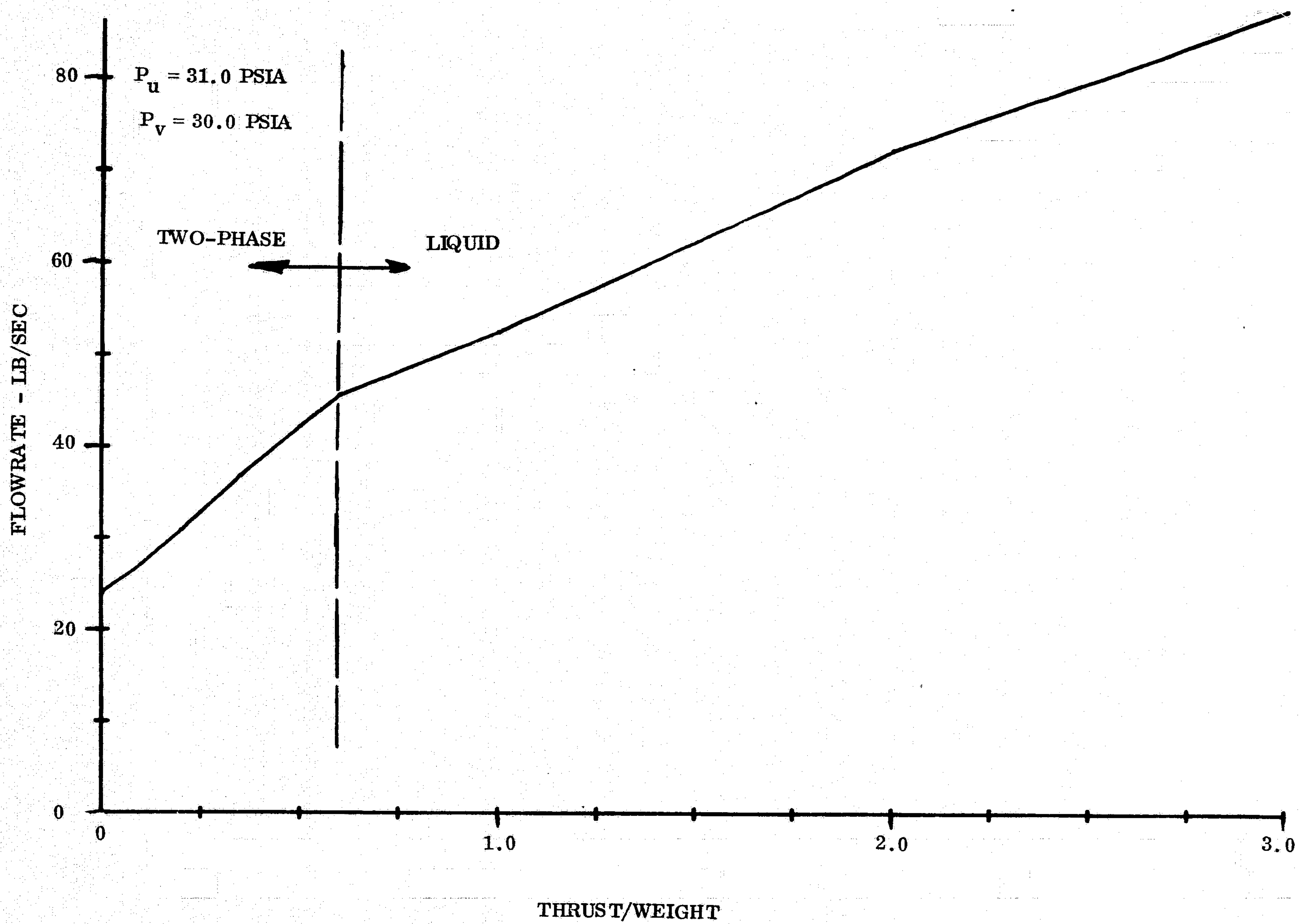
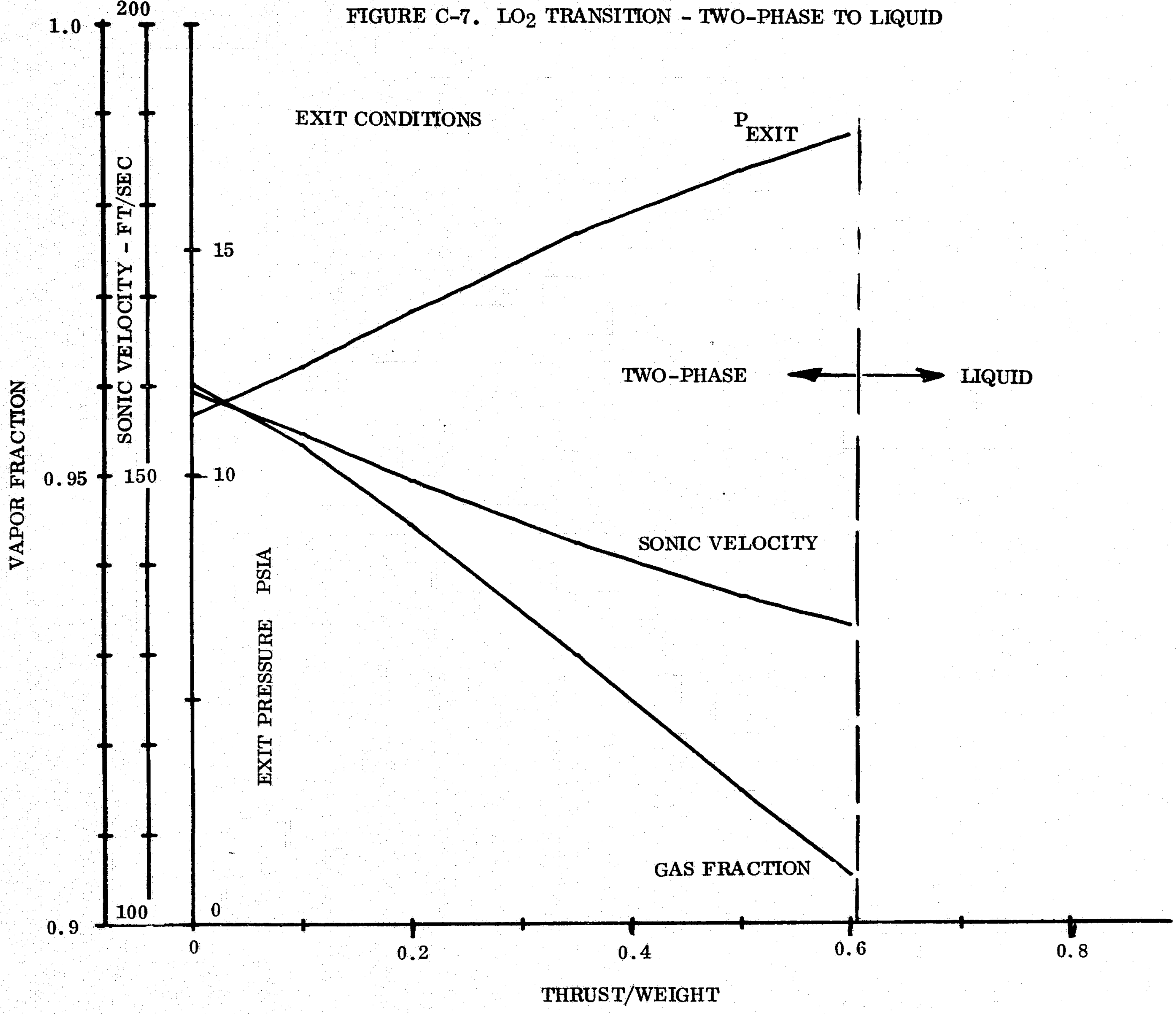


FIGURE C-7. LO_2 TRANSITION - TWO-PHASE TO LIQUID



	P_v psia	P_u psia	$\mathring{\omega}_1/\mathring{\omega}_0$	Typical Dump Time (seconds) F/W 1.0	F/W 0
Low (P_u - P_v)	30.0	31.5	2.54	300	762±
High (P_u - P_v)	30.0	35.2	1.83	300	549

REFERENCES

1. Hord, J., and Voth, R. O.; Tabulated Values of Cavitation B-Factor for Helium, H_2, N_2, F_2, O_2, Refrigerant 114, and H_2O; NBS TN 397, February 1971.

2. Bisselll, W. R., Wong, W. S., and Winstead, T. W.; Analysis of Two-Phase Flow in LH_2 Pumps for O_2/H_2 Rocket Engines," ASME Journal of Spacecraft; Volume 7, No. 6, June 1970.

3. Urasek, D. C., Meng, P. R., and Connelly, R. C.; Investigation of Two-Phase Hydrogen Flow in Pump Inlet Line; NASA TN D-5258; July 1969.

APPENDIX D

ORBITER AVIONICS DESCRIPTION

Appendix D is a compendium of Baseline Orbiter payload support equipment descriptive material extracted from NASA Document JSC-07700, Volume XIV, and applicable Rockwell international documents for reference purposes. The figures included are summarized in Table D-1 below.

Table D-1. Referenced Figures for Appendix D

Figure	Title	Document of Origin
D-1	Avionics Functional Diagram for NASA Payloads	JSC-07700, Vol. XIV
D-2	Avionics Functional Diagram for DOD Payloads	SD 74-SH-0298-1
D-3	Communication Links - Tug/Orbiter	"
D-4	S-Band Payload Antenna Gain	"
D-5	Data Processing & Software Subsystem Diagram	"
D-6	Multifunctional CRT Display System	"
D-7	Typical CRT Display	"
D-8	C&W & Performance Monitoring I/F	"
D-9	Orbiter Crew Station and Equipment	"
D-10	Aft Flight Deck	"
D-11	Payload Uplink Data Flow	JSC-07700, Vol. SIV
D-12	Payload Engineering (TLM) Data Flow	"
D-13	Payload Science Data Flow	"
D-14	Payload Interrogator I/F Connections	MC 478-0105
D-15	Payload Interrogator Block Diagram	"
D-16	Payload Signal Processor I/F Connections	MC 476-0138
D-17	Payload Signal Processor Block Diagram	"
D-18	Payload MDM Block Diagram	JSC-07700, Vol. XIV
D-19	Payload Data Interleaver Block Diagram	"
D-20	Master Timing Unit Block Diagram	"
D-21	C&W Data Flow Diagram	"

ORBITER/PAYLOAD COMMUNICATION INTERFACE FOR NASA PAYLOADS — Figure D-1 shows Orbiter communication, tracking, and data management interfaces with attached and detached NASA payloads. The Orbiter-payload communication range for commands and data transmission is 30 n.mi. The Orbiter-payload tracking range with the rendezvous radar is 10 n.mi. The communication and tracking (C&T) subsystem in the Orbiter incorporates RF communication links with detached payloads and hardwire provisions that support Orbiter-to-attached-payload communications. The RF links

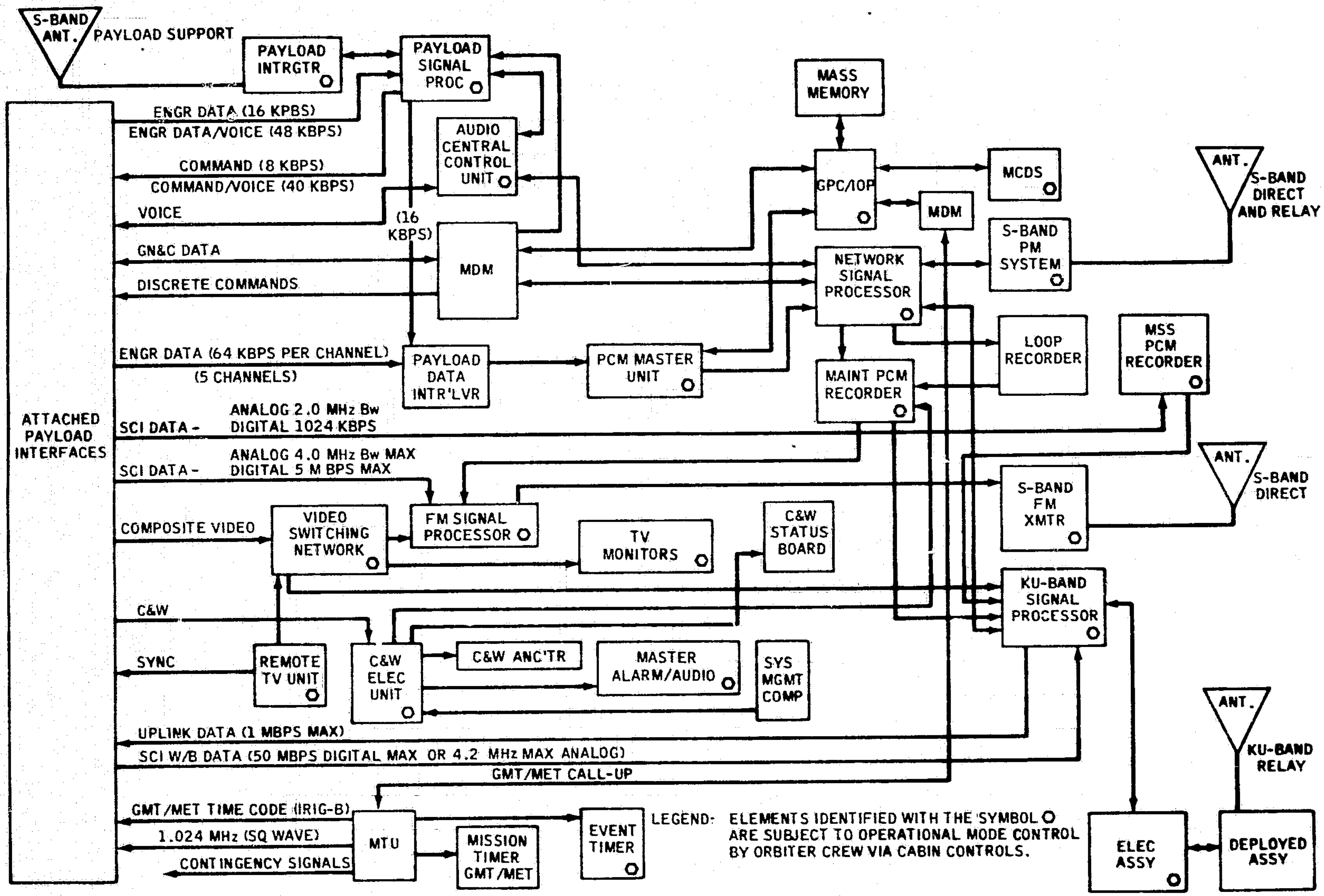


FIGURE D-1. AVIONICS FUNCTIONAL DIAGRAM FOR NASA PAYLOADS also permit the transfer of payload telemetry, uplink data commands, and voice signals to and from the space networks. Orbiter transmitters, receivers, and signal structure are compatible with the established characteristics of NASA's Space Tracking and Data Network (STDN), Tracking and Data Relay Satellite (TDRS), and the Air Force's Space-Ground Link Subsystem (SGLS). The Orbiter is equipped to communicate with ground stations, satellites and detached payloads at S-band frequencies. The Orbiter is also equipped to communicate with ground stations via the TDRS at Ku-band frequencies.

The uplink data rate to the payload via the Orbiter is 2 kbps for all payloads. Telemetry data rates to the Orbiter from detached payloads is 16 kbps for NASA and DOD payloads. Telemetry rates from attached DOD payloads is 16 kbps. In addition, 256 kbps of encrypted data from attached DOD payloads can be transmitted directly to the ground via the FM link on a time-shared basis with TV and main engine data. The C&T subsystem accepts either FM or PM data from attached payloads. On DOD missions, the data will be encrypted by payload equipment. Wide-band data or television pictures will be transferred from attached payloads to a mission-supplied tape recorder or to the C&T subsystem's S-band FM transmitter for direct transmission to STDN or SGLS ground stations or to the Ku-band subsystem for transmission to ground stations via the TDRS. The voice-distribution system provides Orbiter-payload and ground-Orbiter-payload duplex voice service, including conference capabilities in either the attached or the detached mode.

The data-processing and software subsystem furnishes the on-board digital computation required to support the payload management (PLM) and payload-handling (PLH) functions. The PLM function is used during prelaunch and orbital phases for payload checkout and status monitoring (passive). The PLH function controls the operation of the manipulator arm(s) and interfaces with the GN&C computer to ensure vehicle stability. Functions in the computer are controlled by the crew through main memory loads from the tape memory. One computer is dedicated to payload on orbit. A second computer provides complete redundancy. Each computer has a memory capacity of 65K 32 bit data words. Flight-deck stations for payload management and handling are equipped with data displays, CRTs, and keyboards for monitoring and controlling payload operations.

<u>ORBITER/PAYLOAD COMMUNICATION INTERFACE FOR DOD PAYLOADS</u> — Orbiter communications, tracking, and data management interfaces with attached and detached DOD payloads are shown in the diagram of Figure D-2. The Orbiter-payload communication range for commands and data transmission is 30 n.mi. The Orbiter-payload tracking ranges with use of the rendezvous radar, is 10 n.mi. The communication and tracking (C&T) subsystem in the Orbiter incorporates RF communication links with detached payloads and hardwire provisions that support Orbiter-to-attached-payload communications. The RF links also permit the transfer of payload telemetry, uplink data commands, and voice signals to and from the space networks. Orbiter transmitters, receivers, and signal structure are compatible with the established characteristics of the Air Force Space Ground Link Subsystem (SGLS).

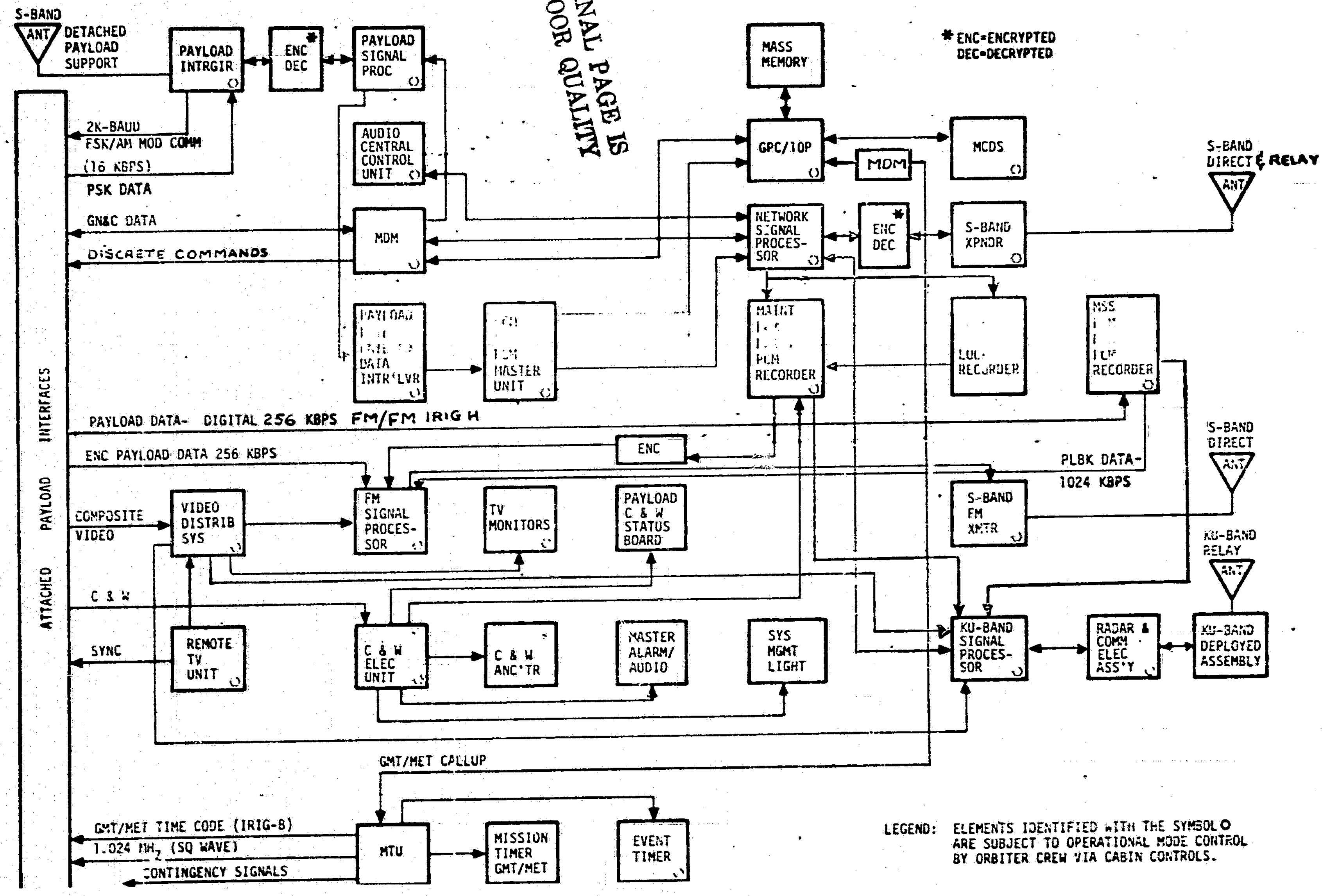


FIGURE D-2. AVIONICS FUNCTIONAL DIAGRAM FOR DOD PAYLOADS

Commands to attached or detached payloads can be forwarded from the ground or generated on board at two kilobauds. Telemetry from detached payloads is received at a 16-kbps over any one of 20 S-band selectable channels. PSK data from attached payloads is received at a rate of 16 kbps on a 1.024-mHz subcarrier. The payload data when received by the Orbiter is interleaved with Orbiter operational telemetry for transmission to ground.

The capability is also provided to receive DOD encrypted data at a rate of 256 kbps for direct to ground transmission when within clear line of sight to ground stations.

The caution and warning subsystem will receive up to TBD payload parameters. In-flight programmable limits are provided at the inputs. The C&W subsystem is backed up by the performance monitoring system. Up to TBD computer-controlled safing commands are made available to safe all hazardous components upon receipt of the corresponding C&W indication.

Closed-circuit television is provided for visual monitoring of payload bay and cabin activity.

GMT and MET time codes in IRIG-B format are provided by the master timing unit (MTU). The MTU also provides a highly stable 1024 mHz square wave to the attached payload.

The Orbiter provides the capability to transmit guidance, navigation, and control (GN&C) data to the payload and receives attitude reference data from a payload-mounted sensor to improve the payload pointing accuracy. The Orbiter computer will provide state vector update data words to the payload. The update data words will include the Orbiter position vector, velocity vector, MET, GMT, and attitude information. The Orbiter pointing capability is ±0.5° and 0.01° per second.

COMMUNICATION LINKS - IUS/ORBITER — Figure D-3 depicts the Orbiter provisions for communication links to detached IUS/payloads. These links are for command and telemetry to maintain safe control over the IUS/payload while in the vicinity of the Orbiter. The communication range is 20 n. mi. maximum.

S-BAND PAYLOAD ANTENNA GAIN — The specifications for the S-band antenna are shown in Figure D-4. The antenna is mounted on the topside of the Orbiter forward section structural outer mold line (OML) at X-558, Y-O, Z-500. The gain characteristics shown on the facing page reflect test results under the conditions stated below:

S-band payload antenna specifications:

Operating frequency	1740 through 1850 mHz 2000 through 3400 mHz

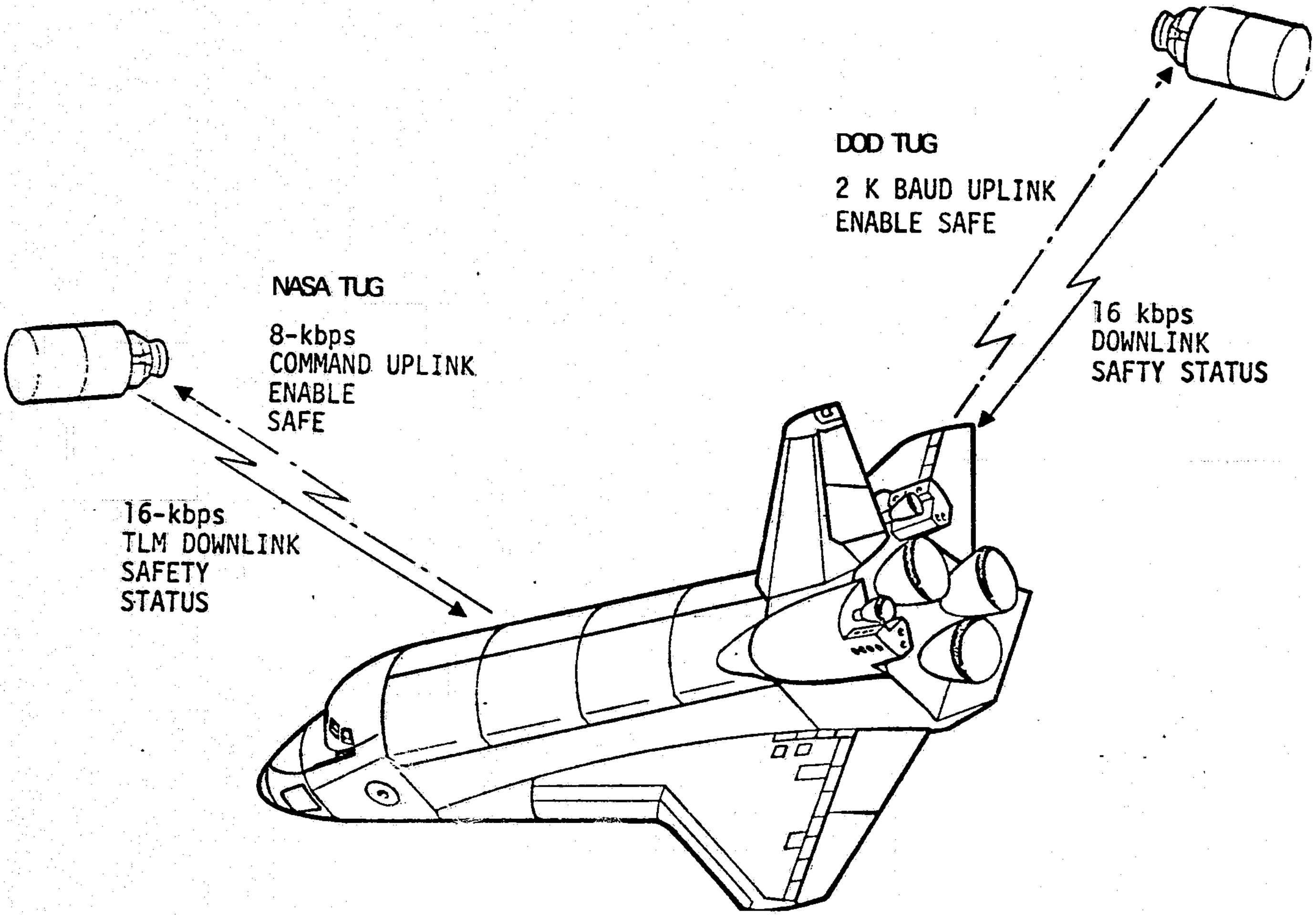
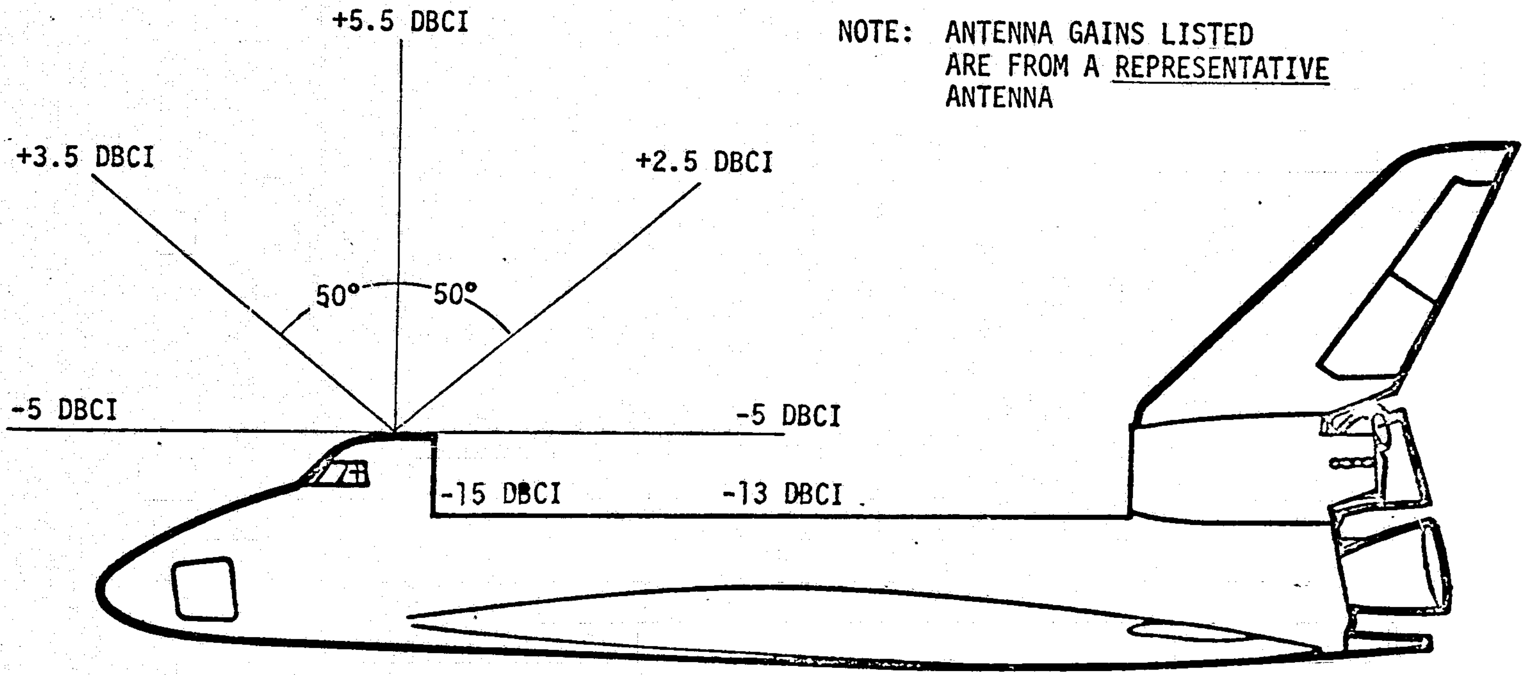


FIGURE D-3. COMMUNICATION LINKS - TUG ORBITER



ANGLE (DEG)	FWD 90	60	50	30	UP 0	30	50	60	AFT 90	120	150
GAIN (DBCI)	-5	+3	+3.5	+4.5	+5.5	+4	+2.5	+3	-5	-13	-15

FIGURE D-4. S-BAND PAYLOAD ANTENNA GAIN

S-band payload antenna specs. (Cont'd.)

Power-handling capability	200 watts of CW
Polarization	RCP
Half-power beamwidth	Plus or minus 50° minimum
Gain	5 dB - ci on axis

Data reflected in Figure D-4

- Antenna gain measurements taken at f = 2.2 gHz
- Two and one-half D flush-mounted payload antenna located 18 inches from forward edge of cargo bay, on top of a partial forward fuselage mockup.
- Test prior to installation of windows
- No rendezvous light installed next to antenna
- Microwave absorber panels installed in window (behind frames)
- No thermal protection system TPS installed.

DATA PROCESSING AND SOFTWARE SUBSYSTEM — The data processing and software subsystem (DP&S) provides data processing capabilities for guidance, navigation, and control (GN&C); communications and tracking (C&T); displays and controls (D&C); system performance monitoring; payload management; payload handling; subsystem sequencing; and selected ground functions with sufficient provision so as not to limit the performance of the subsystems it supports. The DP&S accepts input commands and/or data from the crew, on-board sensors, and external sources; performs computations and processing; and generates output commands and data as necessary to fulfill the requirements specified for GN&C, C&T, D&C, instrumentation, electrical power distribution and control, computers, performance monitor function, and payload handling and management.

The DP&S equipment configuration, Figure D-5, is organized around a computer complex consisting of five general-purpose computers which are interconnected so that they may be operated in redundant groups for critical services. Memory capacity of each computer is 65,000 32-bit words. Additional storage of programs and fixed data is provided by two mass memory units having a data capacity of 134 megabits.

Data transfer between the computer complex and data users employs a data bus network composed of serial, half-duplex data channels operating at one megabit per second.

Interface adaptation between the data bus network and the Orbiter subsystems is accomplished by multiplexer/demultiplexer (MDM) units. These units provide signal conversion capability, digital-to-analog as well as analog-to-digital, in addition to the multiplexing/demultiplexing function.

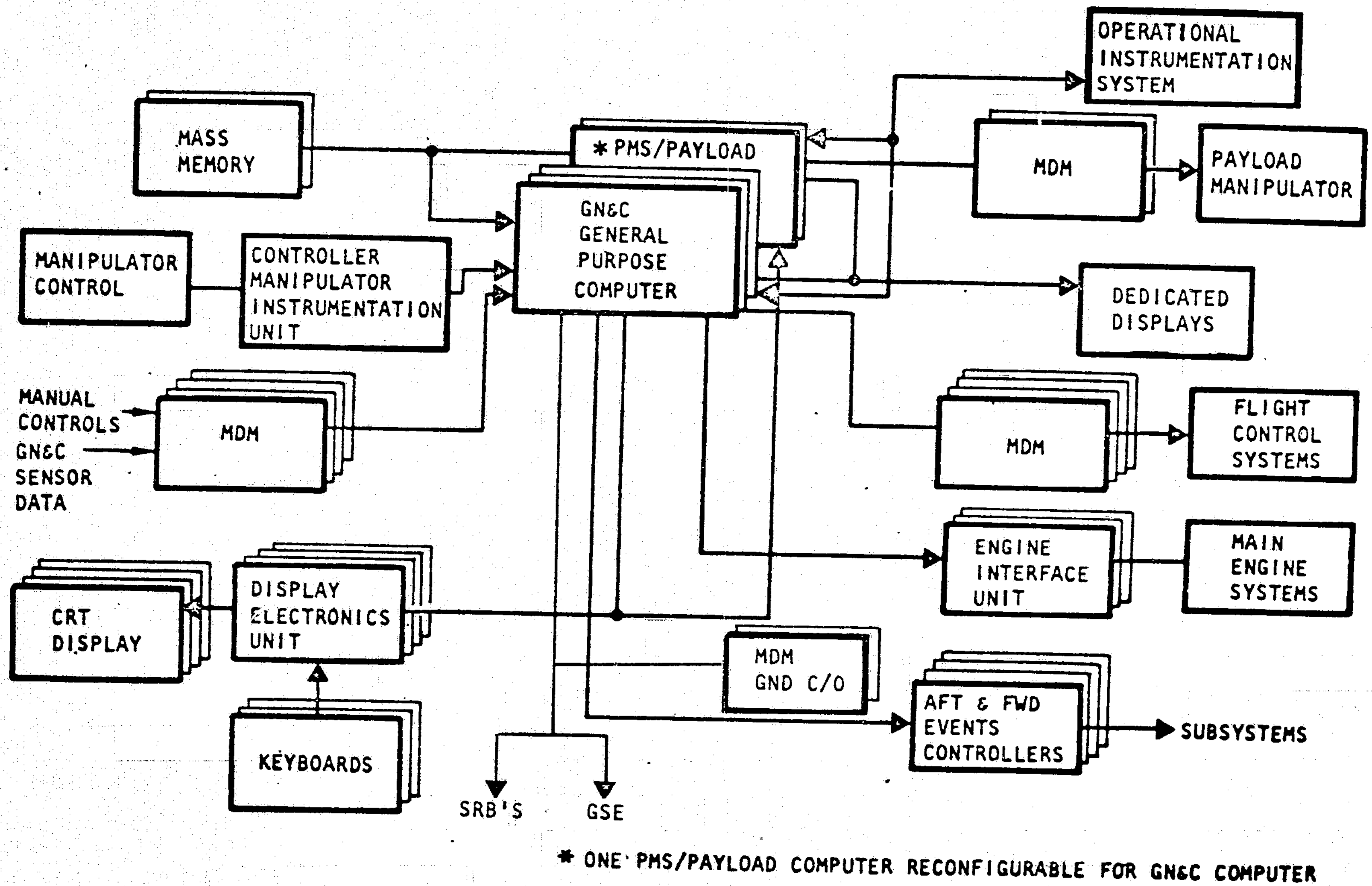


FIGURE D-5. DATA PROCESSING AND SOFTWARE SUBSYSTEM BLOCK DIAGRAM

MULTIFUNCTION CRT DISPLAY SYSTEM (MCDS) — Figure D-6 depicts the MCDS configuration for the Orbiter forward and aft station. The following discussion is provided to clarify the MCDS operation and capabilities.

The Orbiter avionics includes multiple multifunction CRT display systems (MCDSs) to provide the principal flight crew interface for data entry, subsystem modification, program selection, and alphanumeric and graphic data display. The MCDS consists of a keyboard unit (KBU) to provide the capability for manual control and data entry, a display unit (DU) that displays alphanumeric and graphic information of a CRT 5- by 7-inch viewing screen, and a display electronics unit (DEU) that has the multiple role of MCDS interface with the CPCs, storage and processing if display data, and CRT display format generation update, and a refresh. Two KBUs are provided in the forward flight station for use by the pilot and crew commander; a third is located in the rear crew station for use by the mission and payload specialists. As shown, the KBU and DEU have dual communication channels and, in the forward station configuration, the two KBUs interface with three DEU/DU sets. In the aft configuration, the KBU has a single dedicated DEU/DU set. Provisions are included in the Orbiter for growth to a fifth DEU/KBY/DU set that could be used with other specialist operations.

The DEU provides analog video deflection and intensity signals for use by the DU in constructing any one of a predetermined number of selectable formats. A memory is included in the DEU to store instructions used in processing information and to store format programs required by the DEU symbol generator. Variable input data are used by the DEU to update portions of the display and are combined with the fixed display information to produce a complete display. The data used to establish and update the variable portion of the display presentation are received by each DEU in block message form from any of the five GPCs via the four display system data buses. Display format selections are made by operator entries on the keyboard. Information to be entered into the GPCs is displayed by the DEU on the bottom (scratch pad line) of the DU CRT for operator validation before entry into the GPC.

The alphanumeric and graphic data that can be displayed on the DU consist of 10 numerics (0 through 9), 26 alphabetics (A through Z), 10 special symbols (such as decimal point, comma, and plus sign) and 82 other characters whose identification is reserved for future definition. These symbols are generated by stroke techniques using horizontal and vertical deflection signals that cause the CRT beam to trace the required outline in a succession of straight line segments.

STANDARD DISPLAYS & CONTROLS REQUIREMENTS — The Orbiter Display and Control (D&C) function will provide the control program for the interface and usage of the display system (CRT(s) and keyboards). The D&C program interprets keyboard command or requests, provides all overhead associated with display usage, interfaces with mass memory via FCOS for "roll-in" or display programs, etc.; the payload program will provide the individual CRT display program. Usually only one or two

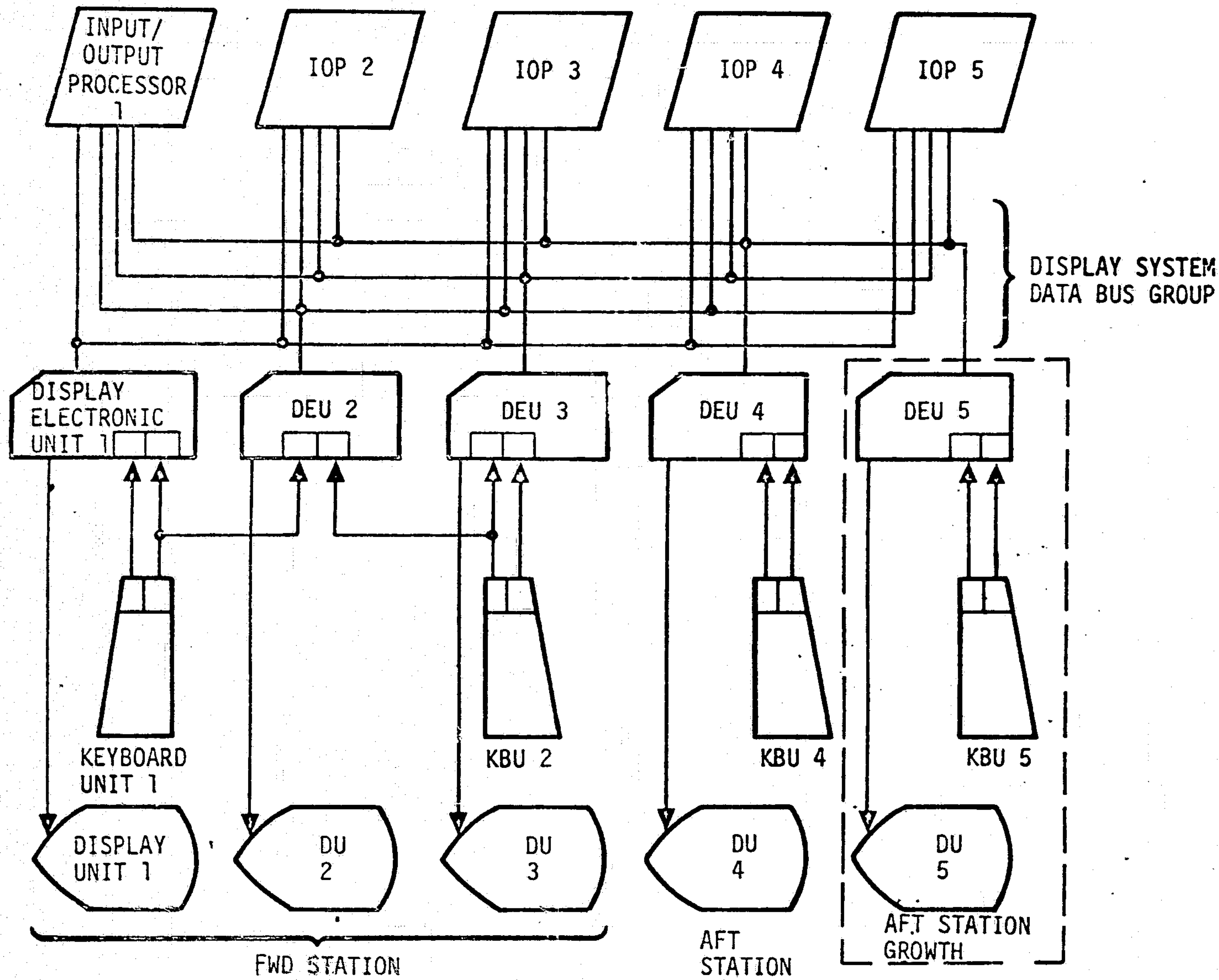


FIGURE D-6. MULTIFUNCTION CRT DISPLAY SYSTEM display page programs are retained in mass memory. As additional display pages are requested, they are "rolled-in" from mass memory overwriting the existing page display programs.

For payload memory sizing purposes each CRT display requires approximately 200 32-bit words of memory. If the display data are to be displayed on the Orbiter displays, the payload program will not be charged with the 200 32-bit word memory. This memory is time-shared with other functions and must be reserved by the Orbiter computer for the functions. If the display is to be presented on a unique payload CRT then the 200 32-bit words will be deducted from the allocated 10,000 32-bit word payload memory.

Normally only the payload display that has been requested will be loaded into the computer. The remaining displays will be resident on the mass memory and will be loaded into the Orbiter computer overlaying the memory assigned to the display which was last requested. A mass memory capacity for 20 unique payload-oriented displays per mission is provided.

Figure D-7 shows a typical CRT format which may be stored in memory and called up by operator entries on the keyboard (KBU). Information to be entered into the Orbiter computer is displayed on the bottom (scratch pad line) of the CRT for operator validation before entry.

C&W AND PERFORMANCE MONITORING FUNCTION INTERFACE — The relationship between the hardwired C&W and PMF software C&W backup is shown in Figure D-8 for DOD and NASA payloads. Both the primary and backup paths include data recording for use in subsequent analysis. The capability of data display from the MCDS exists at both the forward station and aft station. The baseline payload provisions are five annunciators for the forward station C&W. Implementation of an MSS C&W capability for payloads beyond the existing baseline provisions requires Level II negotiations. The Orbiter does not segregate C&W parameters by category of fixed or variable limits for either the Orbiter or a payload. Hardwired C&W parameters are redundantly backed up by the software of the PMF. An out-of-tolerance condition will then be evident from both the hardwired C&W parameters and the backup from the PMS; e.g., both the dedicated C&W annunciator and the backup annunciator will illuminate. The capability for in-flight reset of a trip threshold for any hardwired C&W parameter is provided at the MSS using the C&W status board. A similar capability for the software backup is provided at the MCDS. Payload C&W shall be limited to out-of-tolerance measurements which may propagate, if uncorrected, to the loss of the Orbiter vehicle and/or crew. Those payload parameters which cannot have an impact upon the Orbiter and/or crew, even though the effect may result in compromising the payload, are not presently candidates for the Orbiter C&W system.

/ /0111 GPC MONITOR C DDD/HH:MM:SS
DDD/HH:MM:SS

	1	2	3	4
FW1	077766			003302
FW2	003303			003302
FW3	011044		012144	
FW4	070700			
FW5	011401	011400	011100	011400
FW6	110076		110077	
FW7	131001	133000		
FW8	177007			
FW9	041111		141100	041101
FW0	040062	040162	040762	
SW1	001577	002577	002577	002577
SW2	121100			
SW3	077767			
SW4	000000		000001	
SW5	170613			170063
SW6	155764			
SW7	000111			

X——MESSAGE LINE——X
X——MESSAGE LINE——X
X——SCRATCH PAD LINE MESSAGE——X

FIGURE D-7. TYPICAL CRT DISPLAY

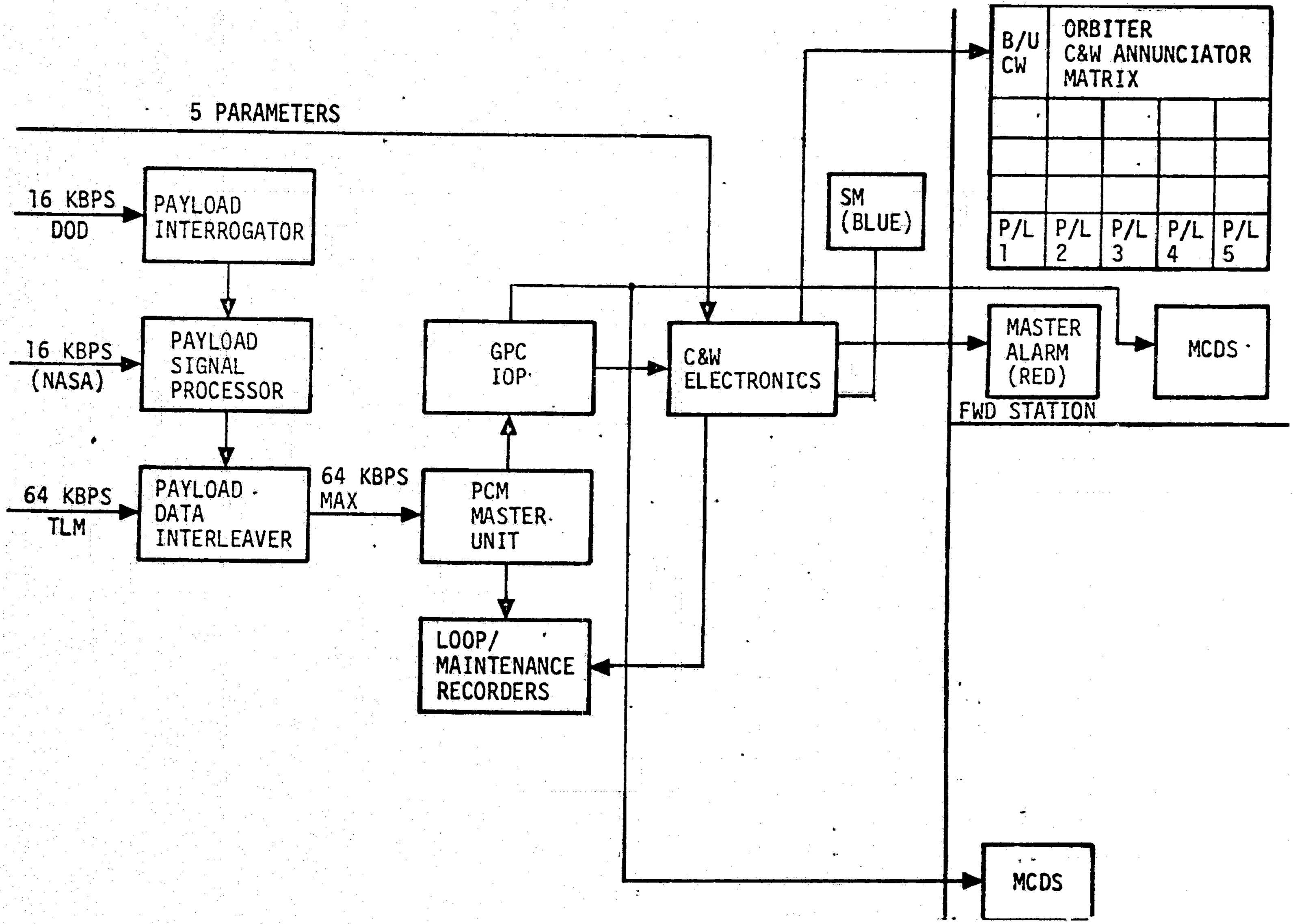


FIGURE D-8. C&W AND PERFORMANCE MONITORING FUNCTION INTERFACE

ORBITER CREW FLIGHT DECK STATIONS — Figures D-9 and D-10 identifies and illustrates the relative position of the various crew stations on the Orbiter flight deck. The following information describes the crew functions aboard the Orbiter.

1. Commander and pilot - In command of the flight and responsible for the overall space vehicle, payload flight operations, and vehicle safety. Proficient in all phases of vehicle flight, payload manipulation, docking, and subsystem operations: command, control, and monitoring. Knowledgeable of payload and payload systems as they relate to flight operations, communications requirements, data handling, and vehicle safety. The pilot's duties, as second in command, are essentially the same as those of the commander.

2. Mission specialist - Responsible for interfacing of payload and Orbiter operations and managing payload operations. Proficient in vehicle and payload subsystems, flight operations, and payload communications data management. Crew may include more than one mission specialist.

3. Payload specialist - Responsible for the applications, technology, and science payload/instrument operations. Detailed knowledge of instruments, operations, requirements, objectives, and supporting equipment. Crew may include more than one payload specialist.

Flight-deck displays and controls are organized into four functional areas: (1) two forward-facing primary flight stations for vehicle operation, (2) two aft-facing stations, one for payload handling and one for vehicle control, (3) a payload-specialist station for management and checkout of active payloads, and (4) a mission-specialist station for Orbiter subsystem/payload interface, power, and communications control in the remaining flight deck area.

The primary flight (forward) stations are organized in a familiar pilot-copilot relationship with sufficient duplication of displays and controls to permit the vehicle to be piloted from either seat and permit one-man emergency return. Manual flight controls include rotation and translation hand controllers, rudder pedals, and speed brake controllers at each of the forward stations.

ORBITER/PAYLOAD SUPPORT EQUIPMENT — Payload communication flow diagrams are shown in the following figures (D-11 through D-21) for the major interface units used by Tug.

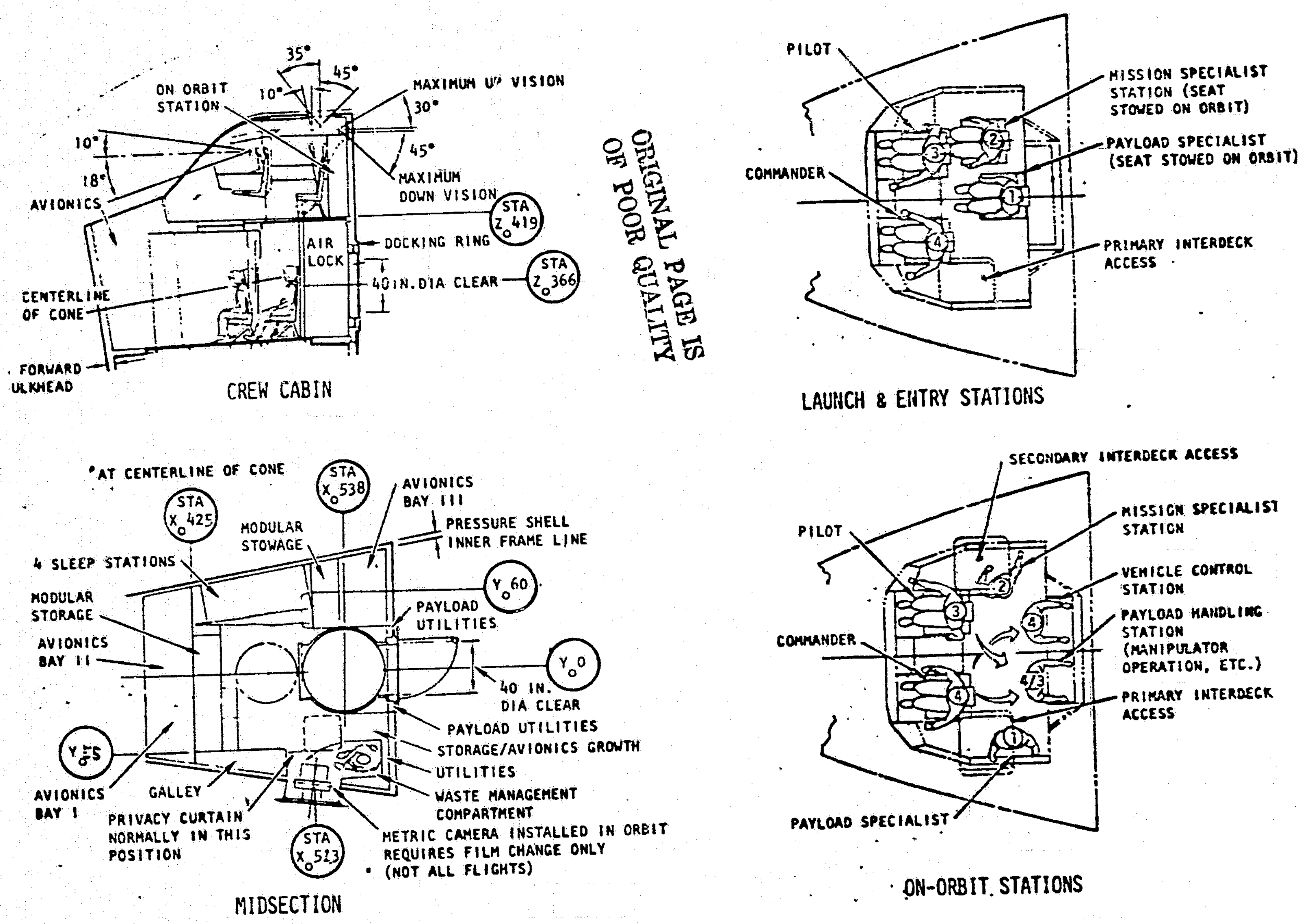


FIGURE D-9. ORBITER CREW STATION AND EQUIPMENT SUBSYSTEM

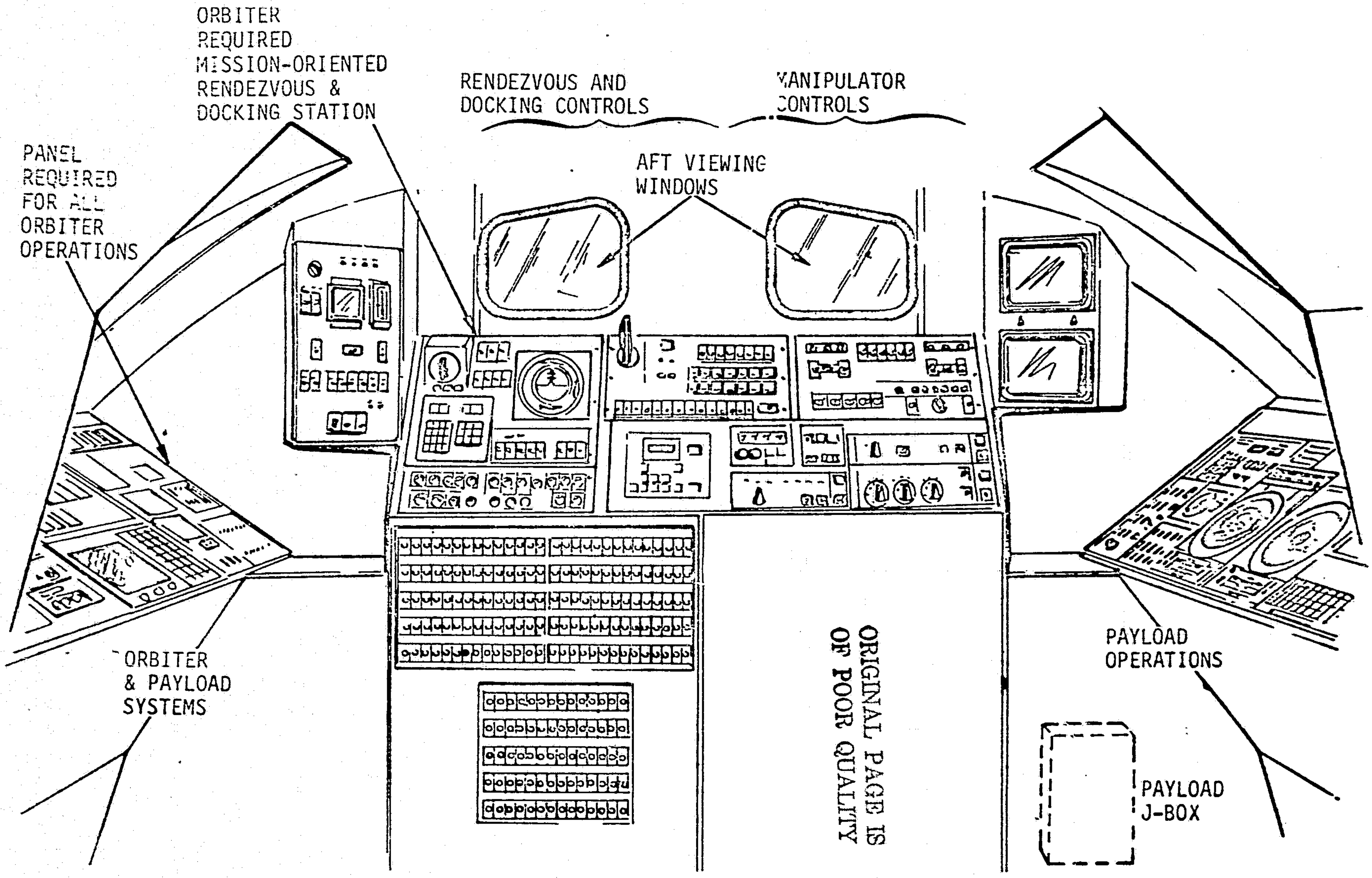


FIGURE D-10. AFT FLIGHT DECK

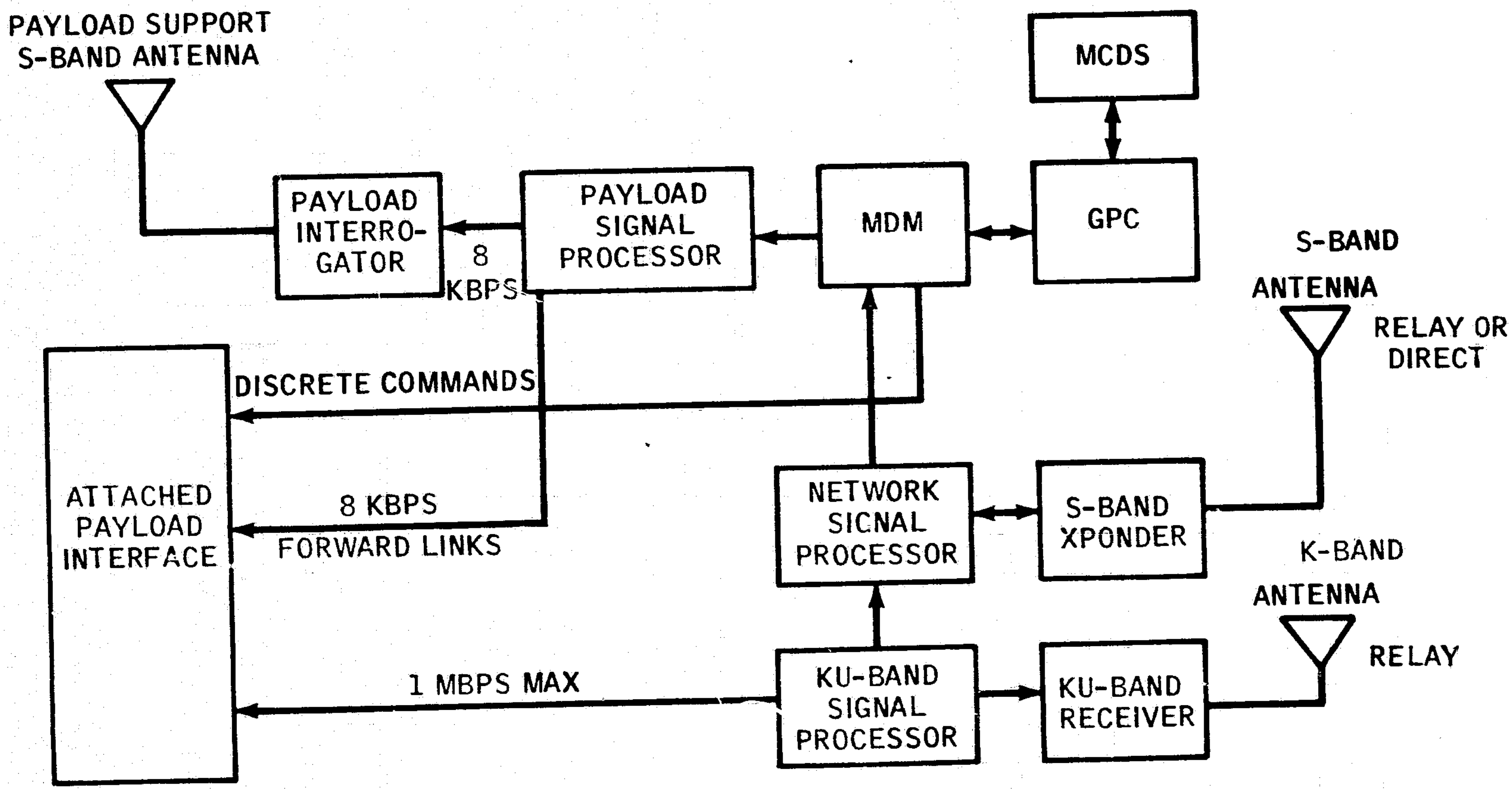


FIGURE D-11. PAYLOAD UPLINK DATA FLOW

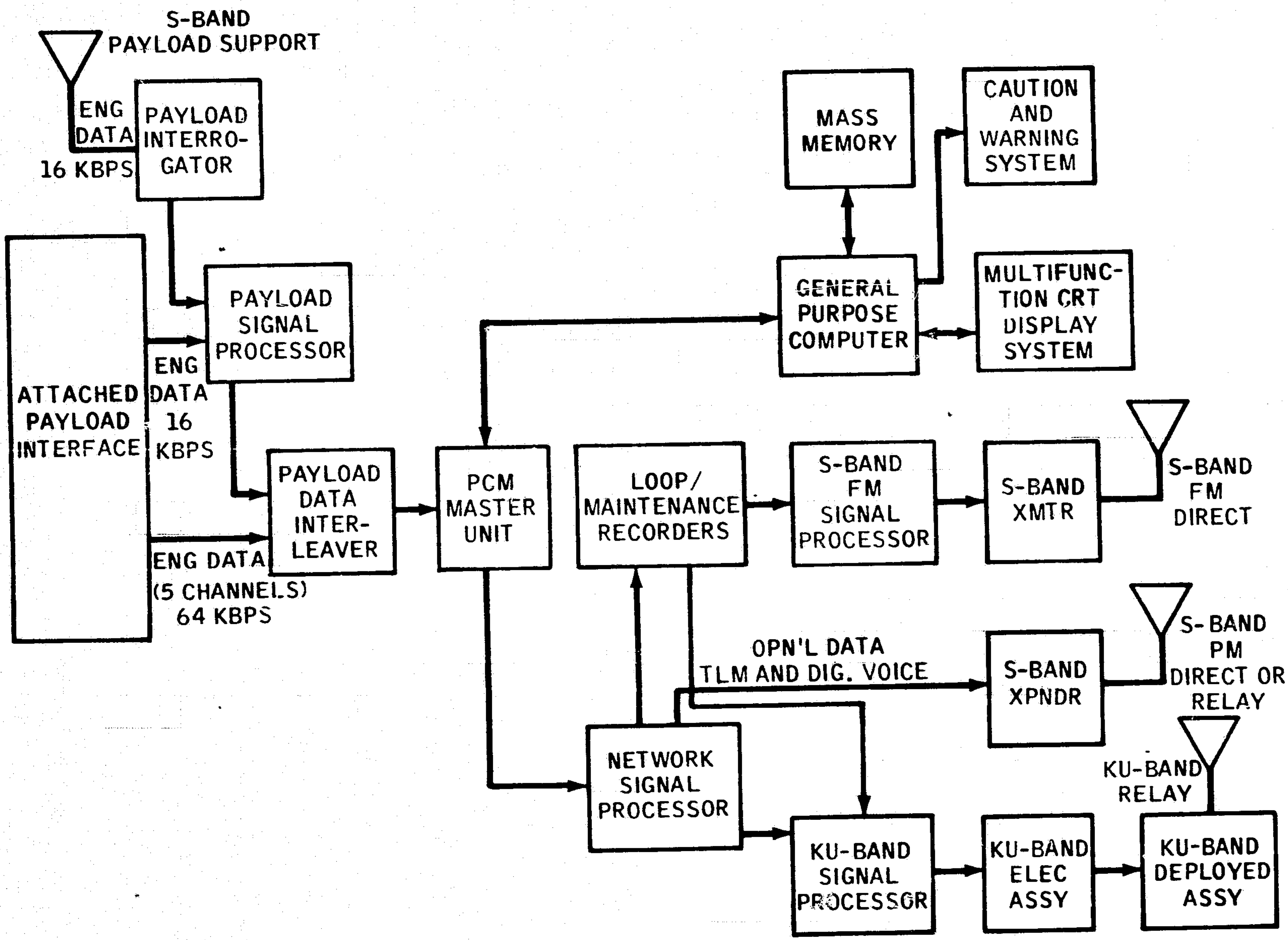


FIGURE D-12. PAYLOAD ENGINEERING (TLM) DATA FLOW

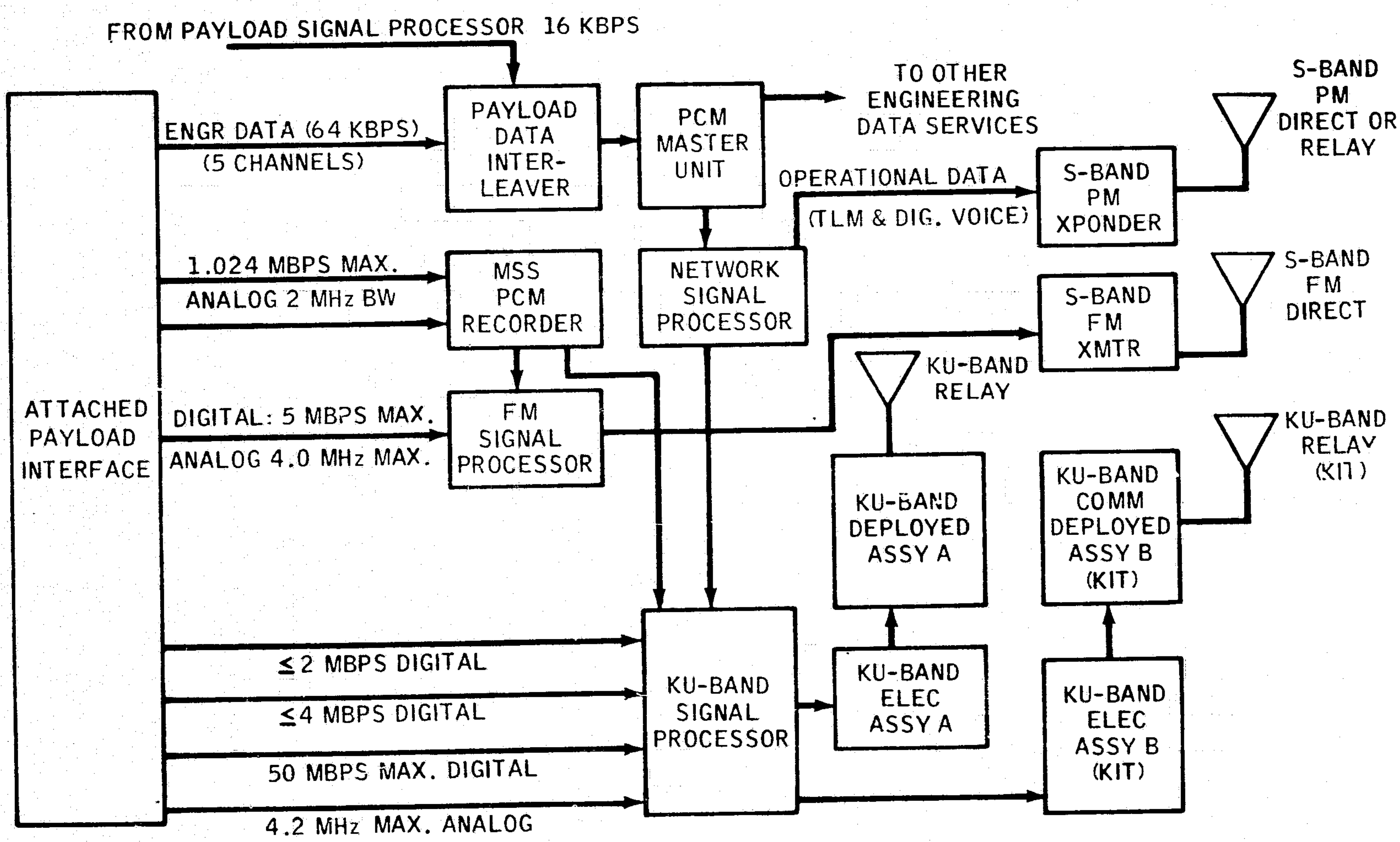


FIGURE D-13. PAYLOAD SCIENCE DATA FLOW

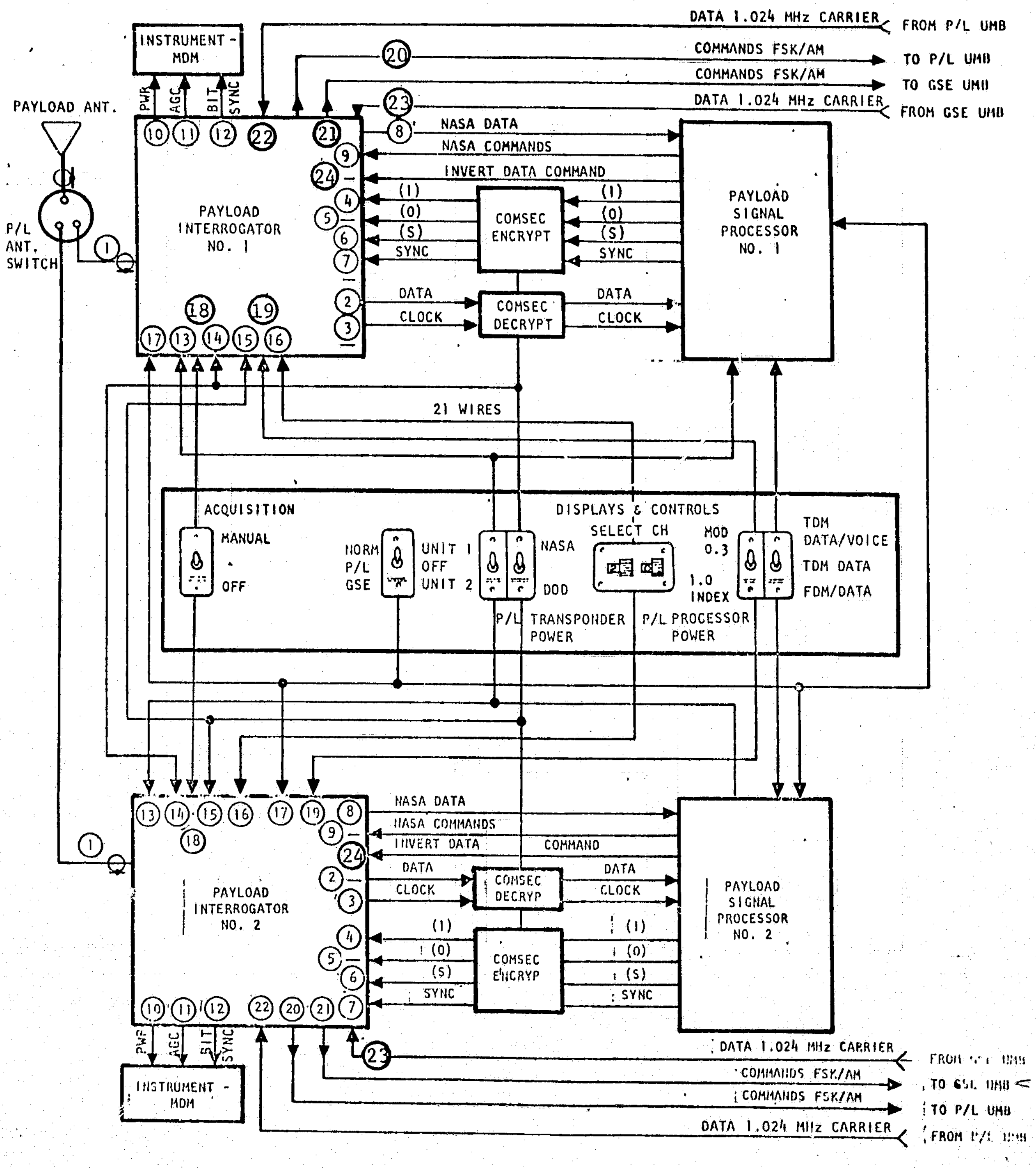


FIGURE D-14. PAYLOAD INTERROGATOR I/F CONNECTIONS

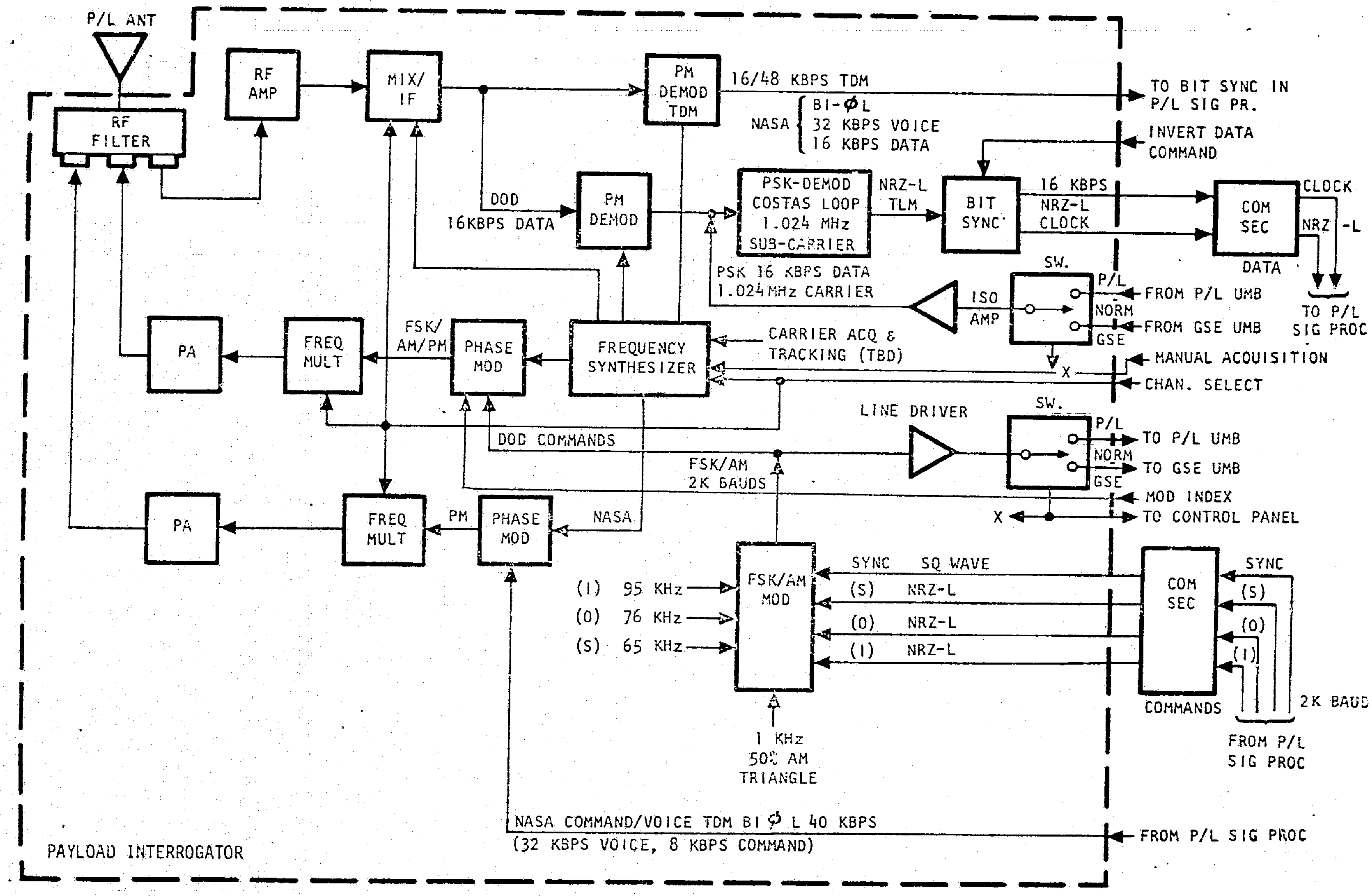


FIGURE D-15. PAYLOAD INTERROGATOR BLOCK DIAGRAM

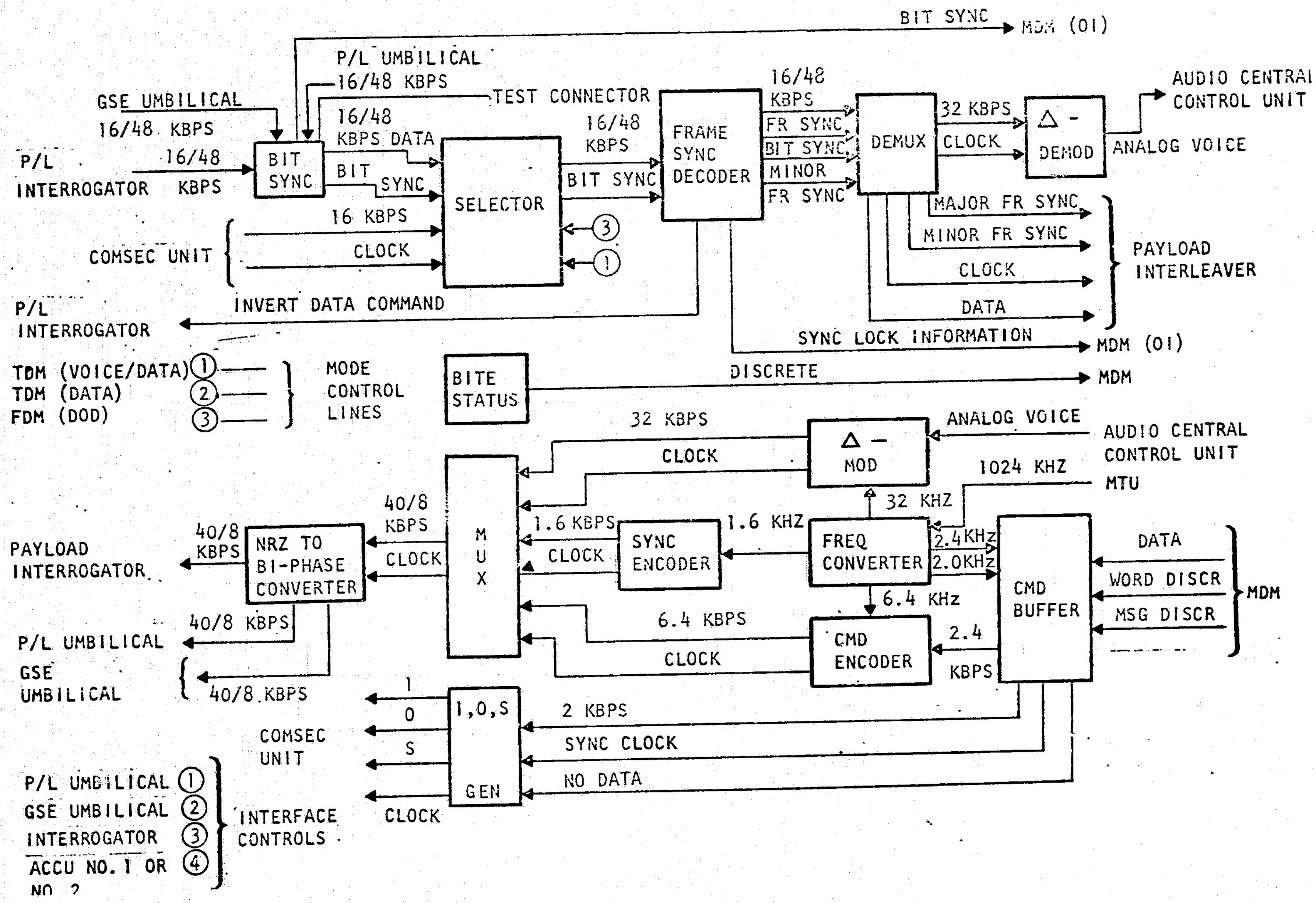


FIGURE D-16. PAYLOAD SIGNAL PROCESSOR I/F CONNECTIONS

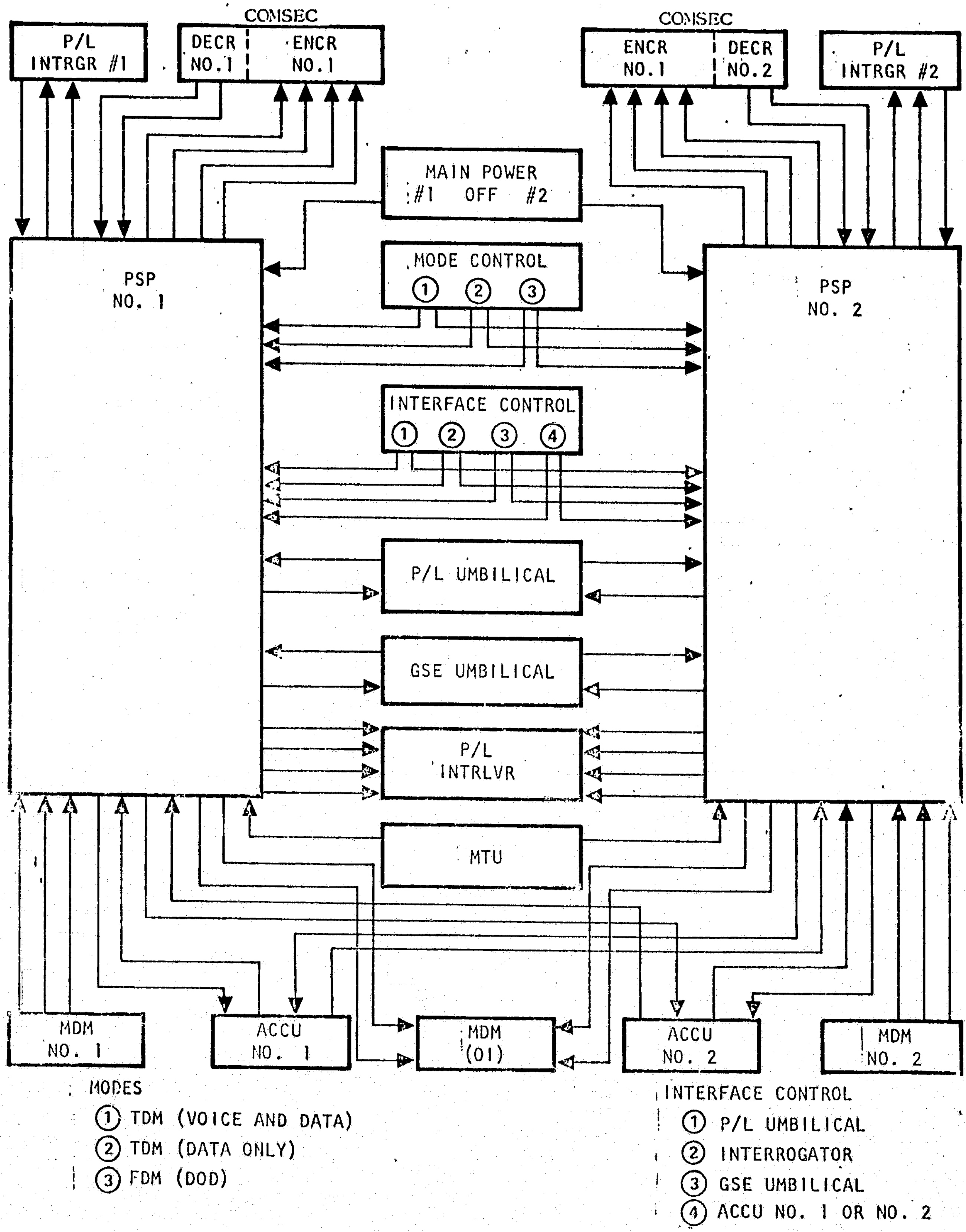


FIGURE D-17. PAYLOAD SIGNAL PROCESSOR BLOCK DIAGRAM

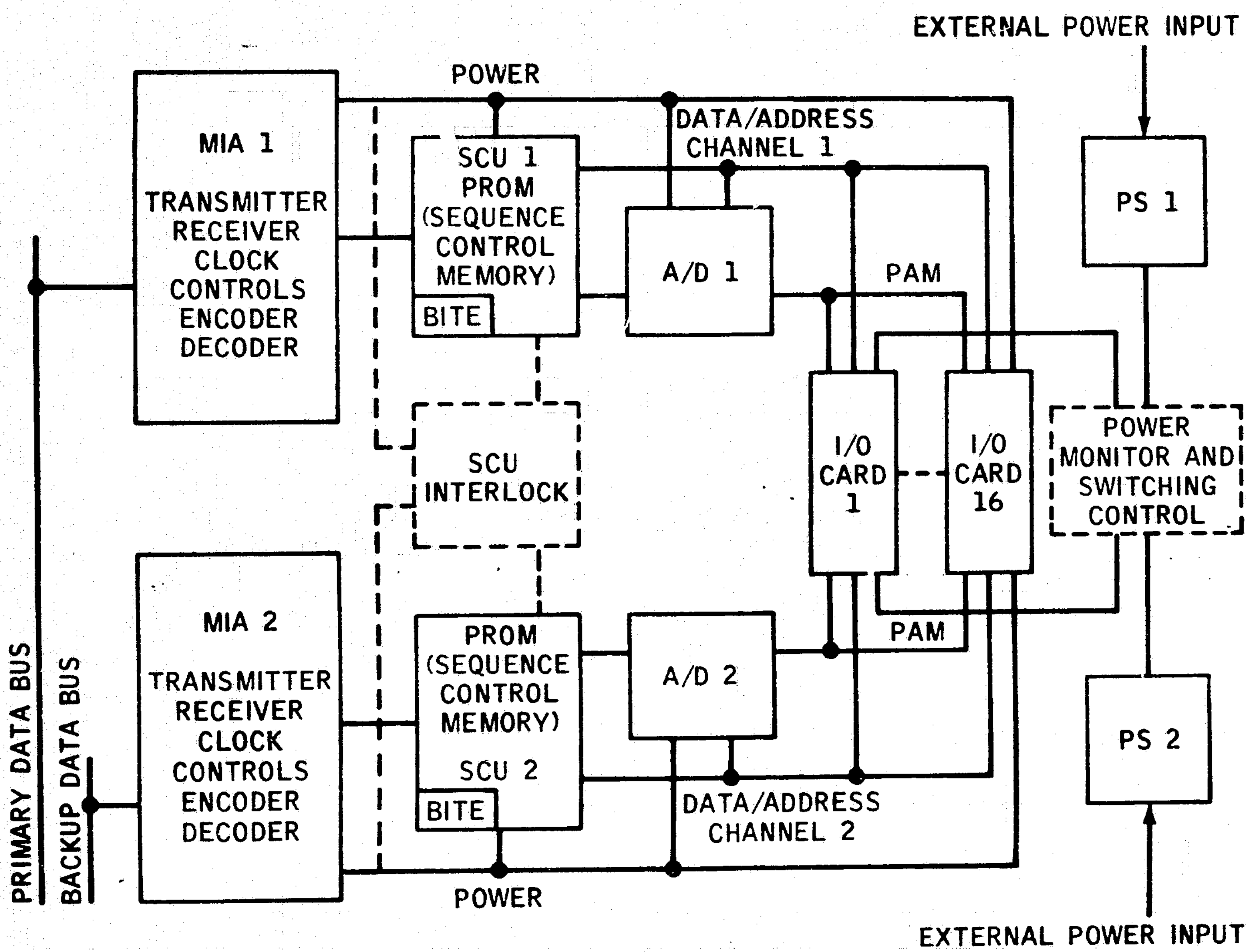


FIGURE D-18. PAYLOAD MDM BLOCK DIAGRAM

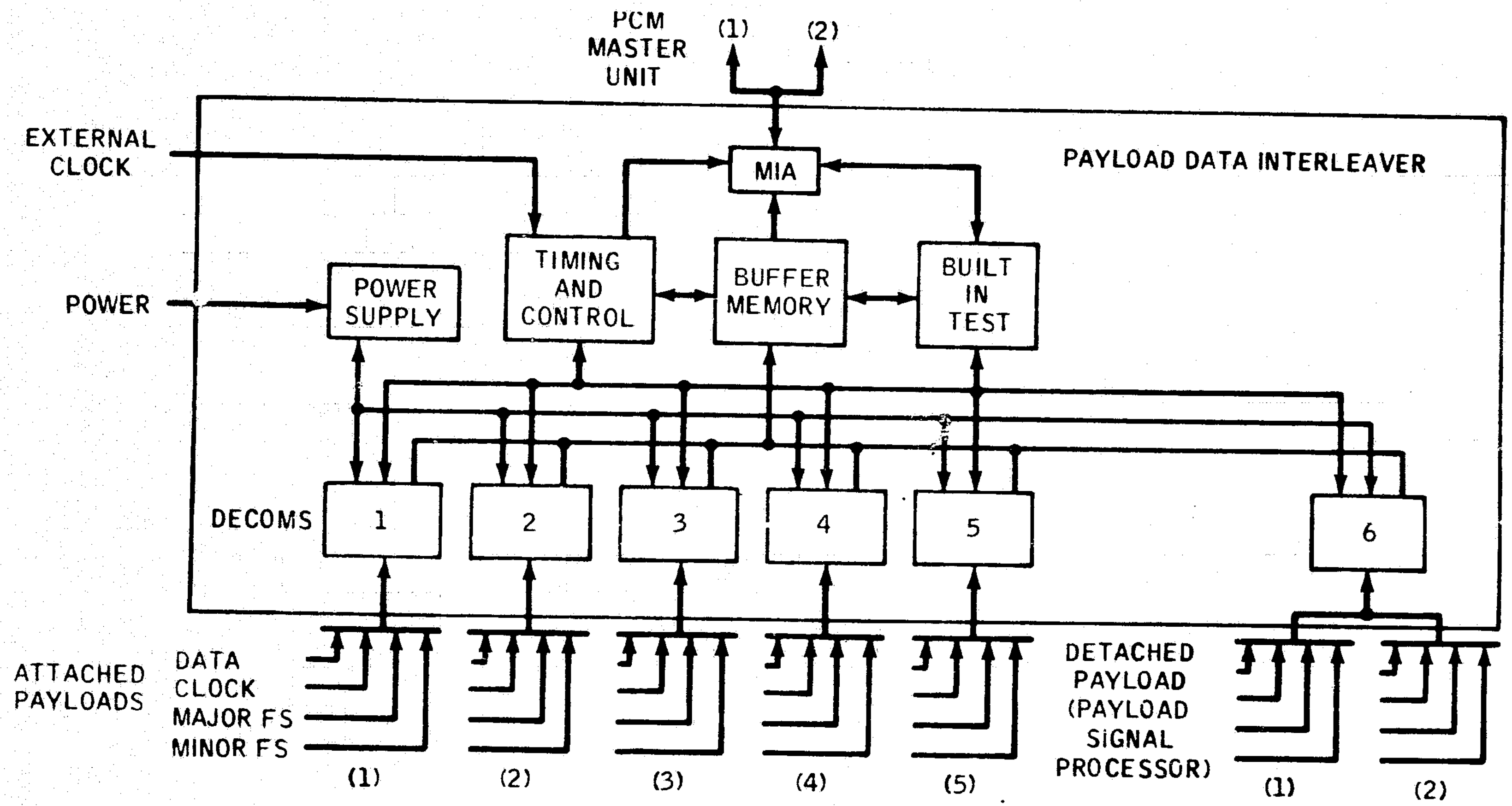


FIGURE D-19. PAYLOAD DATA INTERLEAVER BLOCK DIAGRAM

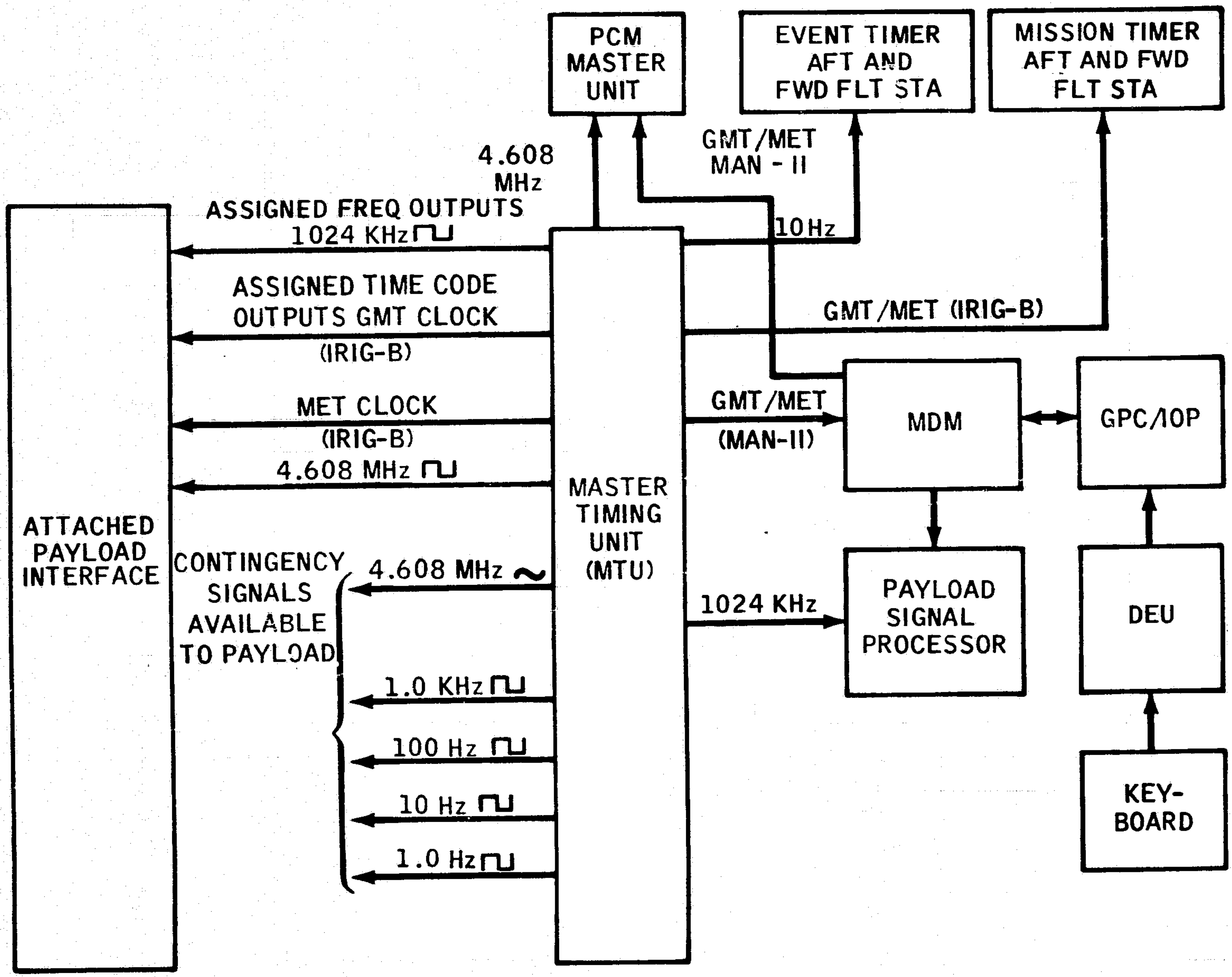


FIGURE D-20. MASTER TIMING UNIT BLOCK DIAGRAM

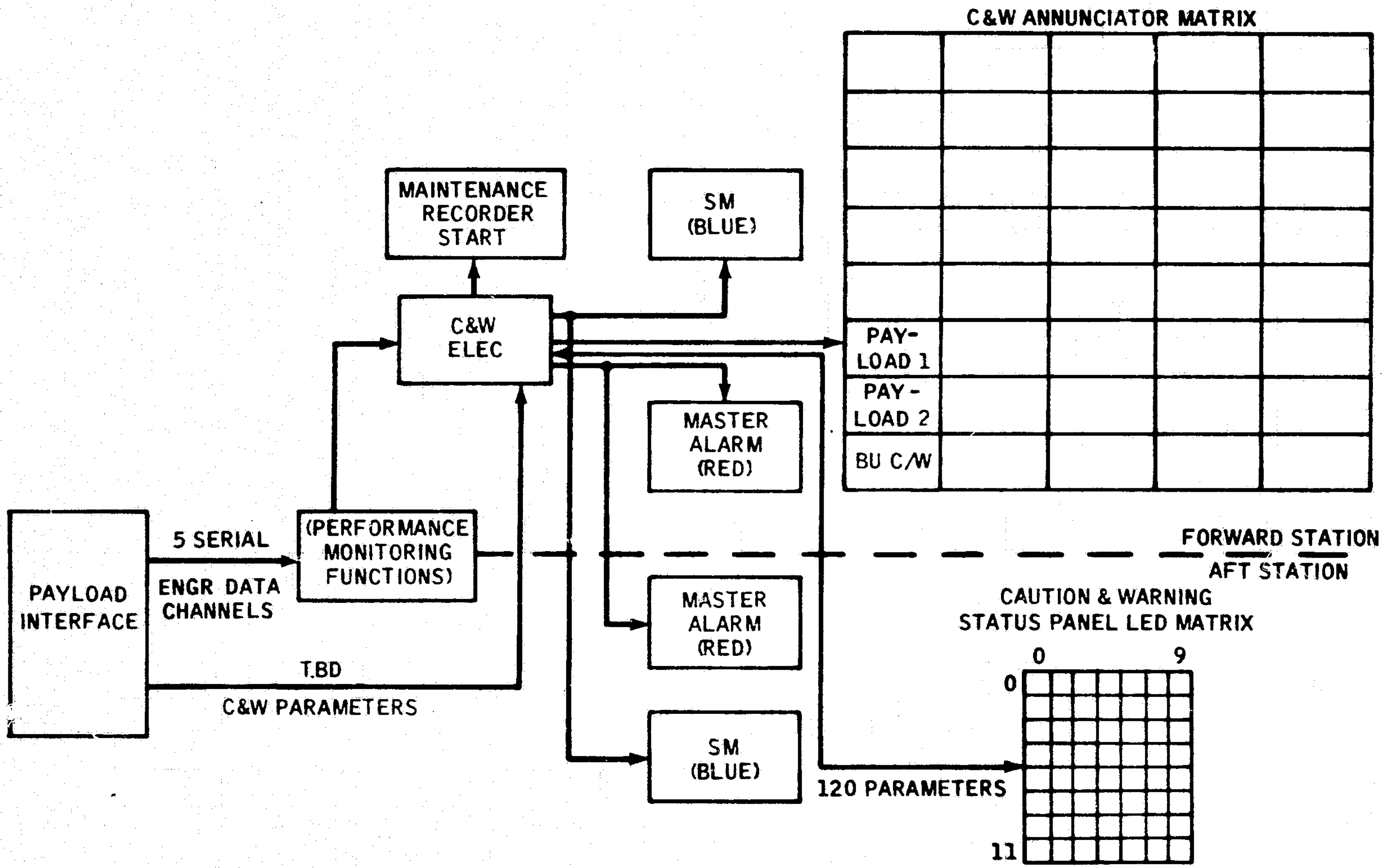


FIGURE D-21. C&W DATA FLOW DIAGRAM

APPENDIX E

ENGLISH UNITS TO INTERNATIONAL (SI) SYSTEM CONVERSION FACTORS

LENGTH

inches	× 2.54	=	centimeters
feet	× 0.3048	=	meters
nautical miles	× 1.852	=	kilometers
degrees	× 0.01745	=	radians

AREA AND VOLUME

square inches	× 6.451	=	square centimeters
square feet	× 0.0929	=	square meters
cubic inches	× 16.387	=	cubic centimeters
cubic feet	× 0.0283	=	cubic meters

MASS AND DENSITY

pounds mass	× 0.4536	=	kilograms
slugs	× 14.5939	=	kilograms
pounds/inch^3	× 27,680.0	=	kilograms/m^3
pounds/foot^3	× 16.018	=	kilograms/m^3

MASS AND VOLUME FLOW RATES

pounds mass/sec	× 0.4536	=	kilograms/sec
cubic feet/sec	× 0.0283	=	cubic meters/sec
cubic inches/min	× 16.387	=	cubic centimeters/min

FORCE AND PRESSURE

pounds force	× 4.4482	=	newtons
pounds/inch^2	× 0.6895	=	newtons/cm^2
pounds/inch^2	× 6.895	=	kilonewtons/m^2

VELOCITY

feet/second	× 0.3048	=	meters/second
rpm	× 0.1048	=	radians/second

TEMPERATURE

°Fahrenheit	$-32 \div 1.8$	=	celsius
°Rankine	$\div 1.8$	=	kelvin

ENERGY, WORK AND POWER

Btu	$\times 1.055 \times 10^3$	=	joule
kilowatt hour	$\times 3.6 \times 10^6$	=	joule
Btu/hour	$\times 0.2929$	=	watt
horsepower	$\times 0.7457$	=	kilowatt

MISCELLANEOUS

inertial	slug-ft^2	$\times 1.3558$	=	kg-m^2
gravitational constant	32.2 ft/sec^2		=	9.8 m/sec^2
torque	ft-lb	$\times 1.3558$	=	meter-newtons
specific impulse	lbf-sec/lbm	$\times 9.8064$	=	newton-sec/kg
enthalpy	Btu/lb	$\times 2.3258 \times 10^3$	=	joules/kg
heat transfer coefficient	Btu/hr ft^2 °F	$\times 0.1441$	=	watts/m^2 K