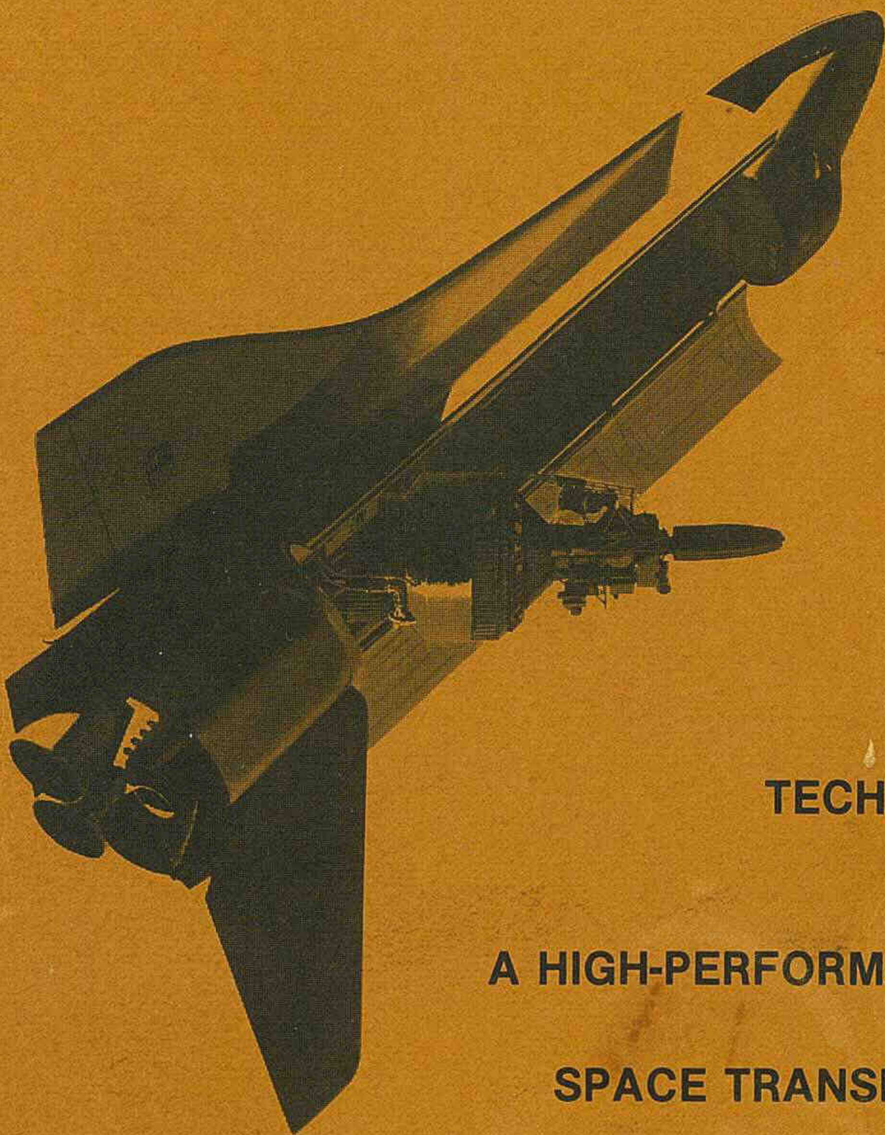
REPORT CGTD-2



CENTAUR G
TECHNICAL DESCRIPTION

A HIGH-PERFORMANCE UPPER STAGE FOR USE IN THE SPACE TRANSPORTATION SYSTEM

GENERAL DYNAMICS
Convair Division

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January 1982

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Prepared by
GENERAL DYNAMICS CONVAIR DIVISION
P.O. Box 80847
San Diego, California 92138

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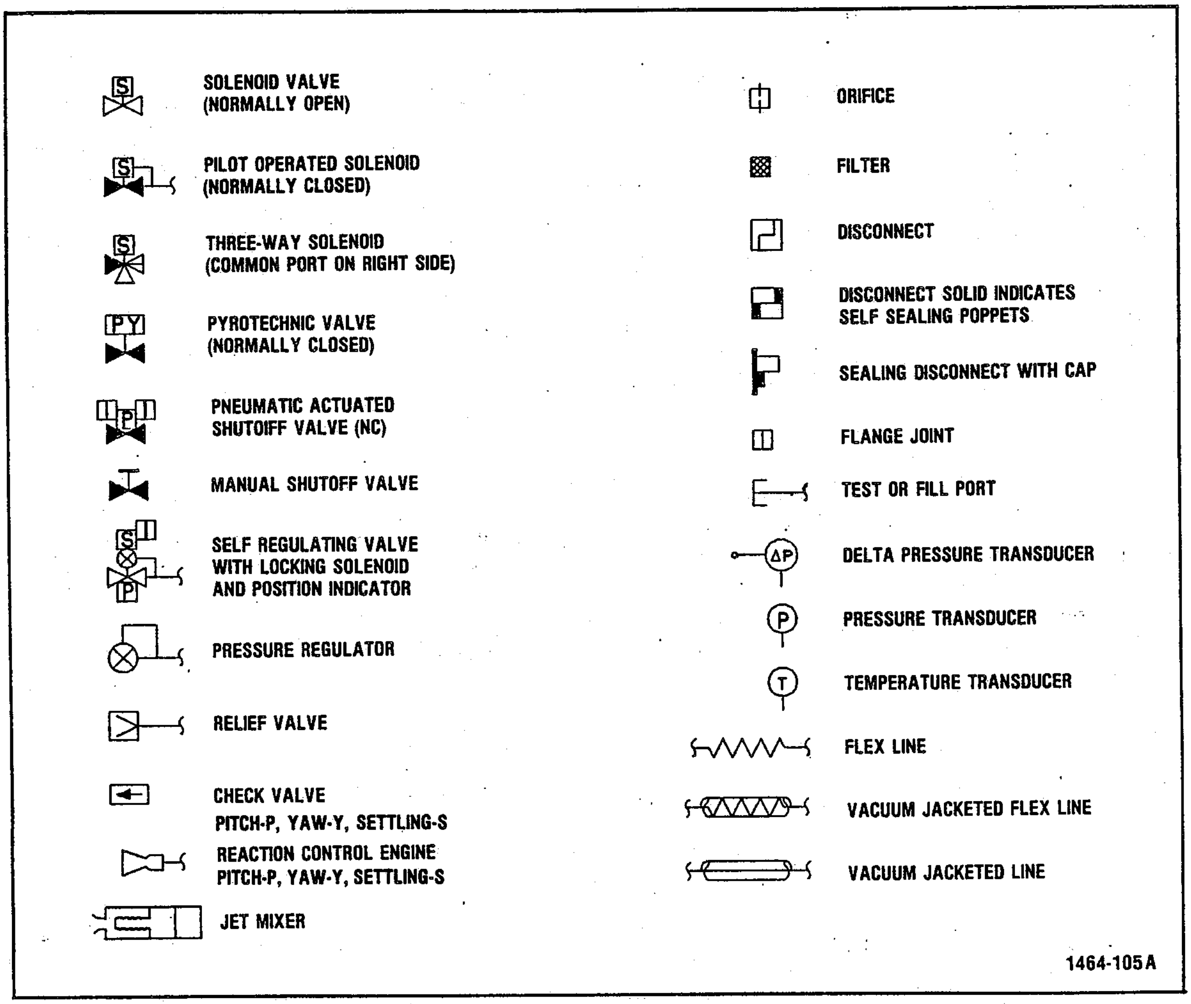
ACRONYMS AND ABBREVIATIONS

A/C	Atlas/Centaur
AFD	Aft Flight Deck
AFETR	Air Force Eastern Test Range
AFO	Abort From Orbit
AOA	Abort Once Around
ASE	Airborne Support Equipment
ATO	Abort to Orbit
CAD	Computer-Aided Design
CASE	Centaur Airborne Support Equipment
CCA	Centaur/CISS Assembly
CCAFS	Cape Canaveral Air Force Station
CCC	Command/Control/Communication
CCE	Centaur Cargo Element
CCLS	Computer-Controlled Launch Set
CCT	Centaur CISS Transporter
CCTE	Computer-Controlled Test Equipment
CCU	Central Control Unit
CCVAPS	Computer-Controlled Vent and Pressurization System
CDR	Critical Design Review
CG	Center of Gravity
CDU	Control Distribution Unit
CIL	Critical Items List
CISS	Centaur Integrated Support System
CITE	Cargo Integration Test Equipment
CPOCC	Centaur Payloads Operations Control Center
CPU	Central Processing Unit
CRT	Cathode Ray Tube
CRTP	Centaur Transport Pallet
CSS	Centaur Support Structure
CSTP	CISS Transport Pallet
CU	Control Unit
CWEA	Caution and Warning Electronic Assembly
C&W	Caution and Warning
C_3	Orbital Energy
DA	Deployment Adapter
DAC	Digital Analog Converter
DCU	Digital Computer Unit
DDR	Digital Derived Rate
DDTE	Design Development Test & Evaluation
DET	Design Evaluation Test
DMA	Direct Memory Access
DoD	Department of Defense
DOF	Degrees of Freedom
DPT	Design Proof Test
DSO	Discrete Signal Output
DUFTAS	Dual-Failure-Tolerant Arm/Safe Sequencer
ECS	Environmental Control System
EDU	Electrical Distribution Unit
EFH	Extra Full Hard
EGA	Earth Gravity Assist
ELS	Eastern Launch Site
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ETR	Eastern Test Range
EVA	Extravehicular Activity
FAST	Flight Analogous Software Test
FCR	Flight Control Room
FM	Frequency Modulated
FMEA	Failure Mode and Effects Analysis
FOM	Figure of Merit
FPR	Flight Performance Reserve Propellants
FRD	Functional Requirements Document
FRR	Functional Requirements Review
FTA	Fault Tree Analysis
G&N	Guidance & Navigation
GET	Ground Elapsed Time
GFP	Government-Furnished Property
GH_2	Gaseous Hydrogen
GHe	Gaseous Helium
GN_2	Gaseous Nitrogen
GN&C	Guidance, Navigation, and Control
GO_2	Gaseous Oxygen
GPC	General-Purpose Computer
GSE	Ground Support Equipment
GTS	Ground Telemetry System
HCS	Helium Control Skid
HER	Hardware Extension Remote
IAR	Integration Analysis Review
IAT	Initial Acceptance Test
ICD	Interface Control Document
ICS	Interpretive Computer Simulator
IDR	Intermediate Design Review
IMG	Inertial Measurement Group
IRGU	Integrating Rate Gyro Unit
IRU	Inertial Reference Unit
ISPM	International Solar Polar Mission
ITP	Integrated Test Plan
IUS	Inertial Upper Stage
I/O	Input/Output
JSC	Johnson Space Center
JPL	Jet Propulsion Laboratory

kbps	Thousand bits per second
KSC	Kennedy Space Center
kW	Kilowatt
lbf	Pounds Force
LCC	Launch Control Center
LDIE	Local Digital Interface Electronics
LeRC	Lewis Research Center
LH_2	Liquid Hydrogen
LHCS	Liquid Hydrogen Control Skid
LMSC	Lockheed Missile & Space Company
LN_2	Liquid Nitrogen
LOCS	Liquid Oxygen Control Skid
LO_2	Liquid Oxygen
LSI	Launch System Integration
LSSP	Launch Site Support Plan
LVC	Launch Vehicle Contingency Propellants
MCC	Mission Control Center
MDAC	McDonnell Douglas Astronautics Company
MDM	Multiplexer/Demultiplexer
MECO	Main Engine Cutoff
MES	Main Engine Start
MET	Mission Elapsed Time
MLP	Mobile Launch Platform
MMSE	Multi-Use Mission Support Equipment
MPSR	Multi-Purpose Support Room
MSS	Mission Specialist Station
MSE	Mobile Support Equipment
MUX	Multiplexer
NPSH	Net Positive Suction Head
N_2H_4	Hydrazine
OMS	Orbital Maneuvering System
OPF	Orbiter Processing Facility
PAST	Preflight Analogous Software Test
P/L	Payload
PCM	Pulse Code Modulation
PCOS	Power Changeover Switching
PCR	Payload Changeout Room
PDI	Payload Data Interleaver
PDR	Preliminary Design Review
PE	Propellant Excess
PGHM	Payload Ground Handling Mechanism
PI	Payload Interrogator
PIP	Payload Integration Plan
PLIS	Propellant Loading Indicator System
PLS	Propellant Loading System
PLIU	Propellant Level Indicating Unit
PM	Propellant Margin
POCC	Payload Operational Control Center
PROM	Programmable Read-Only Memory
psid	Pounds Per Square Inch — Differential
psig	Pounds Per Square Inch — Gage
PSP	Payload Signal Processor
PTC	Passive Thermal Control
PU	Propellant Utilization
PICU	Pyro Initiator Control Unit
PWA	Pratt & Whitney Aircraft
RAM	Random Access Memory
RCS	Reaction Control System
RF	Radio Frequency
RMU	Remote Multiplexer Unit
RSS	Rotating Service Structure
RTLS	Return to Launch Site
RTSL	Real-Time Simulation Laboratory
SAEF	Spacecraft Assembly & Encapsulation Facility
S/C	Spacecraft
SC	Signal Conditioner
SCU	Sequence Control Unit
SEF	Software Engineering Facility
SES	Software Engineering System
SEU	System Electronics Unit
SGLS	Space Ground Link System
SID	System Interface Document
SIF	System Integration Facility
SIR	System Interface Requirements
SIU	Servo Inverter Unit
SLF	Shuttle Landing Facility
SMCH	Standard Mix Cargo Harness
SPCU	Standby Pneumatic Control Unit
SPAPL	Space Programs Approved Parts List
SPIF	Shuttle Payload Integration Facility
SRM	Solid Rocket Motor
SSP	Standard Switch Panel
Sta	Station
STAR	Shuttle Turnaround Assessment Report
STE	Special Test Equipment
STDN	Space Tracking & Data Network
STS	Space Transportation System
S/W	Software
TAL	Trans-Atlantic Landing
TALA	Trans-Atlantic Landing Avoidance
TC	Titan/Centaur
TDRSS	Tracking and Data Relay Satellite System
TEMPEST	Secured Communications Code Word
TGS	Telemetry Ground Station
TIU	Telemetry Interface Unit
TT&C	Telemetry, Tracking, and Command
TTF	Test and Transport Fixture
TVS	Thermodynamic Vent System
UPS	Uninterruptible Power Source
VAB	Vehicle Assembly Building
VAFB	Vandenberg AFB
VPF	Vertical Processing Facility
VPHD	Vertical Payload Handling Device
WSGT	White Sands Ground Tracking
XMT	Transmitter

Fluid Systems Schematic Legend



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FOREWORD

Integration of the Centaur vehicle into the Space Shuttle offers a significant increase in the performance capability of the Space Transporation System. During the last two years, substantial contractor and NASA activity (General Dynamics Convair Division and Rockwell; LeRC, JSC, and KSC) led to NASA's conclusion that the present Centaur vehicle can be integrated safely into the Shuttle.

The vehicle described in this document can perform the Galileo, Solar Polar, and TDRSS missions for NASA. It provides a payload capability of more than 10,600 pounds into geosynchronous orbit. Centaur G takes advantage of the Shuttle's 15-foot-diameter payload bay and maximizes the spacecraft length capability.

The configuration is derived from the flight-proven Atlas/Centaur and Titan/Centaur vehicles. The 120 in.-LO_2 tank is unchanged and a conical section is added to transition to the 170-in. diameter hydrogen tank. One obvious advantage of this configuration is that it can accommodate longer payload lengths than a stretched 120-inch-diameter configuration.

The following chapters present Shuttle/Centaur mission considerations, describe the Shuttle/Centaur airborne and ground hardware/software configurations and technical approaches, and outline the integrated ground and flight operations.

Shuttle/Centaur configurations and approaches discussed in this document are based on current development and integration planning. The major ground rules and assumptions factored into these configurations include:

1. Previous safety review results remain applicable.
2. Centaur/spacecraft will fly as a dedicated Shuttle payload.
3. Impact on Shuttle hardware/software and facilities will be minimized.
4. Doors-closed abort duration will be no greater than 6.5 hours.
5. Centaur/spacecraft will be installed in the Orbiter payload bay via the payload ground handling mechanism (PGHM).
6. A new LH_2 T-0 disconnect panel will be provided in the Orbiter midbody at the present T-4 OMS ΔV panel location.
7. JSC 07700, Volume XIV, Revision G, dated 26 September 1980, provides applicable design requirements; e.g., acoustic noise levels, etc.
8. JSC 07700, Volume X, Appendix 10.16, is a condensed version of the basic Volume X document, containing only those program-level technical requirements which pertain to the Shuttle/Centaur Centaur airborne support equipment (CASE).

2

TECHNICAL SUMMARY

OVERVIEW OF SHUTTLE/CENTAUR

Introduction

Integration of the flight-proven Centaur into the Space Shuttle offers a significant increase in the capability of the Space Transportation System. This task is being accomplished with minimum modification to Centaur or the Shuttle by using the Centaur Integrated Support System (CISS), as illustrated in Figure 2-1. The requirements of the NASA Galileo, International Solar Polar missions, and TDRSS and DoD geosynchronous missions are satisfied by the Centaur G configuration. Basic Shuttle integration and safety considerations have necessitated some additional changes to the present Atlas/Centaur configuration.

Shuttle/Centaur G (Figure 2-2) is capable of injecting a 10,600-pound, 40-foot-long spacecraft into a geosynchronous orbit with 0-degree inclination.

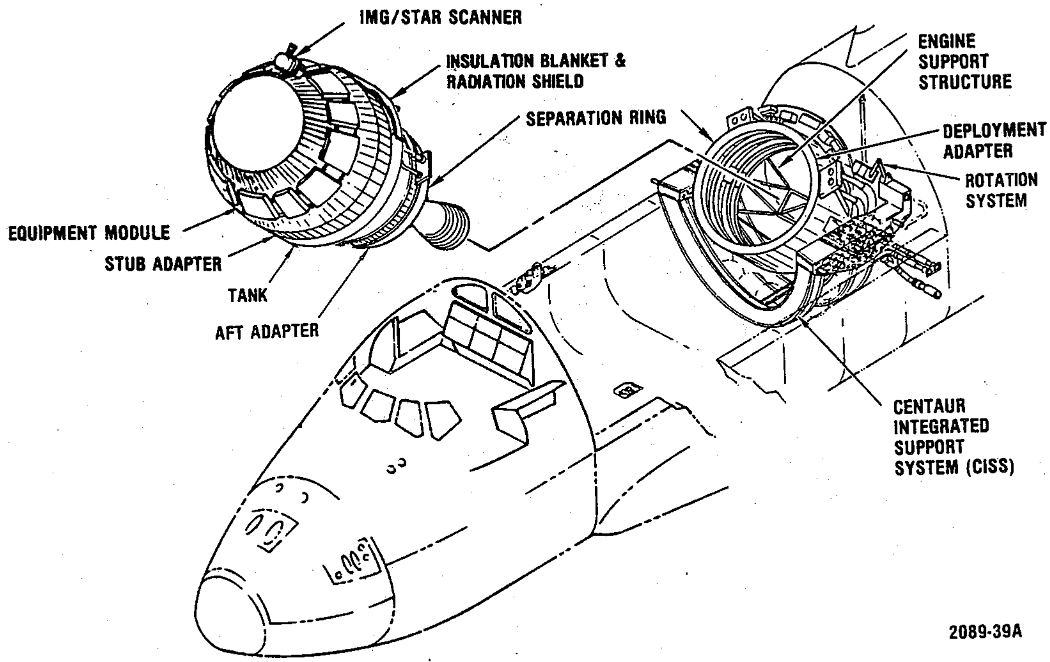

Figure 2-1. Shuttle/Centaur System For Centaur G.

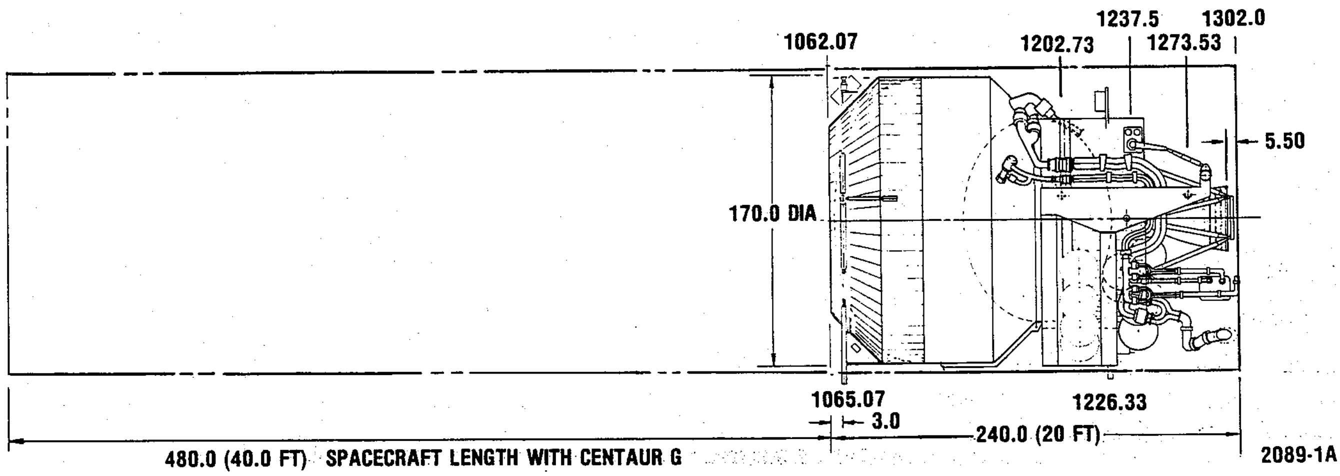

Figure 2-2. Centaur G and Spacecraft Length Capability.

Baseline Mission and Options

The baseline mission incorporates a single burn of the Centaur main engines to inject the spacecraft into an earth escape trajectory. This burn occurs nominally 45 minutes after separation from the Orbiter, which has been inserted into a 150-nmi circular parking orbit. Table 2-1 summarizes major events occurring before the first burn. This mission profile is applicable to the NASA Galileo and ISPM missions.

Centaur predeployment events are controlled automatically from the CISS, with crew functions used as necessary to initiate on-orbit deployment or caution/warning safing functions (Figure 2-3).

The principal mission option is a geosynchronous mission. This mission incorporates two burns of the Centaur main engines to inject the spacecraft into a geosynchronous orbit, as illustrated in Figure 2-4. The first burn occurs nominally 45 minutes after separation from the Orbiter.

The second Centaur burn occurs after a 5¼-hour Hohmann transfer coast, during which an

Table 2-1. Centaur G Mission Events Before First Burn.

Event	Time
Ascent	**Time from Lift-off**
Shuttle lift-off	0
ET Separation	8 min., 16 sec.
OMS-1	8 min., 54 sec.
OMS-2	44 min., 7 sec.
Open Payload Bay Doors	1 hr, 20 min.
Initiate CCE On-Orbit Mode	1 hr, 27 min.
Deployment	**Time to Centaur MES 1**
Initiate Centaur Checkout	−3 hr, 17 min.
Go/no-go to Deploy	−1 hr, 54 min.
Perform Star Scan	−1 hr, 54 min.
Rotate Deployment Adapter	−1 hr, 24 min.
Commit Centaur/Spacecraft	−1 hr, 1 min.
Go/no-go to Separate	−47 min.
Separation	−46 min.
Parking Orbit Coast	**Time to Centaur MES 1**
Activate Centaur RCS	−41 min.
Perform Spacecraft Pointing Maneuvers	−40 min.
Orient to Centaur burn attitude	−10 min.
MES 1	0

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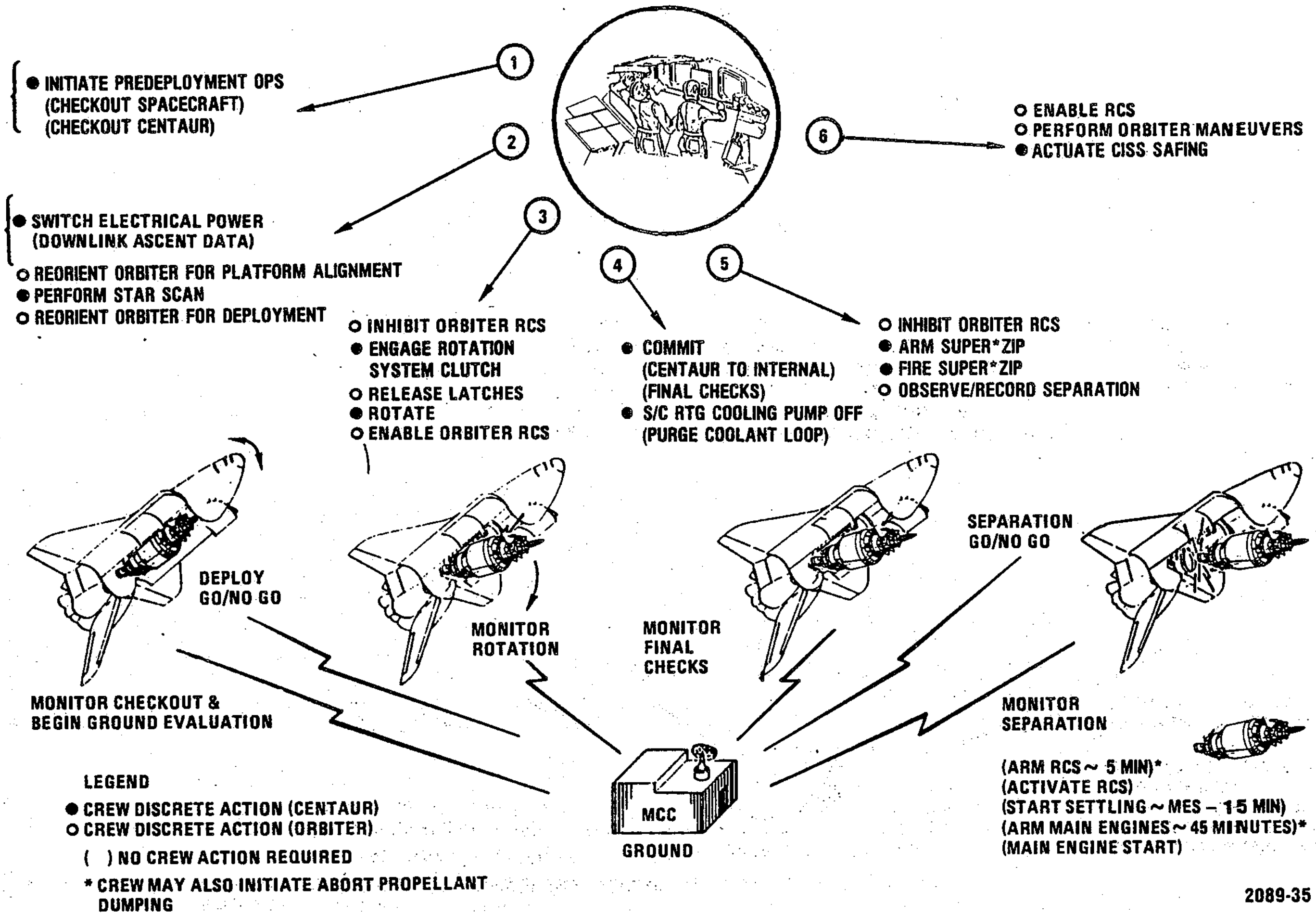


Figure 2-3. Crew-Intiated Tasks.

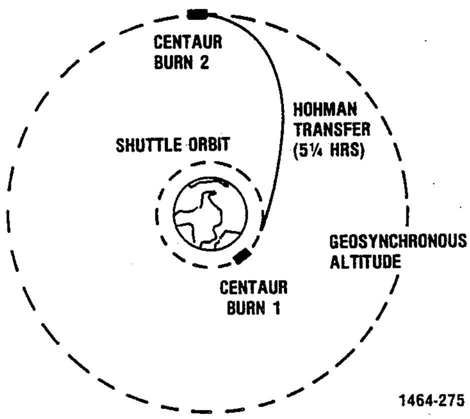


Figure 2-4. Geosynchronous Mission.

attitude update maneuver will be performed to increase the accuracy of the terminal orbit.

Based on the applicable weights summarized in Table 2-2, this mission profile results in a spacecraft weight capability to geosynchronous orbit of 10,600 pounds with an orbital inclination of 0 degrees. This performance is based on Centaur deployment from the Orbiter at the nominal time. However, while attached to the Orbiter, the Centaur G can accommodate extended space residency with a corresponding loss in gross spacecraft weight of 150 and 700 pounds for the additional one and two-day backup opportunities, respectively.

Such mission flexibility is readily accommodated by our present software logic and structuring with only minor changes anticipated to meet mission-peculiar and DoD-unique security requirements. Our approach includes preflight ground initialization of the Centaur general-purpose computer and prelaunch calibration of the inertial measurement unit; both then function continuously until the end of the mission.

Table 2-2. Centaur G Weight Summary.

Item	Weight (lb) Centaur G (Baseline Planetary)	Centaur G (DoD GEO)
Total loaded weight	49,308	55,829
Total support weight	8,169	9,029
Spacecraft airborne support equipment	450	1,700
Centaur airborne support equipment*	7,719	7,329
Total vehicle weight	41,139	46,800
Spacecraft gross weight**	5,359	10,600
Centaur tanked weight	35,780	36,200
Centaur jettison weight	5,881	6,241
Centaur dry weight	5,460	5,687
Centaur residuals	421	556
Centaur expendables	29,899	29,934
Propellants	29,780	29,705
Main impulse	29,285	28,965
Non-propulsive	495	740
Hydrazine	117	250
Helium	2	4

* Conservatively assumed same as NASA version
** Includes mission adapter 2089-2A

The overall ground operations flow required to check out the Centaur/CISS thoroughly, mate the spacecraft, and assemble and launch them in the Space Shuttle is illustrated in Figure 2-5.

System Description

The overall Centaur G vehicle is 19.5 feet long with a maximum LH_2 tank diameter of 170 inches (Figure 2-6). External protuberances (rings, stringers, insulation, harnessing, and fluid lines) will not violate the 180-inch payload envelope under any identified dynamic or thermal environmental conditions when Centaur G is supported within the Orbiter.

The Centaur vehicle includes a stub adapter and equipment module attached to the forward end. These adapters support Centaur avionics, provide a mounting interface for the spacecraft, and react the loads between Centaur and Orbiter forward attachments. An aft adapter and separation ring attached to the aft end of Centaur distribute acceptable circumferential line loads into the tank and provide pyrotechnic-actuated separation for Centaur deployment from the Orbiter.

The pressure-stabilized Centaur G propellant tank will be constructed in a manner very similar to that of the present Atlas/Centaur, although several geometry differences exist, as indicated in Figure 2-7.

Construction techniques for welding high-strength stainless steel have proven highly reliable for Atlas/Centaur in the last fifteen years. The double-wall intermediate bulkhead is identical on all Atlas/Centaur and Shuttle/Centaur tanks with minor differences at the cylindrical ring joints. Similarly, the aft bulkhead is identical on all Centaur tanks, thereby retaining our test and flight experience and minimizing modifications to flight-proven fluid systems.

The stub adapter, aft adapter, and equipment module are very similar to structures flown on Atlas/Centaur and Titan/Centaur. The stub adapter and the aft adapter will be constructed of titanium, as used on Titan/Centaur for long-coast missions.

Centaur's insulation system consists of two polyimide, fire-resistant foam blankets enclosed by a multilayer radiation shield/helium containment

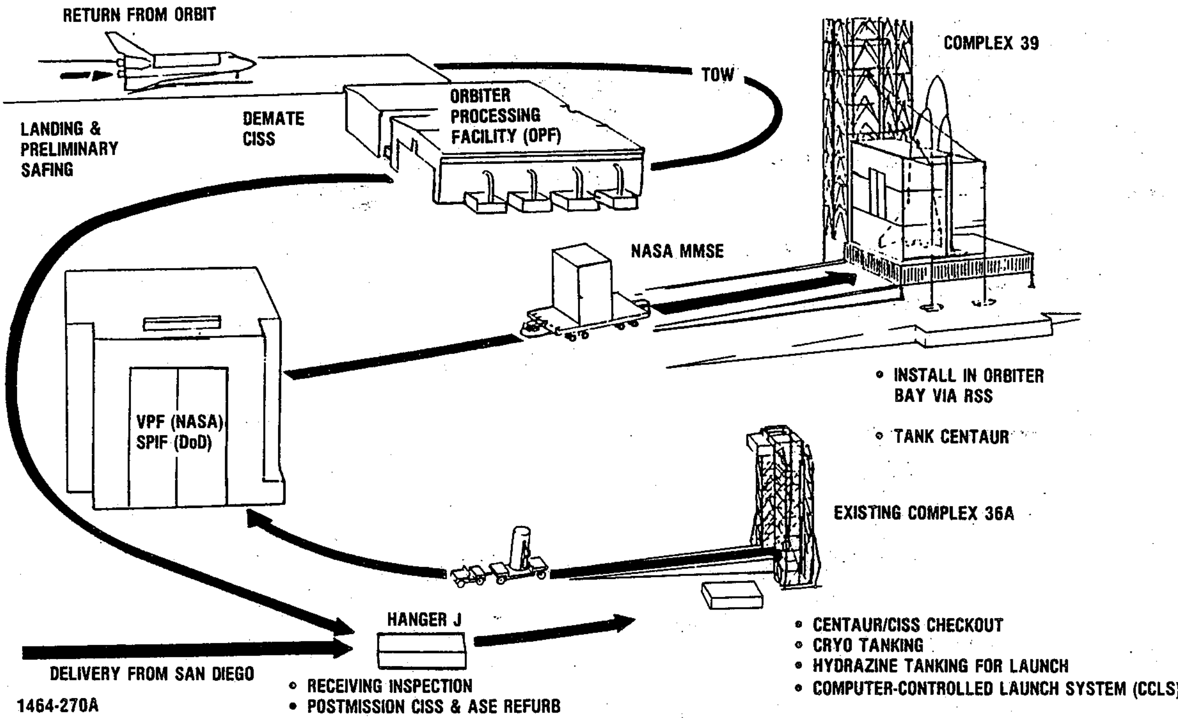


Figure 2-5. Centaur G Ground Operations At ELS.

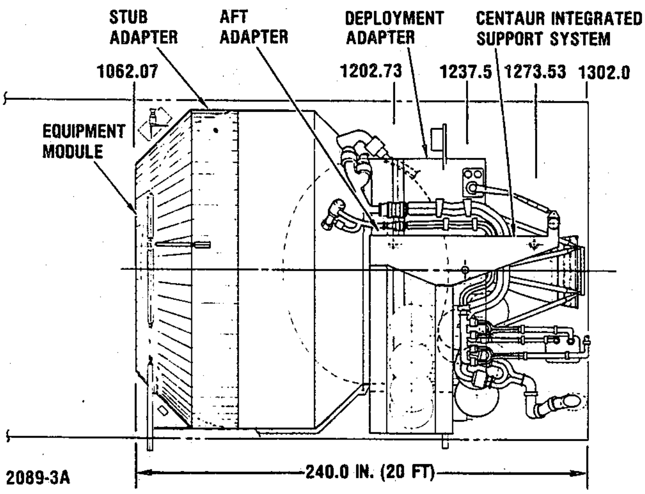


Figure 2-6. Shuttle/Centaur G Fluid Systems and Mechanisms.

membrane over the entire LH_2 tank. The LH_2 tank insulation blanket is purged with helium before launch and during abort.

The Centaur LO_2 tank aft bulkhead supports the two RL10A3-3A engines and the associated LO_2 and LH_2 propellant supply systems. The RL10 engines will be requalified to operate at a nominal 6:1 mixture ratio and a thrust of 15,000 lb. A simple adjustment allows this increased mixture ratio capability. More than forty test firings have demonstrated satisfactory engine performance at mixture ratios of 6:1 or greater.

The aft bulkhead also supports the hydrazine monopropellant reaction control system and the hydraulic system that supplies power to gimbal the main engines to effect flight control. The bulkhead also supports pneumatic storage and supply sys-

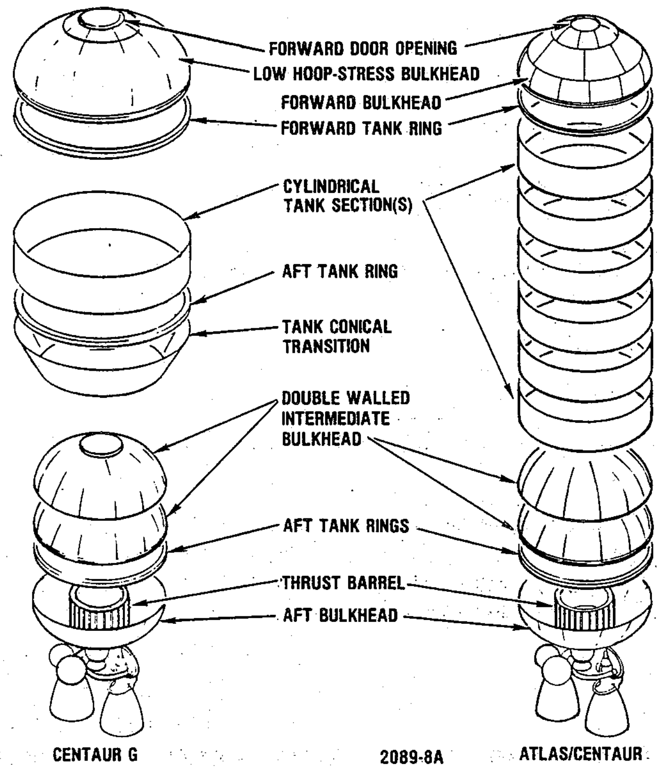


Figure 2-7. Centaur G and Atlas/Centaur Tanks.

tems and the tank vent systems used to control tank pressurization.

Propellants are supplied to the main engines with specified net positive suction head (NPSH) provided by tank pressurization. Tank pressure is controlled by an existing computer-controlled vent and pressurization system (CCVAPS), which injects helium into the tanks before engine start in response to sensed tank pressures. After engine start, the LH_2 tank is pressurized with GH_2, which is bled off the engines. The LO_2 tank is pressurized with helium. The systems are essentially identical for Atlas/Centaur and Shuttle/Centaur vehicles, with the minor exception of line routing, geometry differences, and redundancy.

The Atlas/Centaur avionics system consists of a 16K core memory digital computer unit, a gimballed-platform inertial measurement group, sequence control unit, servo inverter unit, two remote multiplexing units, two signal conditioners, pyrotechnic initiator control unit, associated instrumentation system, propellant utilization and level-sensing system, and an electrical power system and batteries. These systems/units operate together to control all vehicle functions.

Shuttle integration and safety requirements have necessitated a few minor component changes to the Atlas/Centaur avionics system. Where practical, commonality among Atlas/Centaur and Centaur G configurations will be maintained. Mission requirements dictate addition of a star scanner for attitude updating. Shuttle requirements dictate addition of a dual-failure-tolerant arm/safe sequencer, which precludes premature arming of critical Centaur functions. Figure 2-8 reflects Centaur G vehicle avionics system configuration. Mission peculiar avionics changes to meet DoD requirements will include incorporation of an encryptor/decryptor for secure communications, space ground link (SGLS) compatible transponder, telemetry interface unit, and power transfer unit.

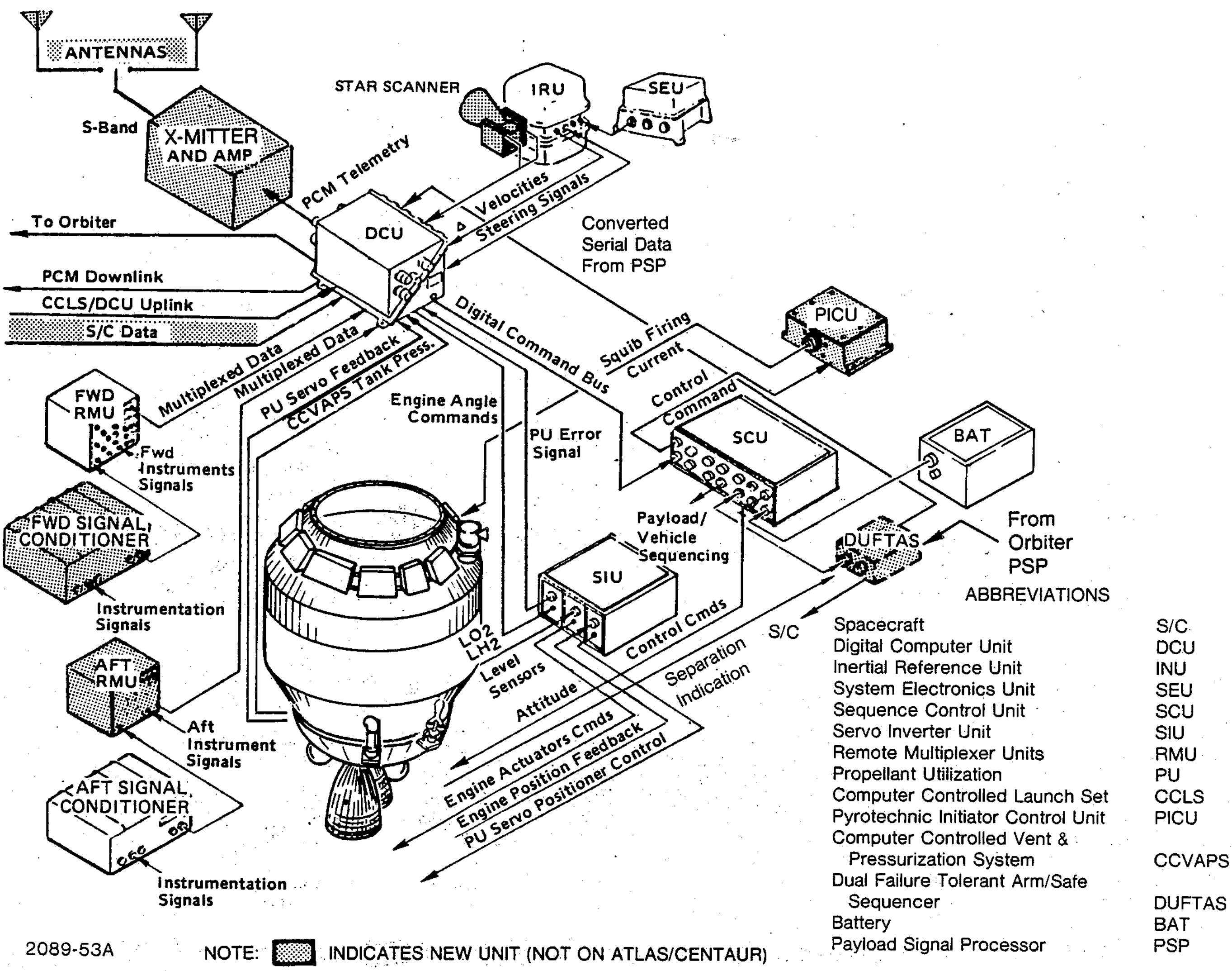


Figure 2-8. Centaur G Avionics.

The Centaur vehicle is supported and serviced while within the Orbiter payload bay via the Centaur Integrated Support System (CISS), as indicated in Figure 2-9. The CISS includes a deployment adapter that supports the Centaur vehicle at the separation ring. The adapter also supports the Centaur main engines via a truss structure on the aft end and supports various avionic, mechanical, and fluid subsystems and components. The deployment adapter attaches to the Centaur support structure (CSS) via two rotation trunnions. The support structure transfers loads between Centaur and the Orbiter through a five-point support system. It also supports other avionic, mechanical, and fluid subsystems, including systems serving as interfaces between the Orbiter and Centaur.

CISS functional systems include mechanical systems to:

- Rotate the deployment adapter to a separation attitude of 45 degrees.
- Retain the Centaur/CISS within the Orbiter payload bay.

CISS also incorporates fluid systems to:

- Fill and drain the LO_2 and LH_2 propellants on the ground.
- Dump LH_2 and LO_2 propellants in flight.
- Provide helium to Centaur for purging, pneumatic control system pressure, and tank pressurization.
- Vent LO_2 and LH_2 tanks on the ground and in flight.
- Distribute prelaunch GN_2 gas conditioning on the ground.

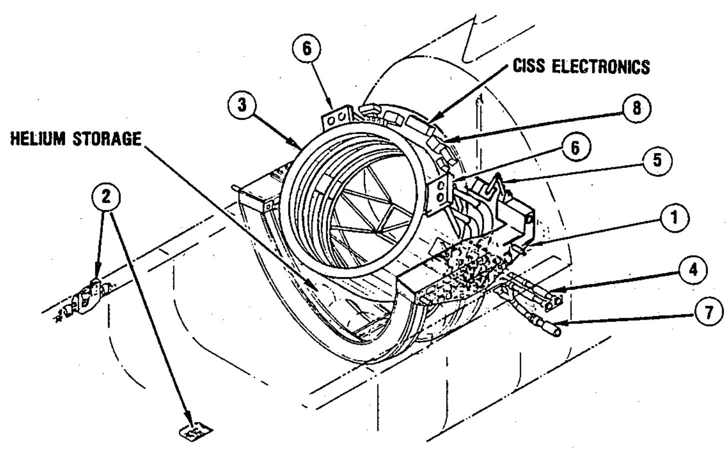
CISS avionics systems include:

- Five control units and two control distribution units that provide up to two-failure-tolerant control of all CISS/Centaur subsystems before deployment.
- A redundant power subsystem to augment Orbiter-supplied electrical power.
- An instrumentation system to distribute data.

Figure 2-10 reflects the baseline CISS avionics configuration that will be modified as required for DoD to provide secure communications, SGLS compatibility, and accurately controlled power to the spacecraft.

Shuttle Integration Considerations

Shuttle/Centaur has been subjected to preliminary Phase 0 and I safety reviews by NASA/JSC and NASA/KSC. It was concluded that Centaur can be integrated safely into the Space Shuttle. Subsequent safety reviews will occur throughout the Centaur G integration effort.



INTERFACE COMPATIBILITY

① FIVE-POINT AFT SUPPORT SYSTEM BETWEEN CISS AND ORBITER (STANDARD FITTINGS)
② THREE-POINT FORWARD SUPPORT SYSTEM BETWEEN CENTAUR AND ORBITER (STANDARD LATCHES WITH STOPS ADDED FOR PASSIVE RESTRAINT)
③ DEPLOYMENT ADAPTER WITH SPRING THRUST TO EJECT CENTAUR
④ FLUID SERVICING FOR LO_2 AND LH_2 FILL & DRAIN, PRELAUNCH/FLIGHT VENTING, ABORT DUMP AND BULKHEAD CAVITY RELIEF
⑤ DEPLOYMENT ADAPTER ROTATION SYSTEM (TO 45 DEGREES)
⑥ FUEL AND OXIDIZER DISCONNECT PANELS

SAFETY CONSIDERATIONS

⑦ PROPELLANT ABORT DUMP
⑧ FIVE AUTONOMOUS CONTROL UNITS PROVIDE TWO-FAILURE TOLERANT CONTROL

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Figure 2-9. Centaur Integrated Support System.

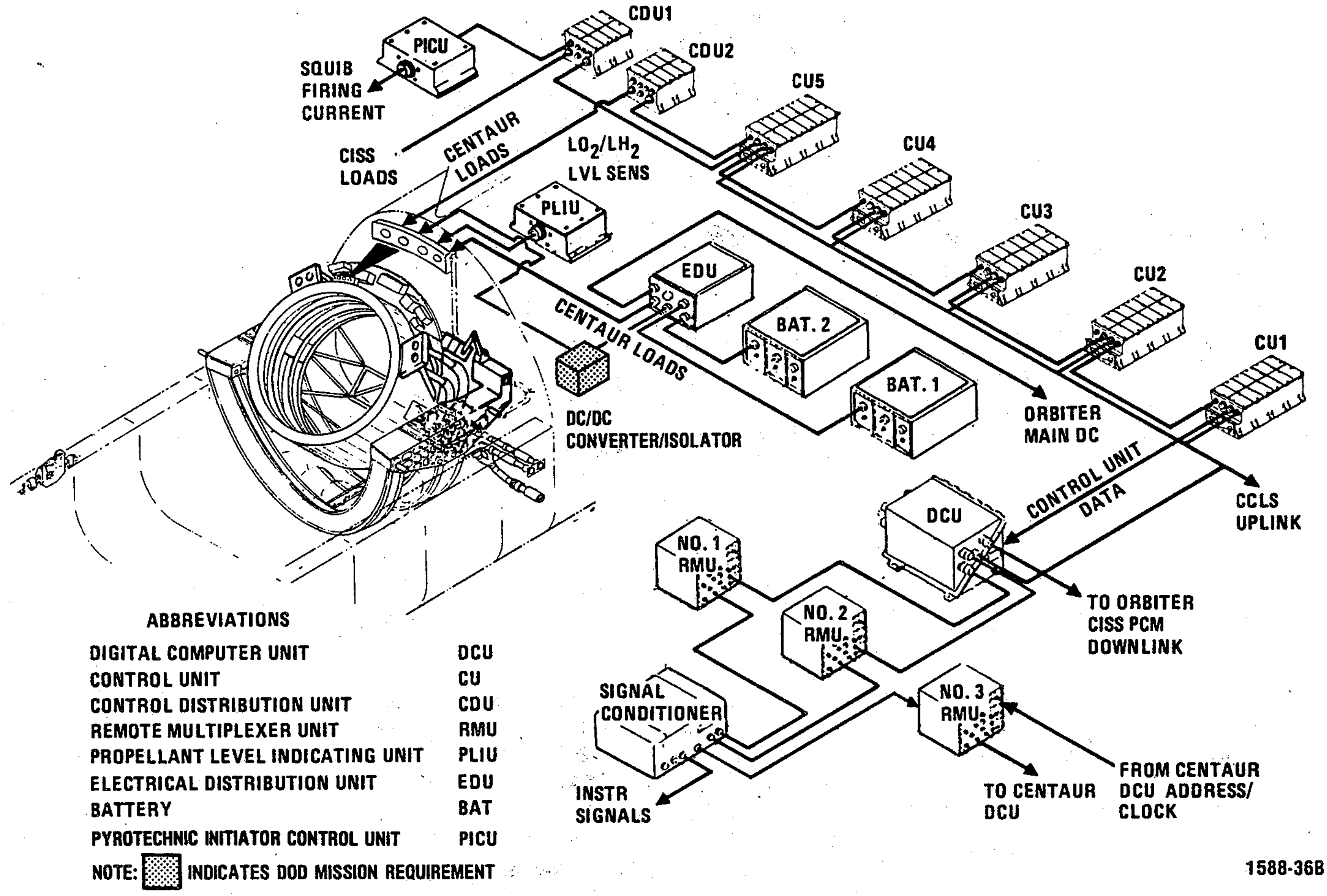


Figure 2-10. Centaur Integrated Support System Avionics.

Major Centaur-to-Orbiter fluid interfaces are shown in Figure 2-11.

During Orbiter-initiated aborts, the Centaur propellants will be dumped. This provides several significant advantages:

- Return (landing) cargo weight is reduced by nearly 30,000 pounds.

- Abort to orbit capability occurs earlier in the Orbiter trajectory if propellants are dumped.

- Orbiter performance (lift capability) is increased approximately 2,000 pounds through a reduction in propellant reserves necessary to accomplish a return-to-launch-site abort mode. This arises from the reduction in cargo weight.

Self-imposed restrictions and close control of changes to the flight-proven Atlas/Centaur vehicle systems will ensure that the demonstrated high reliability will be retained or enhanced for Centaur G. Essential changes will incorporate well-proven design and construction techniques.

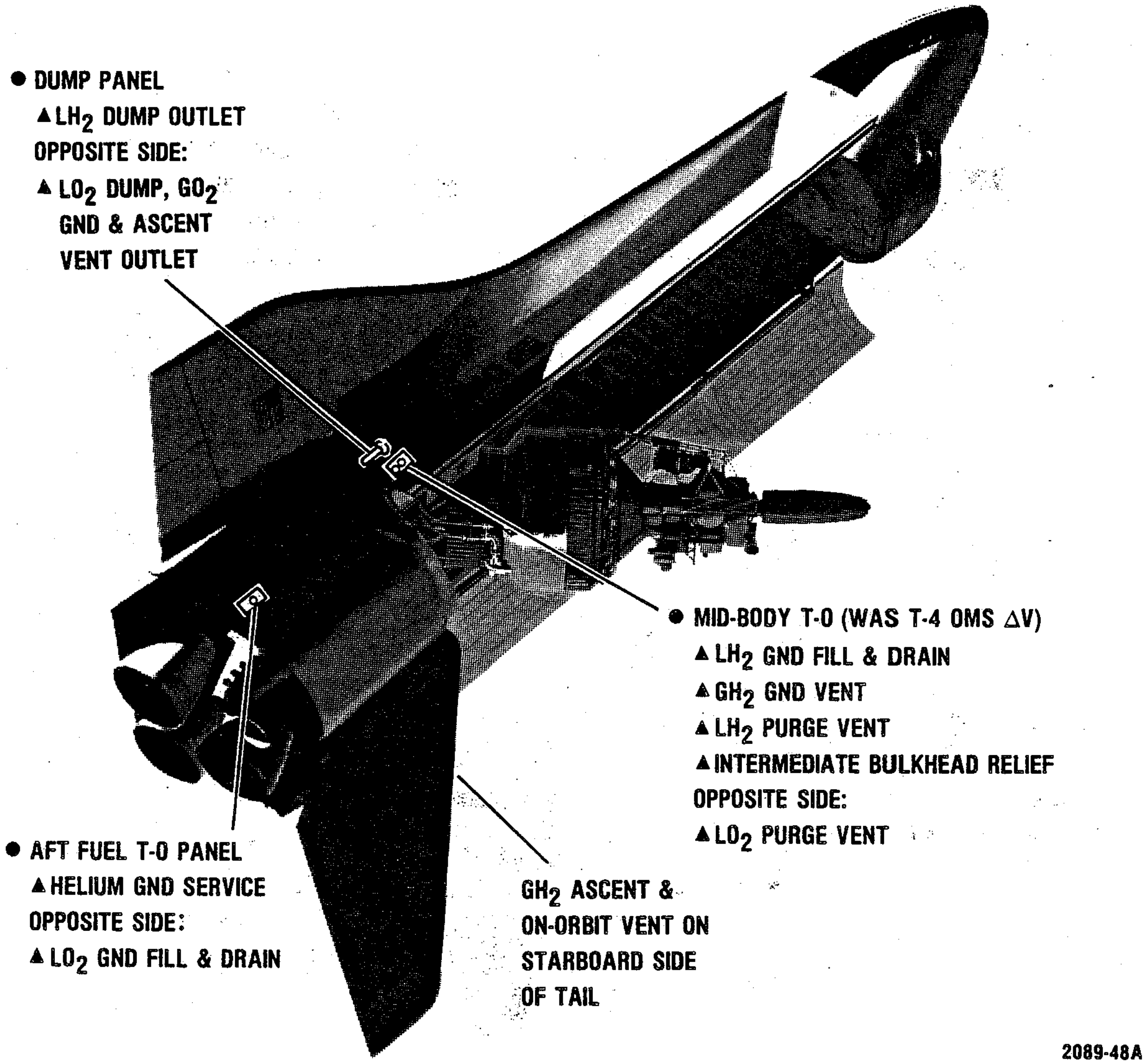


Figure 2-11. Centaur G Fluid Interfaces With Orbiter.

3

TECHNICAL DESCRIPTION

3.1 GENERAL

This chapter describes technical features of the Centaur G that General Dynamics proposes to develop for NASA and Air Force use. The baseline Centaur G and mission-peculiar modifications required for various mission options are covered.

Design, development, test, and evaluation (DDT&E) of Centaur G described in this chapter include:

- Mission requirements development.
- Centaur flight vehicle design, development, analysis, software development, and mission peculiars.
- Centaur integrated support system design, development, analysis, software development, and mission peculiars.
- Ground support equipment and facilities design, development, analysis, and software development.
- Ground and flight operations development and planning.
- Hardware and software development and qualification testing.

Table 3-1. Baseline Mission Requirements.

Item	Application NASA One-Burn	Application DoD Two-Burn
• Parking orbit:		
150-nmi circular	x	x
28.5-deg inclination (due-east launch)	x	x
• Final orbit:		
Geosynchronous (elliptic or circular)		x
Earth-escape (hyperbolic C_3 = 50 km^2/sec^2)	X	
Inclination: 0 to 28.5 deg		x
28.5 deg	x	
• Longitude at injection:		
Permissable range specified		x
• Nominal Centaur deployment:		
Preselected time on first day	x	x
• Backup deployment opportunities; revolutions past nominal:		
16 and 32		x
1 and 2	x	
• Contingency opportunity; additional parking orbit revolutions after separation from orbiter:		
1		x
0	x	
• Spacecraft weight:		
5,000 to 10,600 lb		x
5,359 lb	x	
• Spacecraft length:		
up to 40 ft	x	x

3.2 BASELINE MISSIONS/ CONFIGURATION SELECTION

Baseline missions for both one- and two-burn Centaurs are considered.

3.2.1 ONE-BURN BASELINE MISSION — The baseline reference NASA mission adopted for engineering design and analysis of Centaur G is the planetary 1985 Galileo (ΔV + EGA) launch, achieved with a single Centaur burn from a 150-nmi parking orbit provided by the STS. This burn places the spacecraft in a heliocentric orbit, which is later modified by an in-space velocity addition (ΔV) provided by the spacecraft propulsion system and an Earth Gravity Assist (EGA) swing-by. The Galileo spacecraft encounters the planet Jupiter some four years after launch. Requirements for this NASA baseline mission are summarized in Table 3-1.

3.2.2 TWO-BURN OPTIONAL MISSION — The reference DoD mission adopted for engineering design and analysis of Centaur G is a geosynchronous orbit (period of about 24 hours) achieved with two Centaur burns, the first of which departs from a 150-nmi parking orbit provided by the STS. The second burn occurs about 5.25 hours later to attain the geosynchronous orbit at the desired inclination. A generic "performance mission box" of requirements for the DoD reference mission is presented in Table 3-1. NASA geosynchronous orbit mission requirements are assumed to lie within this "box."

3.2.3 PROPOSED CENTAUR G CONFIGURATION — An assessment of the NASA and DoD near-term mission requirements has led to selection of a representative configuration for the Centaur to satisfy both the NASA one-burn and DoD two-burn optional missions with minimal mission-peculiar differences. This Centaur configuration is characterized by:

- Approximately 19.5-foot overall length
- Approximately 4,445-lb LH_2 and 25,594-lb LO_2 capacity (similar to Atlas/Centaur).

- Standard length RL-10 engines.
- A 6:1 nominal mixture ratio (nominal specific impulse = 442.4 seconds).
- Low-profile forward LH_2 tank bulkhead and 45 degree transition angle to LO_2 tank.

The selected tank configuration (Figure 3-1) provides a 40-foot payload length in the payload bay.

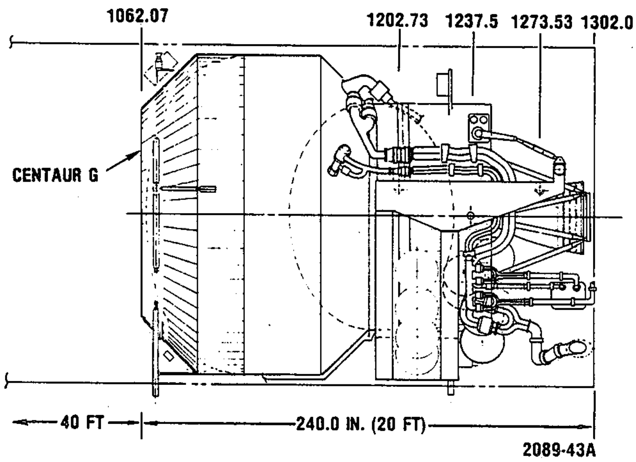


Figure 3-1. Centaur G Configuration.

Since performance with the well-proven Atlas/Centaur propulsion system is adequate for the baseline missions, the standard-length engine bells will be used.

3.2.4 MISSION PERFORMANCE

3.2.4.1 Earth-Escape Mission — Centaur G can inject 5,600 pounds of payload into an Earth-escape orbit with an energy of 50 km^2/sec^2 for launches from the Eastern Launch Site utilizing a 150-nmi circular, 28.5 degree inclined parking orbit supplied by the STS. The Shuttle lift requirement for this application is less than 50,000 lb, as indicated by the weight summary of Table 3-2. Figure 3-2 presents the orbital energy capabilities of the Centaur G for payload weights up to 6,000 lb. Also shown is the increased capability for Centaur G with a STAR 37E kick stage added. Mission requirements for the 1985 Galileo ($\Delta V + EGA$) baseline mission and the 1986 Solar Polar mission (ISPM) are included.

3.2.4.2 Geostationary Mission — Centaur G can inject 10,600 pounds of payload into a geostationary orbit (circular, zero inclination) for launches from the Eastern Launch Site, departing from a 150-nmi, 28.5-degree inclined parking orbit supplied by the STS. The Shuttle lift requirement for this application is only 55,829 pounds, as indicated in the weight summary of Table 3-2.

Table 3-2. Centaur G Baseline Mission Weight Summary.

Item	Weight (lb) Centaur G (Baseline Planetary)	Centaur G (DoD GEO)
Total loaded weight	49,308	55,829
Total support weight	8,169	9,029
Spacecraft airborne support equipment	450	1,700
Centaur airborne support equipment*	7,719	7,329
Total vehicle weight	41,139	46,800
Spacecraft gross weight**	5,359	10,600
Centaur tanked weight	35,780	36,200
Centaur jettison weight	5,881	6,241
Centaur dry weight	5,460	5,687
Centaur residuals	421	556
Centaur expendables	29,899	29,934
Propellants	29,780	29,705
Main impulse	29,285	28,965
Non-propulsive	495	740
Hydrazine	117	250
Helium	2	4

* Conservatively assumed same as NASA version
** Includes mission adapter 2089-2A

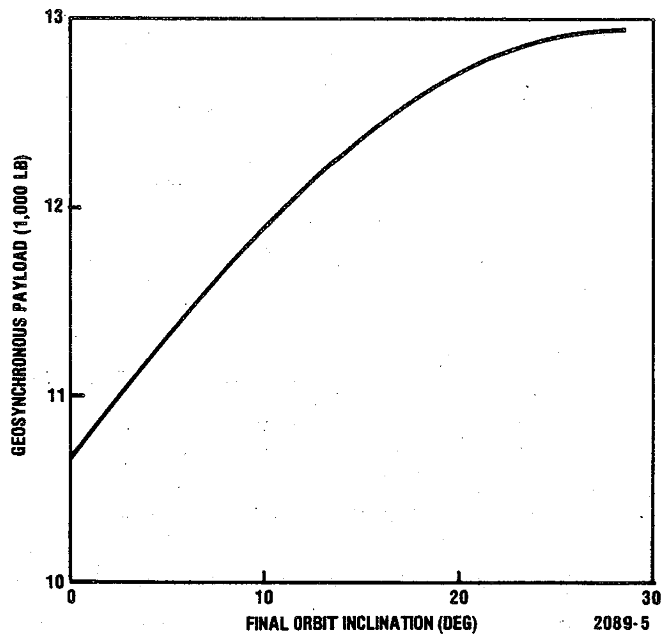


Figure 3-2. Centaur G Geosynchronous Orbit Capability.

3.2.4.3 Effects on Non-Zero Inclination and Eccentricity — Figure 3-3 presents geosynchronous performance capability as a function of final orbit inclination to show the sensitivity for other than equatorial missions. Note that for a final inclina-

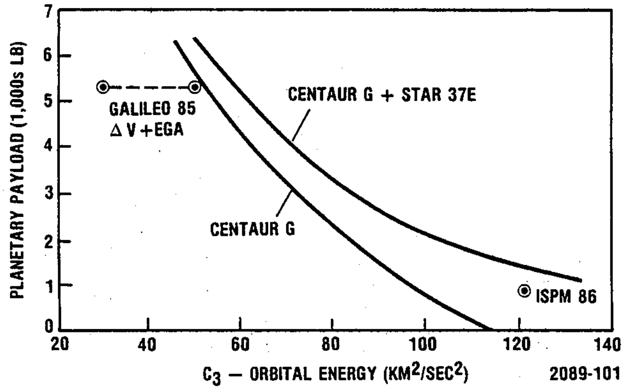


Figure 3-3. Centaur G Planetary Performance.

tion of 10 degrees, for example, the geosynchronous payload capability is increased to 11,900 pounds.

Centaur G can also achieve noncircular geosynchronous orbits, if desired. Performance capability for slightly eccentric geosynchronous orbits is nearly the same as for circular orbits.

3.2.4.3.1 Longitude Placement — To obtain a specified geosynchronous injection longitude, the above performance values may be degraded somewhat, depending upon the number of revolutions required in the parking orbit and the particular phasing technique employed to achieve the desired final placement. Alternative methods and corresponding performance capabilities associated with a given mission longitude requirement and opportunity interval are discussed below.

3.2.4.3.2 Nominal Optional DoD Mission — Requirements of the baseline DoD mission specify a permissible range of placement longitude, and a specific nodal crossing for initial deployment from the Orbiter payload bay. The previously quoted geostationary payload capability of 10,600 pounds applies here since no appreciable performance loss due to hydrogen boiloff occurs during the first day in orbit.

3.2.4.3.3 Backup Deployment Opportunities — To meet requirements for providing two backup deployment opportunities spaced 24 hours apart each after the initial (primary) opportunity, Centaur will incur hydrogen boiloff during the additional 16 to 32 revolutions in the parking orbit. The estimated payload loss amounts to 150 and 700 pounds for the additional one and two-day backup opportunities, respectively.

3.2.5 FLEXIBILITY FOR CONTINGENCIES — The versatility of Centaur software and the excess payload capability for existing missions provide mission flexibility by allowing many options for contingency planning. The geosynchronous mission will be used to illustrate examples of Centaur flexibility.

For example, Centaur software capability increases mission flexibility by allowing Centaur deployment and/or mission initiation on successive revolutions in the parking orbit. Orbit parameters can be selected from previously validated multiple-targeting sets as a function of time to account for mission initiation delays. Software for contingency options has been flight-proven; typical examples are automated in-flight re-targeting capability for HEAO launches (Atlas/Centaur) and provision for contingency parking orbit revolution for Voyager launches (Titan/Centaur).

3.2.5.1 Preplanned Drift Rate — At synchronous injection, Centaur can provide variable payload drift rates according to the number of orbit delays needed to reach the proper longitude placement in a specified time (if required). Centaur's excess payload capability can be used for extra batteries and control gas to stop the satellite drift rate at the correct longitude placement. Obviously, this excess payload capability can also provide multiple parking orbit revolutions outside the Orbiter bay and multiple revolutions in the transfer orbit with Centaur software providing targeting parameters.

3.2.5.2 Contingency Revolution — A contingency revolution in the parking orbit after separation from the Orbiter can readily be provided by Centaur, if the corresponding 23°W change in geosynchronous placement longitude is acceptable. Centaur can provide this capability at a small loss in performance from the reference geostationary mission capability; i.e., 10,600 pounds. If desired, the primary placement longitude may then be achieved using satellite drift, at a cost of added spacecraft propellants.

3.2.5.3 Contingency Revolution Alternative Option — Another example of Centaur versatility is that it can, if desired, provide the *same* longitude placement during the contingency revolution as during the primary opportunity. Thus, the same longitude placement of the spacecraft can be attained on either of two successive revolutions of the parking orbit in a matter of just a few hours, rather than a few days by using satellite drift. This is accomplished by using a non-Hohmann fast-transfer technique that has an associated performance loss. The magnitude of this degradation can be held to 1,100 pounds by proper mission planning. It is emphasized that achieving the same placement longitude on two successive parking orbit revolutions is not a requirement, but is an available *option* that can increase mission planning flexibility.

3.3 CENTAUR CONFIGURATION

This discussion of the configuration is structured to first provide a basic description of the baseline single-burn planetary mission, Shuttle/Centaur G, followed by a definition of the modifications required to meet geosynchronous mission requirements for NASA and DoD. Figure 3-4 summarizes these modifications.

3.3.1 CENTAUR SYSTEM GENERAL CONCEPT

3.3.1.1 Centaur G Vehicle — The Centaur vehicle consists of a 10-foot-diameter LO_2 tank that transitions to a 14-foot 2-inch, diameter LH_2 tank. The cryogenic tanks are insulated with combinations of helium-purged foam blankets and radiation shields. The forward end of the vehicle consists of a bolted-on cylindrical stub adapter and a conical equipment module, which provides mounts for all vehicle electronics packages. The aft end of the vehicle consists of a cylindrical aft adapter and a pyrotechnic separation ring.

The vehicle avionics sytem performs the functions necessary for autonomous control of the Centaur vehicle from Orbiter separation through postseparation maneuvers.

The GN&C system for the baseline Centaur G is the Atlas/Centaur GN&C system with minor modifications. The system was completely redesigned to NASA Hi-Rel standards in 1972. A star scanner has been added for attitude update.

The telemetry system is compatible with the Orbiter Ground Spaceflight Tracking and Data Network (GSTDN) and Tracking and Data Relay Satellite System (TDRSS) links, and permits data uplink via the Orbiter when Centaur is attached.

Electrical power to safety-related avionics control functions is inhibited until the Centaur is a safe distance from the Orbiter.

Centaur G avionics for DoD missions will be modified to incorporate spacecraft interface requirements. The avionics will also incorporate secure communications features and replacement of the baseline transmitter with a transponder compatible with the Space Ground Link System.

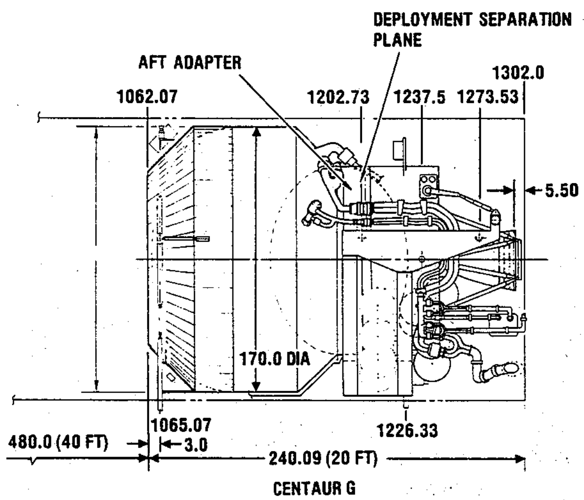
3.3.1.2 Centaur Integrated Support System (CISS) — The CISS consists of a Centaur support structure (CSS), a deployment adapter, and the associated CISS electronics and fluid systems (Figure 3-5). The CSS adapts the Centaur vehicle and deployment adapter to the Orbiter through a five-point support system. The deployment adapter attaches to the aft end of Centaur at the separation ring and to the CSS through two rotation trunnions and guide keel pin.

During deployment, the vehicle is rotated 45°, to its separation attitude, by a rotation mechanism attached to the deployment adapter.

Fluid systems ducting and gimbals are provided to interconnect the various propellant tank service lines to their associated Orbiter overboard service ports (Figure 3-6). The gimbals permit the Centaur to be rotated to the deployment position while maintaining all safety-related systems in a connected and functional state.

Helium storage spheres and two-failure-tolerant pressurization and pressure regulation systems supply all helium for pressurizing Centaur tanks, actuating vent and dump system valves, and providing the necessary system purges to manage Centaur propellants safely.

CISS avionics performs all control functions



ITEM	IDENTIFIED MISSION PECULIAR DIFFERENCES: BASELINE	DoD (GEOSYNCHRONOUS)
VEHICLE ELECTRICAL SYSTEM	1 BATTERY AT 100 AMP-HOUR EACH	PLUS 3 BATTERIES AT 150 AMP-HOUR EACH PLUS 1 POWER TRANSFER UNIT
TELEMETRY, TRACKING & COMMAND SYSTEM	TDRSS COMPATIBLE TRANSMITTER (NO UPLINK)	SGLS COMPATIBLE TRANSPONDER, PLUS 1 TELEMETRY INTERFACE UNIT, ENCRYPTOR (GFE), 1 DECRYPTOR (GFE) & 1 DoD COMMUNICATION INTERFACE UNIT (GFE)
HYDRAZINE RCS STORAGE	1 BOTTLE AT 170 LB EACH	2 BOTTLES AT 170 LB EACH
CISS ELECTRICAL POWER SYSTEM	BASELINE	BASELINE & 1 SPACECRAFT POWER DISTRIBUTION UNIT & 1 DC/DC REGULATOR/ISOLATOR (GFE)

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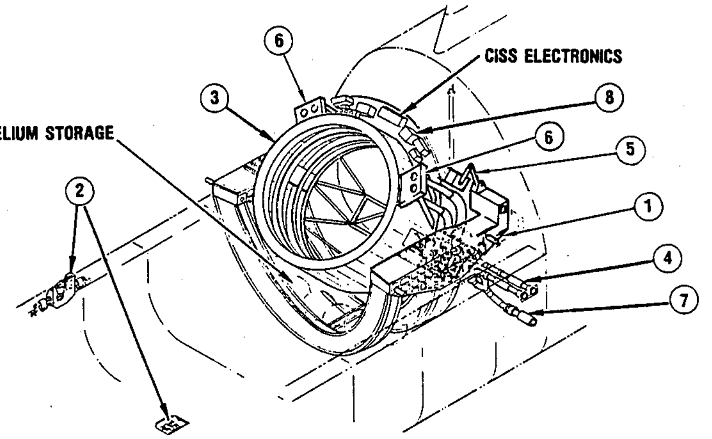
Figure 3-4. DoD Shuttle/Centaur.



INTERFACE COMPATIBILITY

① FIVE-POINT AFT SUPPORT SYSTEM BETWEEN CISS AND ORBITER (STANDARD FITTINGS)
② THREE-POINT FORWARD SUPPORT SYSTEM BETWEEN CENTAUR AND ORBITER (STANDARD LATCHES WITH STOPS ADDED FOR PASSIVE RESTRAINT)
③ DEPLOYMENT ADAPTER WITH SPRING THRUST TO EJECT CENTAUR
④ FLUID SERVICING FOR LO_2 AND LH_2 FILL & DRAIN, PRELAUNCH/FLIGHT VENTING, ABORT DUMP AND BULKHEAD CAVITY RELIEF
⑤ DEPLOYMENT ADAPTER ROTATION SYSTEM (TO 45 DEGREES)
⑥ FUEL AND OXIDIZER DISCONNECT PANELS

SAFETY CONSIDERATIONS

⑦ PROPELLANT ABORT DUMP
⑧ FIVE AUTONOMOUS CONTROL UNITS PROVIDE TWO-FAILURE TOLERANT CONTROL

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Figure 3-5. Centaur Integrated Support System.

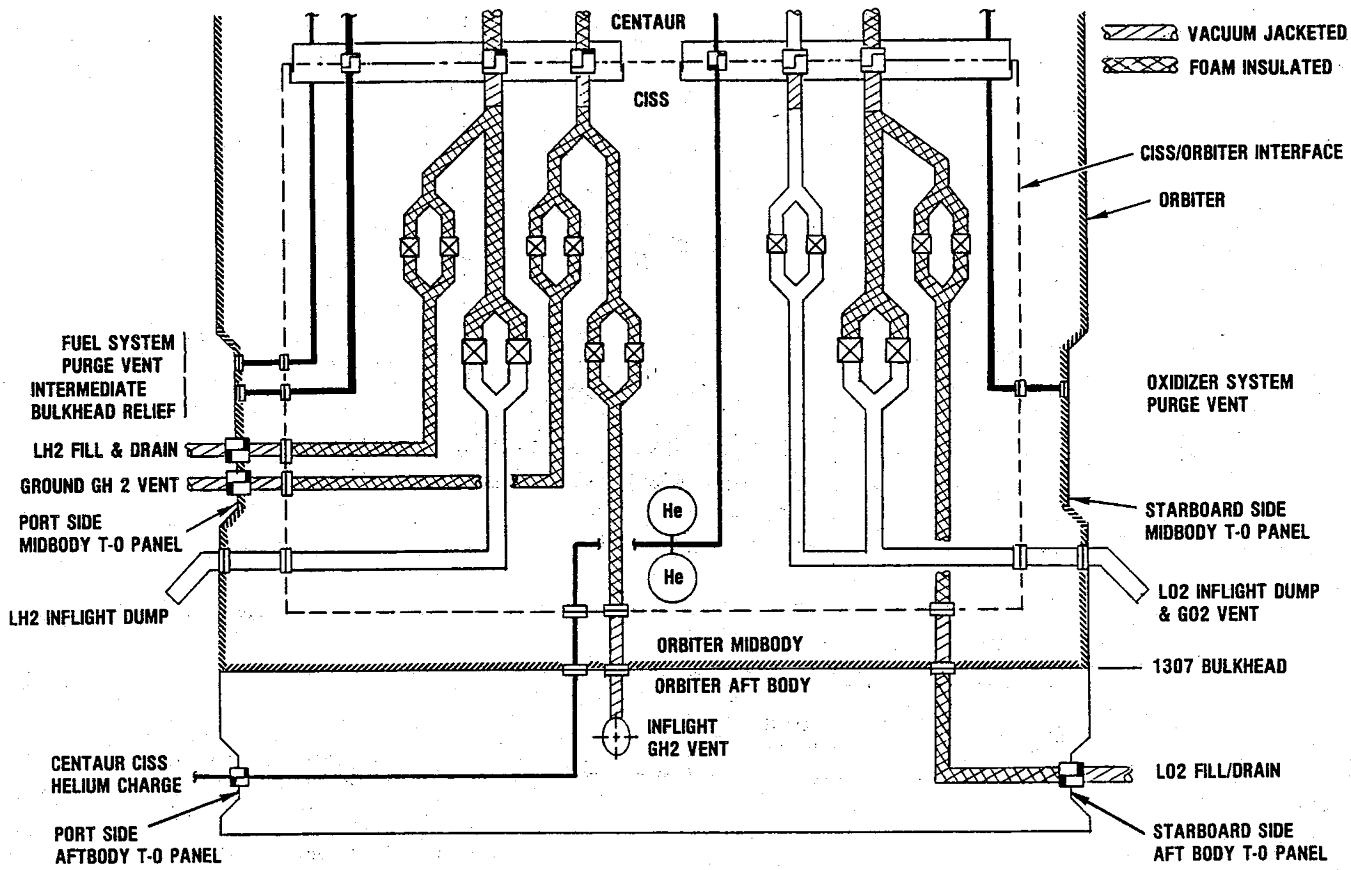

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Figure 3-6. Centaur/Orbiter Fluid Interfaces.

for vehicle safety while the Centaur is attached to the Orbiter and for deployment. Two-failure-tolerant control is achieved with five strings of microprocessor-control avionics, associated sensors, and controllers.

CISS avionics for DoD missions will be modified to add equipment to provide spacecraft-unique power and to control and select the power source. A communication interface unit on the aft flight deck panel, in conjunction with the CISS, services the spacecraft and Centaur vehicle communication system.

3.3.2 STRUCTURAL SYSTEMS

3.3.2.1 Centaur Vehicle — Structural components will be designed to provide ultimate factors of safety equal to or greater than 1.40 while in the orbiter bay and 1.25 after deployment, for all mission design phases. Components will be designed to the limit load factor specified in Tables 4.1.3.1 through 4.1.3.4 of JSC 07700, Vol. XIV, Attachment 1. Loads will be verified by dynamic loads analysis using Orbiter forcing functions supplied by JSC/Rockwell.

Structural components will be designed to react emergency landing loads using ultimate design factors for nonreturnable payloads given in Table 4.1.3.5-1 of JSC 07700, Vol. XIV, Attachment 1.

3.3.2.1.1 Centaur G Tank Configuration — The basic propellant tank arrangement is a LO_2 tank and a LH_2 tank, as illustrated in Figure 3-7. The weight-effective, pressure-stabilized tank configuration has been proven in 463 Atlas flights, 57 Atlas/Centaur flights, and 7 Titan/Centaur flights. This structurally efficient Centaur G tank contains the main engine propellants, establishes vehicle primary structural integrity, and supports vehicle systems and components. NASA has determined that the cryogenic Centaur can be safety integrated into the Space Transportation System. Extensive testing of the Atlas/Centaur tank has demonstrated that the tank has a much greater strength capability than the design values.

The basic tank material is 301 CRES purchased from the mill to an exacting Convair specification. The entire welded tank assembly, including all rings and brackets, is made of 300 series CRES, which minimizes galvanic corrosion. Stress corrosion cracking problems are avoided by the selection of the tank materials and by storage and maintenance activities that provide a periodic protective coating.

Tank raw stock is ultrasonically inspected.

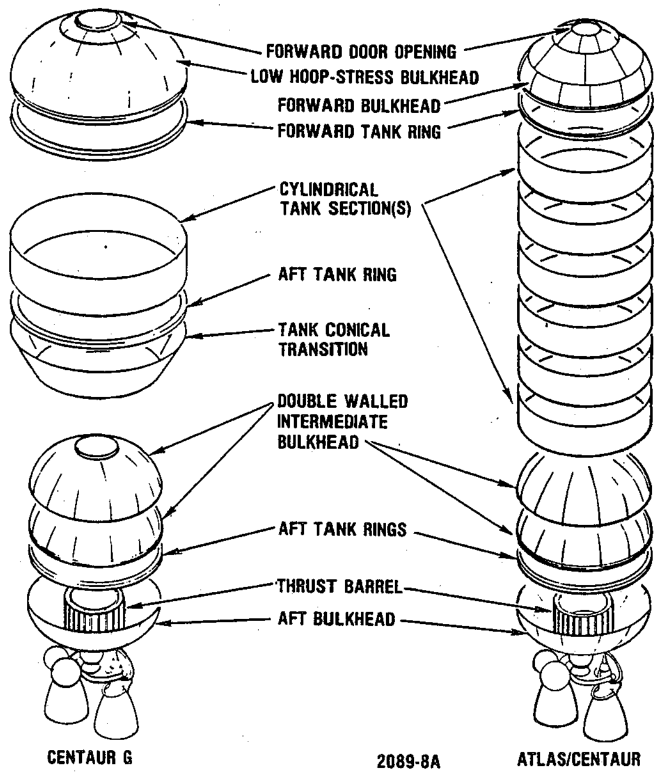


Figure 3-7. Centaur G and Atlas/Centaur Tanks.

Tensile, elongation, and weld joint fatigue tests are run on all tank raw stock and this procedure will be continued. Major structural member integrity is verified by test coupons from parent material. Tank weld samples are tested before, during, and after the machine welding operation. This existing procedure will be continued. All tank weld joints are 100% radiographically inspected. Leak testing is performed on all tank weld joints. All existing and proven Centaur Reliability and Quality Assurance requirements will continue to be imposed on the tank design and manufacturing.

The LO_2 tank is formed by two ellipsoidal bulkheads of 120-inch major diameter and 87.0-inch minor diameter; the configuration is the same as the Atlas/Centaur tank.

The LH_2 tank will consist of a 170-inch-diameter cylindrical section closed by a low hoop stress forward bulkhead and a 45-degree conical aft bulkhead that attaches to the LO_2 tank through a transition ring at its major diameter of 120 inches (Figure 3-8).

The 170-inch diameter for the LH_2 tank cylinder was selected to provide adequate thermal and dynamic clearance between the Centaur G and the STS Oribter payload envelope. Structural rings, insulation, and LH_2 vent duct space requirements were accounted for in selecting the tank diameter as shown in Figure 3-9.

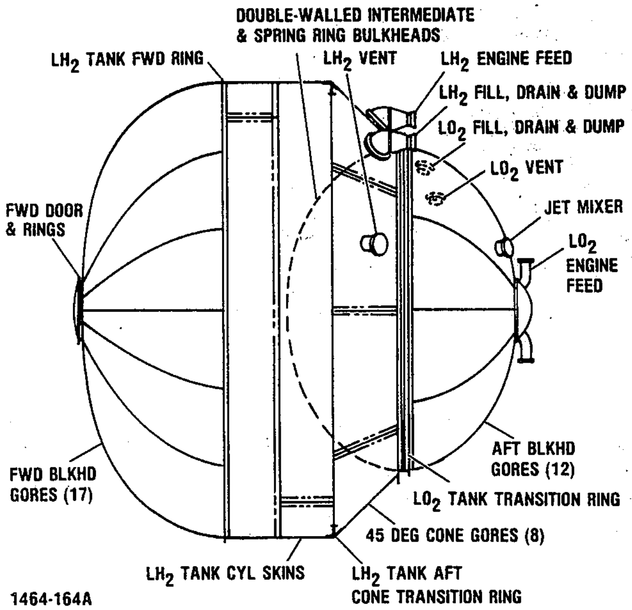


Figure 3-8. Centaur G Propellant Tank Configuration.

The tank volumes will be designed to provide total propellants of 29,638 pounds, including residuals, at a burn mixture ratio of 6.0 pounds (LO_2) to 1.0 pounds (LH_2). Tank skin gages will be based on internal pressures resulting from Centaur engine inlet pressure requirements; see Figures 3-10 through 3-13.

The LH_2 tank forward bulkhead consists of approximately 17 gore sections buttwelded to form a low-hoop-stress bulkhead plus a spherical bulkhead cap as shown in Figure 3-10. Except for the buttweld land areas, the gores will be chem-milled to reduce weight. At the forward end of the bulkhead, an access door will bolt to a door ring, which will be welded to the bulkhead. Welded to the inside of the door ring will be support structure for the tank zero G vent system, a level sensor, and instrumentation. Attachment brackets for various items, such as the zero G vent pressure lines, wiring, and insulation, will be welded to the external surface. Welded to the interior of the bulkhead is attachment bracketry for the pressurizing gas diffuser/dissipator and the LH_2 vent duct as shown in Figure 3-13.

The LH_2 tank cylindrical section will consist of two sections about 21 inches long and 170 inches in diameter. The two skins will be spotwelded, seamwelded, and stove-piped together using existing production techniques as shown in Figure 3-10. The forward skin will mate with the aft end of the forward bulkhead and will contain the stub adapter support ring. The aft skin will mate to the LH_2 tank aft cone transition as shown in Figure 3-12. Both joints will use existing Atlas/Centaur-type spot/seamweld joints. Support structure for items such as vent, pressure lines, purge lines, wiring, and insulation, will be welded to the external surface.

The LH_2 tank aft cone section will consist of approximately eight 45-degree conic skin gores buttwelded together and attached to transition rings at each end. The aft transition ring will also attach to the LO_2 tank. The aft cone LH_2 section will contain LH_2 propellant feed, fill and dump and vent standpipe outlets, as shown in Figure 3-8. Support structure for various items, such as the vent and pressure lines, wiring, and insulation, will be welded to the external surface.

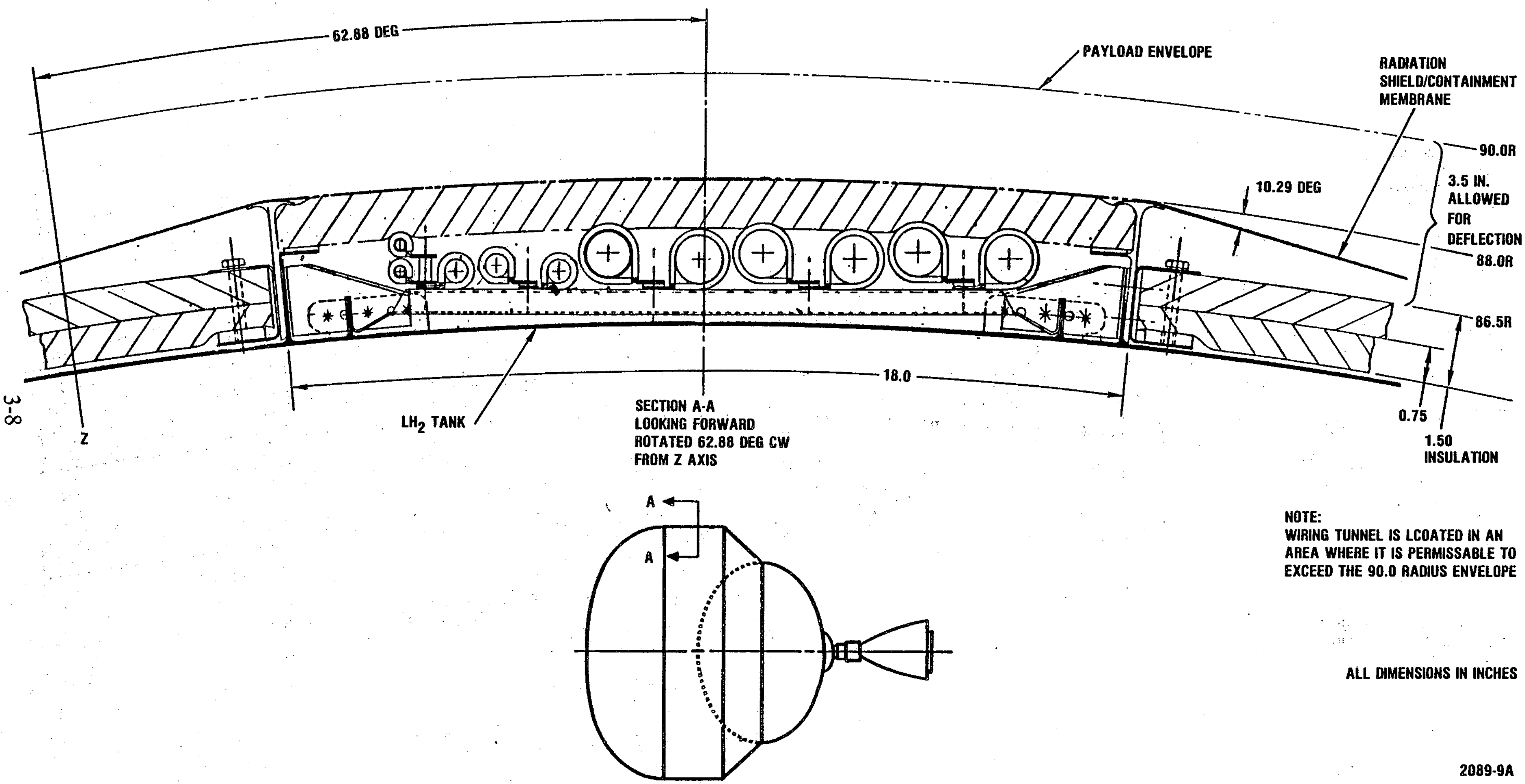
The LO_2 tank forward structural bulkhead will be identical to the existing Atlas/Centaur. It will consist of gore sections buttwelded together to form an ellipsoid and will attach to the aft bulkhead through a short transition skin section. The gore sections will be chem milled to reduce weight except in areas of the buttwelds. Refer to Figures 3-7 and 3-11. The structural bulkhead will be spot and seamwelded to the aft transition ring, providing the same sealing and structural integrity as in the existing Atlas/Centaur.

There is no LO_2 tank cylindrical section except that resulting from the transition ring joint.

The LO_2 tank forward spring ring/insulation bulkhead will be identical to the existing Atlas/Centaur assembly and will attach to the aft bulkhead as in the current Atlas/Centaur design. The insulation bulkhead will consist of gore sections buttwelded together to form an ellipsoid and will be buttwelded to the formed spring ring. The cavity between the forward structural bulkhead and insulation bulkhead will contain insulation identical to the existing Atlas/Centaur; see Figures 3-7 and 3-11.

The LO_2 tank aft bulkhead structure will be identical to that of existing Atlas/Centaur. It will consist of gore sections buttwelded together to form an ellipsoid as shown in Figure 3-8. Support structure will be welded to the bulkhead to support propellant lines, helium and hydrazine bottles, wiring, the engines, electrical boxes, radiation shields, jet mixer etc. Minor differences in these items will be required from the existing vehicle. Internally, the bulkhead will contain the LO_2 tank pressurizing bubbler ring, fill and drain duct, LO_2 stand pipe, P/U probe, and engine thrust barrel. The LO_2 propellant feed sump will be mounted on the aft end of the bulkhead (Figure 3-13).

The thrust barrel structure inside the LO_2 tank will be identical to the existing Atlas/Centaur



NOTE:
WIRING TUNNEL IS LCOATED IN AN AREA WHERE IT IS PERMISSABLE TO EXCEED THE 90.0 RADIUS ENVELOPE

ALL DIMENSIONS IN INCHES

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Figure 3-9. 170-Inch-Diameter Centaur G LH_2 Tank.

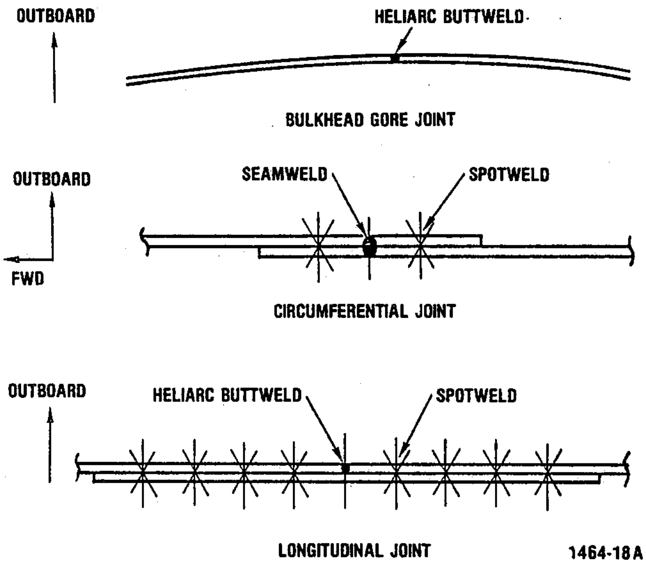

Figure 3-10. Typical Centaur G and Atlas/Centaur Tank Joints

structure, with the exception of some support structure details.

The thrust barrel is a 50-inch diameter, 15.5-inch high cylinder of skin-stringer construction. It reacts engine thrust loads and distributes them into the LO_2 tank aft bulkhead. The forward ring and thrust longerons are 2124 aluminum alloy; the skin and stringers are 2024 aluminum alloy. The cylinder attaches mechanically to the aft ring, which in turn is welded to the LO_2 tank aft bulkhead.

3.3.2.1.2 Centaur G Adapters — Three new vehicle adapters (equipment module, stub adapter, and aft adapter) are being designed for Centaur G. They are similar to existing Centaur adapters in form and function. General Dynamics makes extensive use of finite-element analysis (which has shown a very close correlation with test results) for sizing and designing these adapters.

Equipment Module — The equipment module is a 45-degree conical skin-stringer, aluminum alloy structure with a 170-inch-diameter base. It is 31 inches long and 108 inches in diameter at the forward end. Centaur equipment, chiefly avionics, are mounted on the conical surface. The module will include:

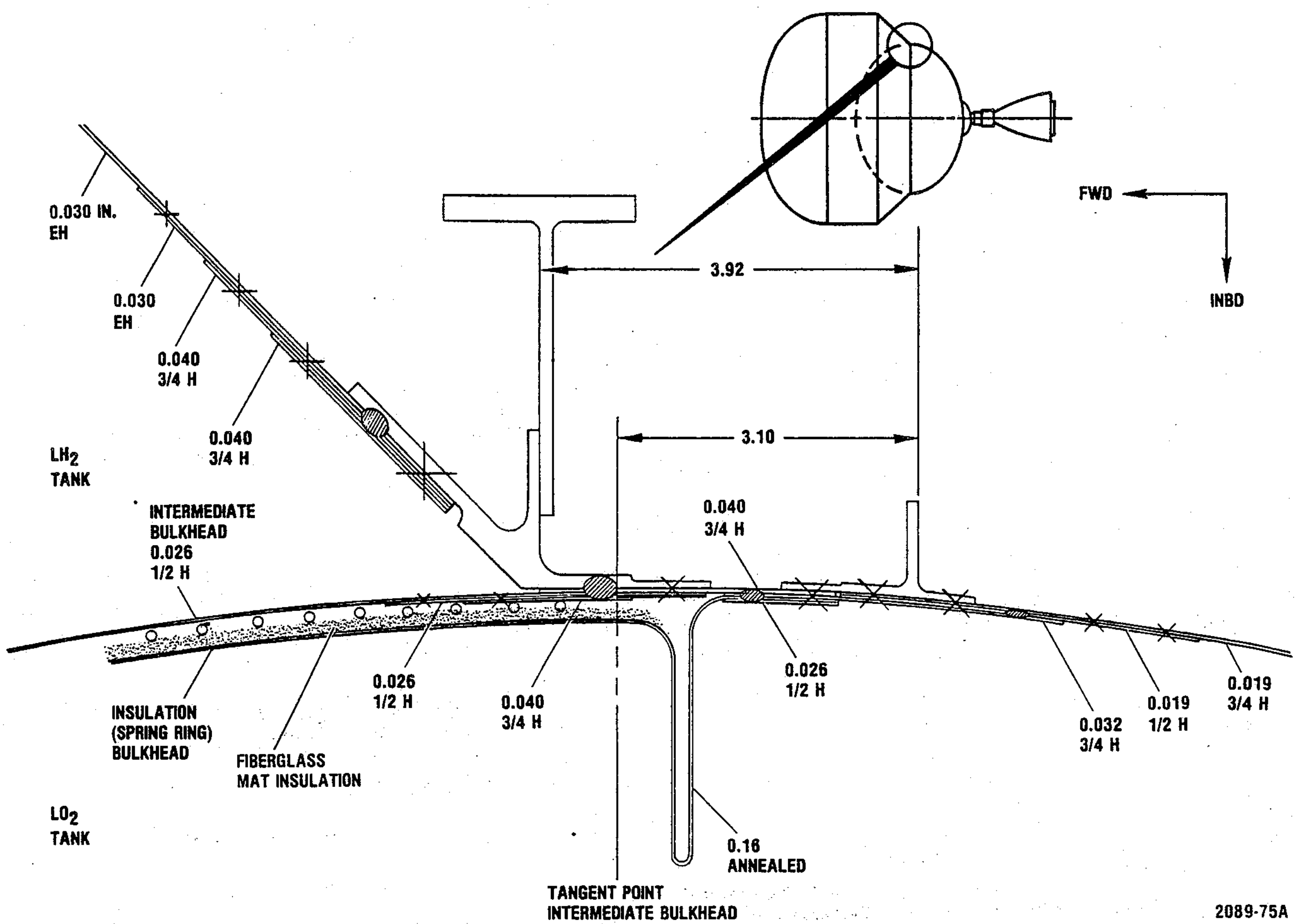

Figure 3-11. Centaur G 45-Degree LH_2 Cone-To-LO_2 Tank Transition Joint.

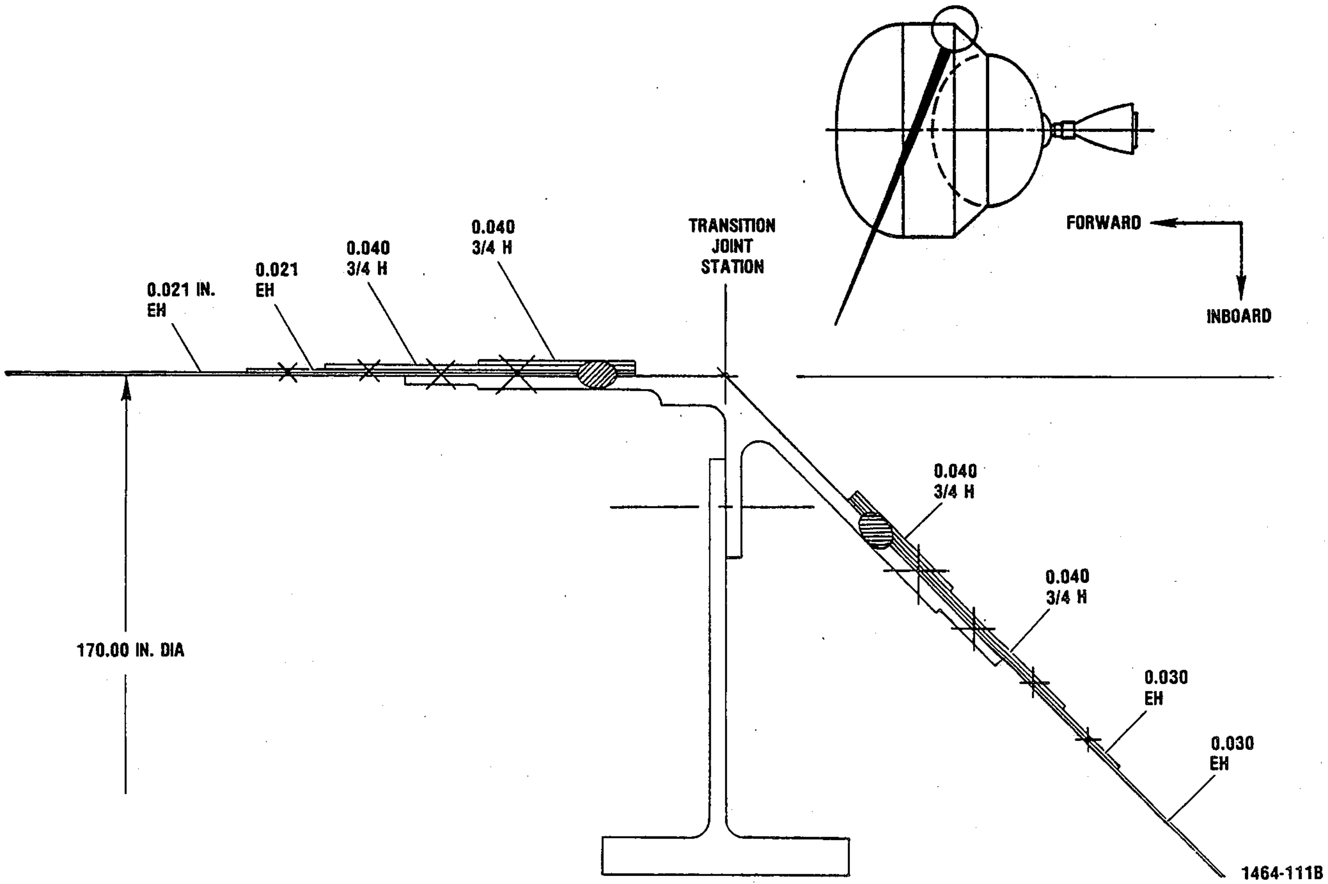

Figure 3-12. LH_2 Tank Cylinder-Aft Conic Transition Ring Joint.

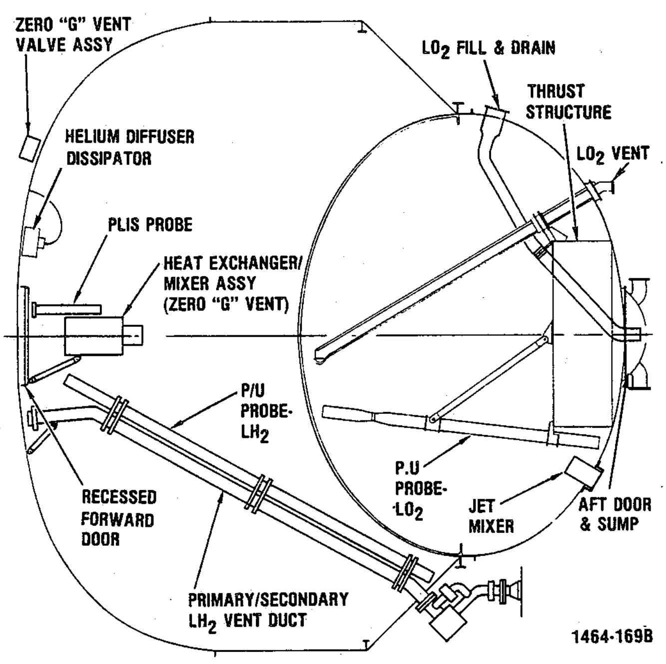

Figure 3-13. Centaur G Tank Internal Installations.

- Two deployable antennas that will be spring-deployed after Orbiter/Centaur separation.
- A stable mounting platform for the inertial reference unit and star scanner.
- An air-conditioning duct for ground cooling of equipment.
- A vent door that will open for Orbiter ascent and close for abort return, if required.
- A flexible diaphragm closing the forward end of the structure in order to isolate the forward bulkhead purge gas insulation compartment.

In addition, the equipment module includes a beam and truss support system that interfaces with the Orbiter payload support system. This support system will provide forward support for Centaur in the Orbiter (Figure 3-14).

The payload mission-peculiar adapters may interface with either the forward end of the equipment module or the 170-inch diameter aft ring of the equipment module.

Stub Adapter — The stub adapter is a 170-inch-diameter cylindrical titanium skin-stringer structure similar to that flown on Titan/Centaur; it is 25 inches long. The aft end of the adapter attaches to the Centaur LH_2 tank forward ring. The forward

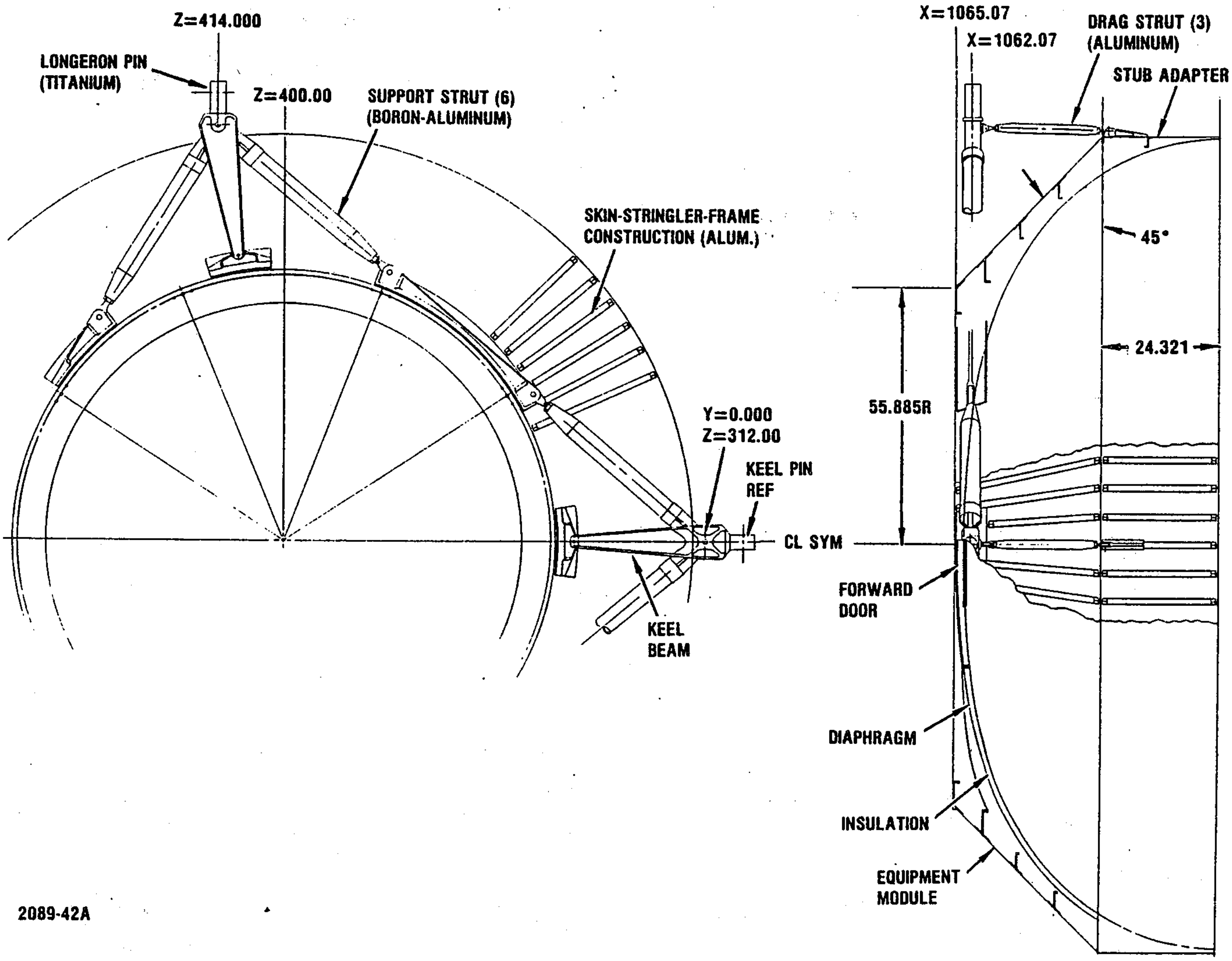

Figure 3-14. Equipment Module and Stub Adapter.

end of the adapter attaches to the equipment module.

The forward end of the LH_2 tank sidewall insulation system attaches to the stub adapter. Also, the forward support truss fore and aft drag struts attach to the stub adapter.

Aft Adapter — The aft adapter is a 10-foot-diameter, 11.2-inch-long, titanium, skin-stringer cylinder structure with attachment rings at each end. This adapter distributes CISS support loads into the Centaur tank and provides an interface for attaching the separation system (Figure 3-15).The forward ring bolts to the LO_2 tank aft ring and the aft ring attaches to the separation ring. The aft adapter is similar in design to the proven Atlas/Centaur interstage adapter. Common design features include attachment ring configuration and bolt pattern, cutout locations, and a stringer spacing of six degrees. The skin is of variable thickness. The adapter cutouts are designed for routing the LH_2 propellant feed duct, LO_2 vent duct, LO_2 fill/dump duct, and electrical wiring to the LO_2 tank aft bulkhead area, and for routing small tubing. Light, efficient support structure is mounted on the aft adapter for the vehicle separation springs, fluid disconnect panels, radiation shields, and wiring.

3.3.2.1.3 Separation System — The reliable Lockheed Super*Zip pyrotechnic separation system, which has become an industry standard, will separate Centaur from the Orbiter. Lockheed will provide a separation ring containing the Super*Zip system. It is a 10-foot-diameter, 5.50-inch-long, aluminum alloy cylinder section with attachment rings at each end. The separation ring simply bolts to the aft adapter and the CISS deployment adapter.

Super*Zip is a dependable, redundant, dual pyrotechnic system. When it fires, a spring system thrusts the Centaur from the CISS deployment adapter. Should the Super*Zip not separate, the Centaur and deployment adapter can safely be

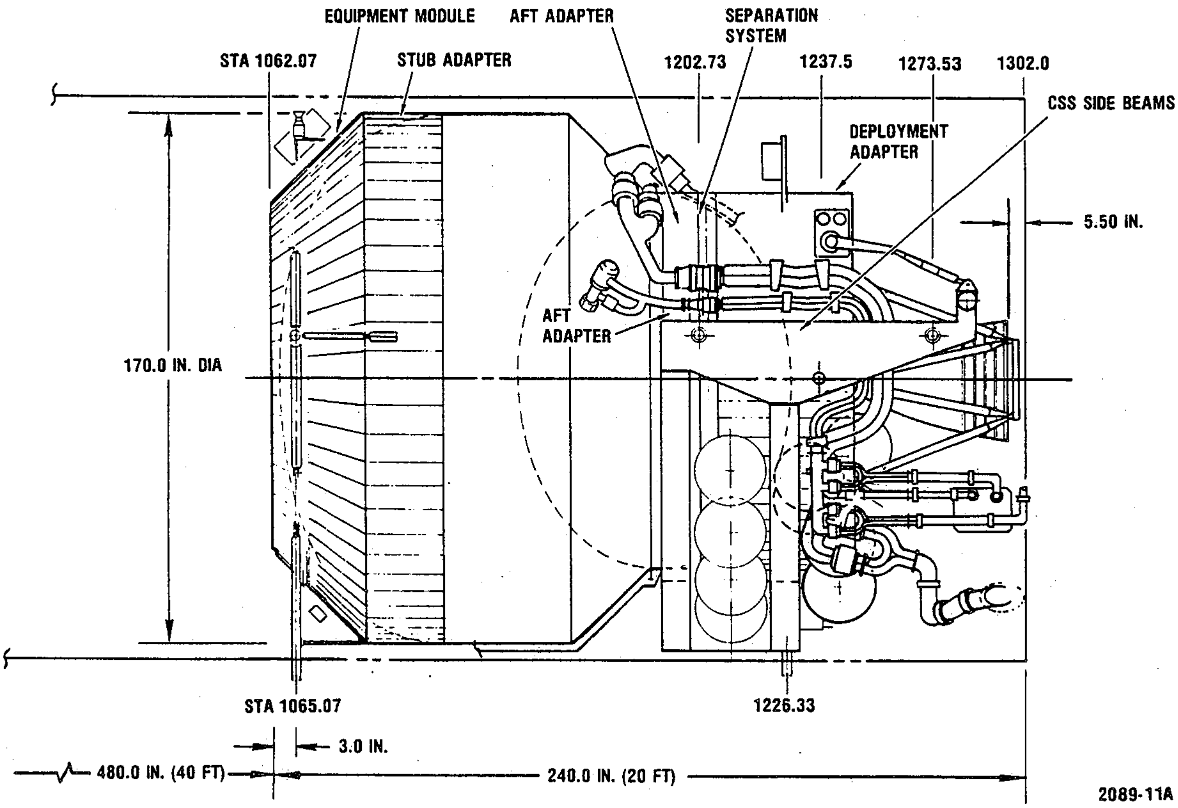

Figure 3-15. Centaur Adapters and CISS.

lowered back into the payload bay, thus providing a two-failure-tolerant system.

A Super*Zip system was used for shroud separation on Titan/Centaur.

3.3.2.1.4 Insulation System — The Centaur G insulation system is functionally identical to the Atlas/Centaur forward bulkhead system. All materials have been selected to meet STS contamination and safety requirements.

LH_2 Tank Insulation System — This system consists of two major portions (Figure 3-16): the forward bulkhead insulation, and the tank sidewall insulation. The forward bulkhead two-layer foam insulation blankets are installed on the hydrogen tank forward bulkhead and enclosed by the cylindrical stub adapter and the conical equipment module. The tank sidewall two-layer foam insulation blankets are attached at the outboard flange of the forward ring of the stub adapter and extend aft along the full length of the hydrogen tank sidewall cylindrical and conical section and are attached to the purge collector plenum.

Sidewall insulation blankets are enclosed by a radiation shield which is sealed to the stub adapter retaining channel at the forward ring flange and the purge plenum at the aft end which provides containment of the blanket helium purge gas. Holes are provided in the stub adapter to connect the forward bulkhead blanket compartment to the sidewall blanket compartment. Vent doors are provided in the equipment module and the purge plenum to vent the insulation blanket compartment during ascent. The insulation blanket compartments are purged with helium before tanking, to purge the GN_2 from the blanket. During tanking,

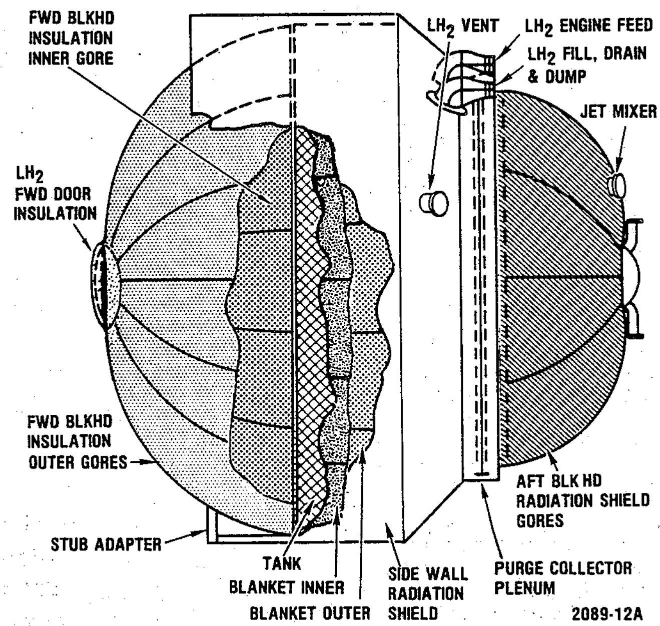

Figure 3-16. Centaur G Insulation.

this helium purge keeps out the payload bay GN_2 purge and maintains a positive ΔP across the radiation shield, to provide insulation. In the event of an abort, the purge is activated to preclude moisture and air from entering during the abort descent and after touchdown. The purge gas enters the forward blanket compartment through a purge tube in the equipment module and flows through the forward bulkhead blanket, through the holes in the stub adapter, aft along the sidewall blanket, and exits into the payload bay through two check valves.

Forward Bulkhead Insulation — The LH_2 tank forward bulkhead is protected/shielded by first a three-layer radiation shield and secondly by a two-layer foam blanket. The three-layer radiation shield has the same properties as the LH_2 sidewall radiation shield, except that the inboard layer shall also perforated (Figure 3-17). This shield is held in place by the same pins holding the foam gores in position.

The foam insulation blankets encompassing the bulkhead is enveloped by a single sheet of 1 mil double aluminized kapton. The insulation blankets shown in Figure 3-16 are installed as two separate blankets, each 3/4-inch thick and installed one over the other with the butt joints offset half the width of the gore, providing a total assembly thickness of 1-1/2 inches.

Each blanket is fabricated in 12 separate gores; they are fastened to each other with pin fasteners. A low-level helium purge is employed to maintain a prelaunch helium environment forward of the bulkhead as shown in Figure 3-18, and the effective thermal conductivity of the insulation approaches that of quiescent helium. However, early in-flight evacuation of the liberally vented insulation yields a system of three layer radiation shield for on orbit thermal control of the forward bulkhead.

LH_2 Tank Sidewall Insulation — The foam insulation design on the Centaur forward bulkhead is also used on the Centaur G LH_2 tank sidewall for pre-launch thermal control. As shown in Figure 3-17, a Kapton/glasscloth/Kapton laminate containment membrane maintains internal helium in the blanket during prelaunch operation. Predicted prelaunch heat flux through the LH_2 tank sidewall is approximately 140 Btu/hr-ft^2. Two radiation shields are positioned outboard of the helium-purged blanket. These laminated shields are liberally ventilated to achieve rapid in-flight radiation shielding of the LH_2 tank sidewall. This

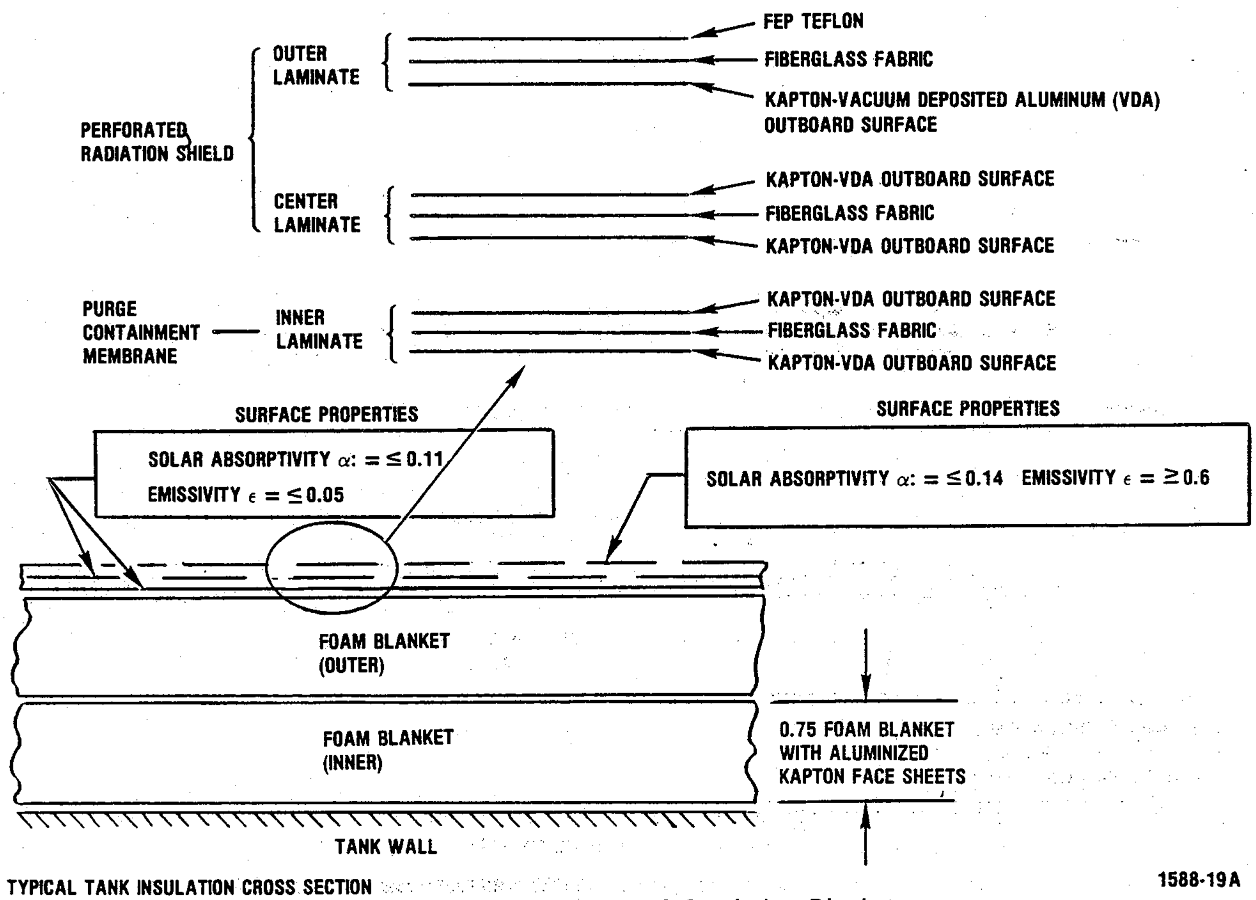

Figure 3-17. Centaur G Insulation Blankets.

system of radiation shields has been thoroughly tested and corroborated on Titan/Centaur missions. Table 3-3 contains a measured sidewall heating rate of 440 Btu/hr on Titan/Centaur-5, corresponding to a heat flux of only 0.88 Btu/hr-ft^2.

Purge and Vent — The insulation system is purged with helium gas introduced at ambient temperature and at 20 to 60 pounds per hour at the forward end of the equipment module. A dual-position vent door on the module opens to vent the compartment during ascent (Figure 3-18). Before riseoff, equipment module purge gas flows into the sidewall insulation at the forward end through holes in the stub adapter. The gas flows aft to an annular purge plenum and vents through relief devices and another dual-position vent door for ascent venting. The doors will close to permit blanket repressurization during an abort reentry sequence when the Centaur tank will contain postdump residual propellants.The restart of purge flow during reentry and the foam blanket rigidity prevents liquid air run off.

LH_2/LO_2 Tank Intermediate Bulkhead — The twin-skin vacuum bulkhead separating the two tanks has been employed successfully on all Centaur vehicles. As shown in Figure 3-11, the assembly contains a fiberglass mat insulation which is maintained in compression by the spring ring bulkhead and by LO_2 tank pressure. Cryo-pumping of the intervening volume following LH_2 tanking yields a low conductance of less than 0.045 Btu/hr-ft^2-R. Table 3-3 shows a typical measured heating rate through the intermediate bulkhead of 710 Btu/hr. This corresponds to an effective conductance of only 0.0393 Btu/hr-ft^2-R.

Table 3-3. Centaur G LH_2 Tank Heating Rates (Btu/hr).

LH_2 Tank Heating Item	TC-5	Centaur G		
	TC-5 6th Coast*	Coast to GEO*	LEO Aft Sun	GEO Aft Sun
Forward bulkhead	213	407	297	45
Stub Adapter	170	241	176	26
Sidewall	440	415	199	228
Wiring Tunnel	82	82	82	82
Feed System	142	85	85	85
Penetrations	223	223	223	223
Total External	1,270	1,453	1,062	689
Intermediate Bulkhead	710	710	710	710
LH_2 Grand Total	1,980	2,163	1,772	1,399

*Zero-g coast with thermal maneuver 1464-312A

LO_2 Tank Aft Bulkhead Radiation Shield — This shielding system includes an outer, semi-rigid fiberglass shield having an aluminized inner surface and a white (polyvinyl-fluoride) outer surface, and twin double-aluminized Kapton inner shields and an inner membrane shield. The system has been employed successfully on numerous Centaur flight vehicles. LO_2 tank aft bulkhead heat flux through the shielding system was measured at 1.0 to 2.0 Btu/hr-ft^2 on TC-5.

3.3.2.2 CENTAUR INTEGRATED SUPPORT SYSTEM — The CISS consists of a Centaur support structure, a deployment adapter, and the associated CISS electronics and fluid lines.

3.3.2.2.1 Centaur G Support Structure (CSS) — The CSS supports the Centaur vehicle and cantilevered

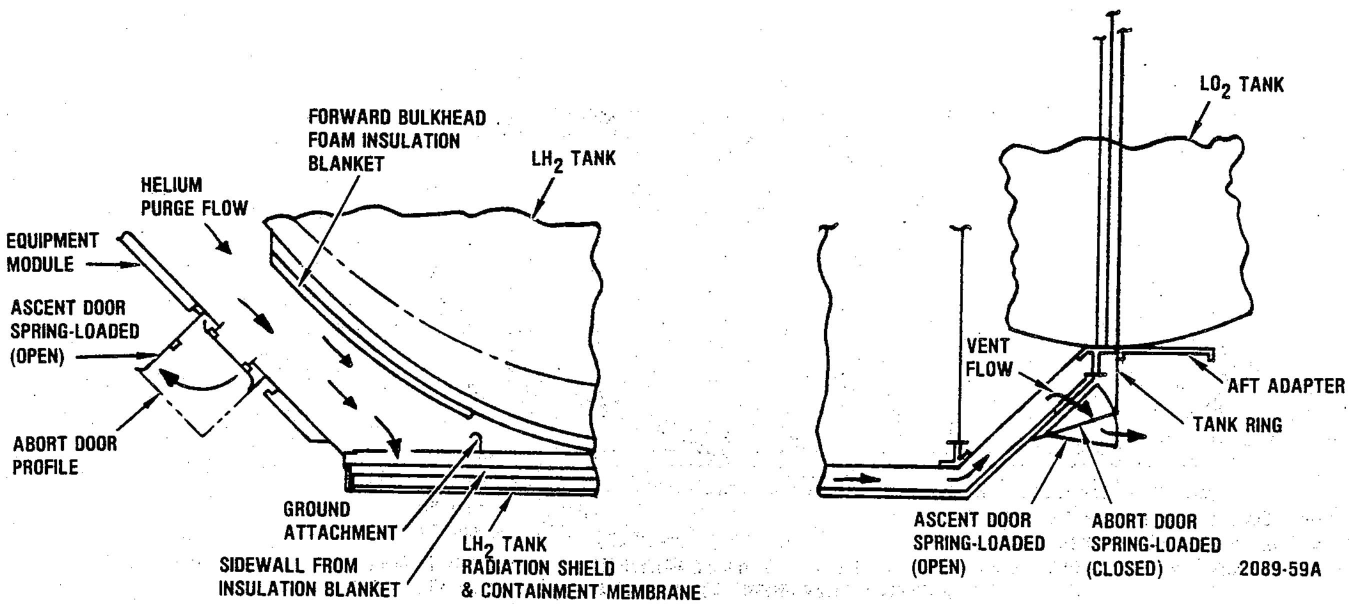

Figure 3-18. Centaur G Insulation Purge and Vent Systems.

payload within the Orbiter payload throughout the STS/Centaur mission and during ground handling operations. The CSS transfers all Centaur axial loads to the Orbiter through the pins at $X_O = 1202.73$ and shares the transfer of yaw loads with the equipment module through the keel pin at $X_O = 1226.33$. Pitch loads are reacted partly at the equipment module and the CSS pins at $X_O = 1202.73$ and 1273.53. The Centaur trunnion pin at $X_O = 1237.5$ allows the deployment adapter and Centaur to rotate before separation; see Figure 3-19.

The CSS structure (Figure 3-20) is aluminum with the exception of the interface pins. Basic construction is conventional aircraft box-beam type with bulkheads and skins. Major elements of the CSS are two side beams, two circular beams, and a six-inch-diameter tubular strut that spans the payload bay and connects the side beams. The two circular beams are conventional riveted, skin-

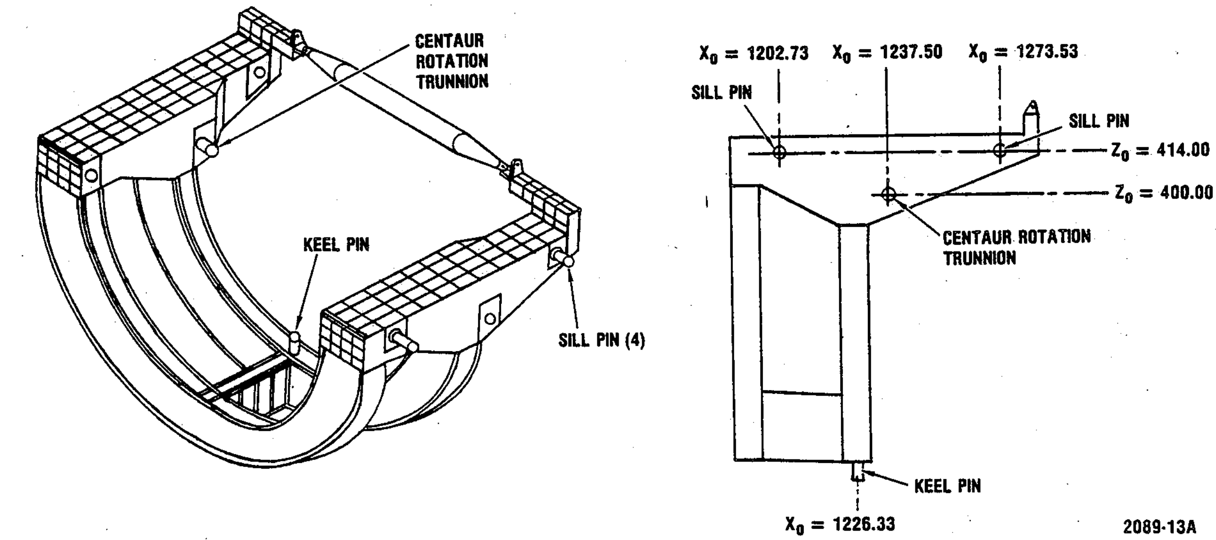

Figure 3-19. The Centaur G Support Structure.

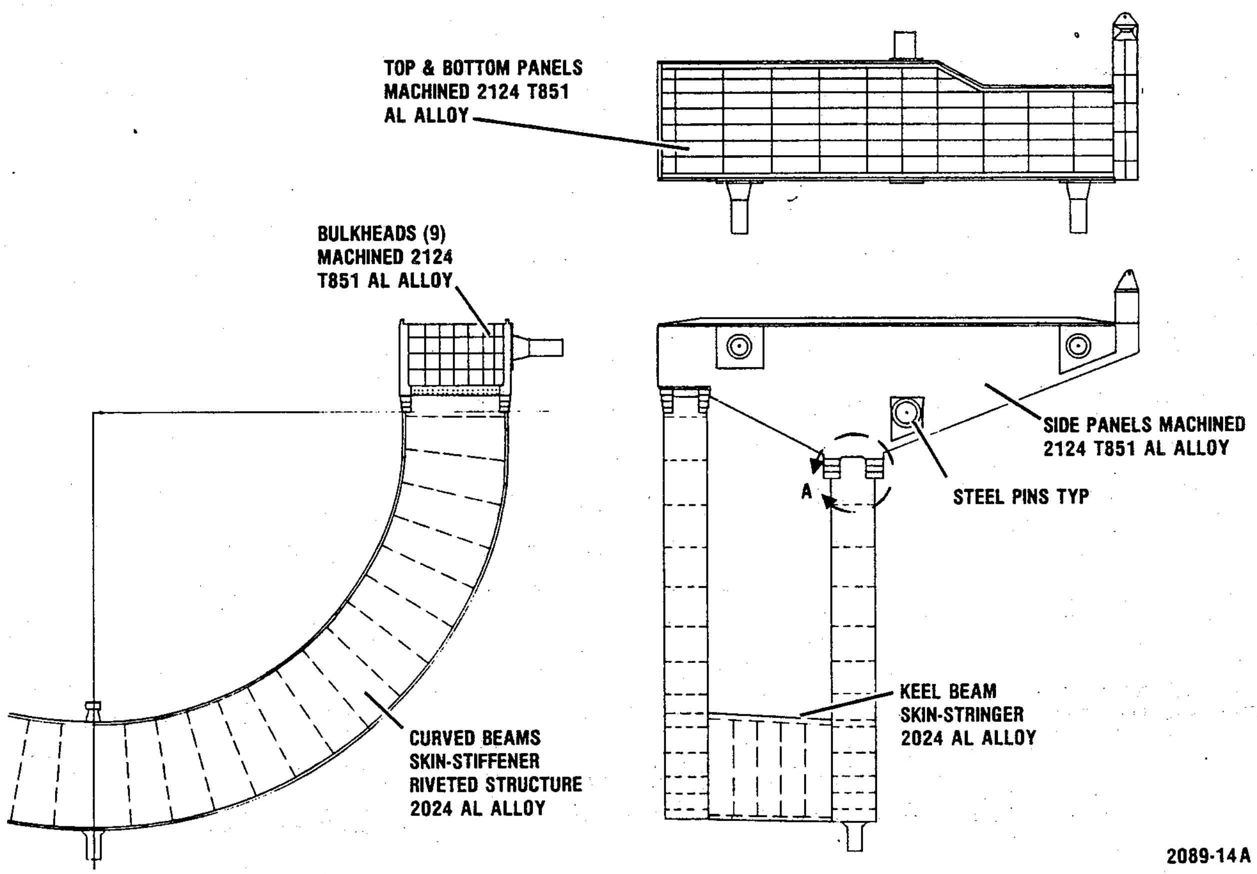

Figure 3-20. Centaur G Support Structure.

stringer construction (Figure 3-21). A riveted keel beam connects the two circular beams. The two side beams consist of large, integrally machined panels built around nine integrally machined bulkheads (Figures 3-20 and 3-22). The interface pins (Figure 3-23) are hollow for maximum weight savings.

Wherever possible, only high stress-corrosion-resistant materials are used. All structural components are designed to provide ultimate factors of safety equal to or greater than 1.40 for all mission design phases. Components are designed to the limit load factor specified in JSC 07700, Volume XIV. The CSS has been analyzed in considerable depth with detailed finite-element models. Optimization techniques developed during our Orbiter mid-fuselage design have been used extensively in the design of the structure.

3.3.2.2.2 Centaur G Deployment Adapter — The Centaur G deployment adapter (Figure 3-24) interfaces with the vehicle through the Super*Zip separation ring. The adapter effectively transfers Centaur loads to the Centaur support structure during flight, supports the rotation mechanism, and spring thrust system. The basic structure of the 10-foot-diameter, 44-inch-high adapter is conventional aluminum skin-stringer-frame. It has four

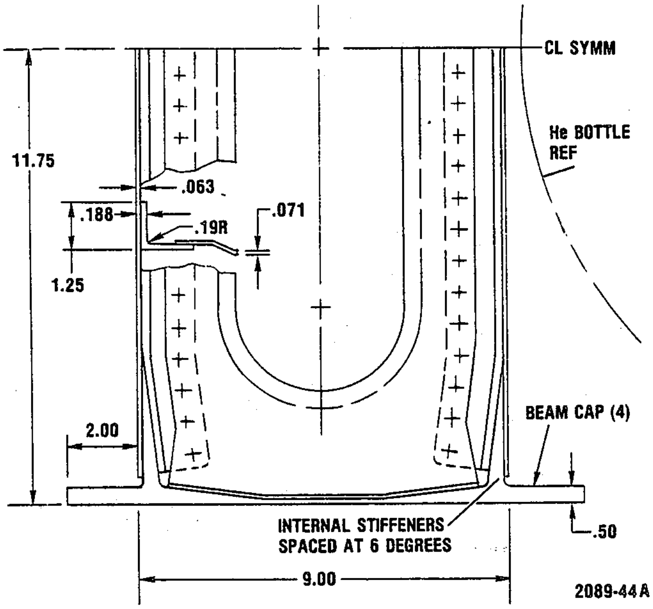

Figure 3-21. CSS Circular Beam Cross-Sections.

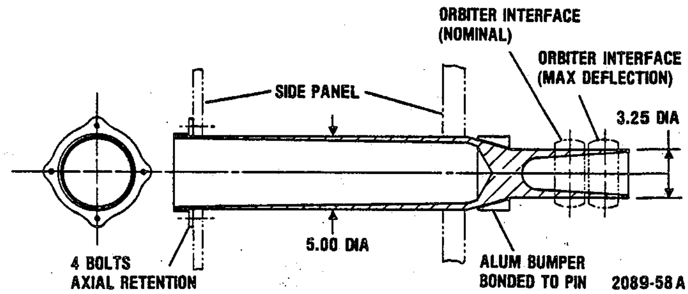

Figure 3-23. Steel Interface Pins.

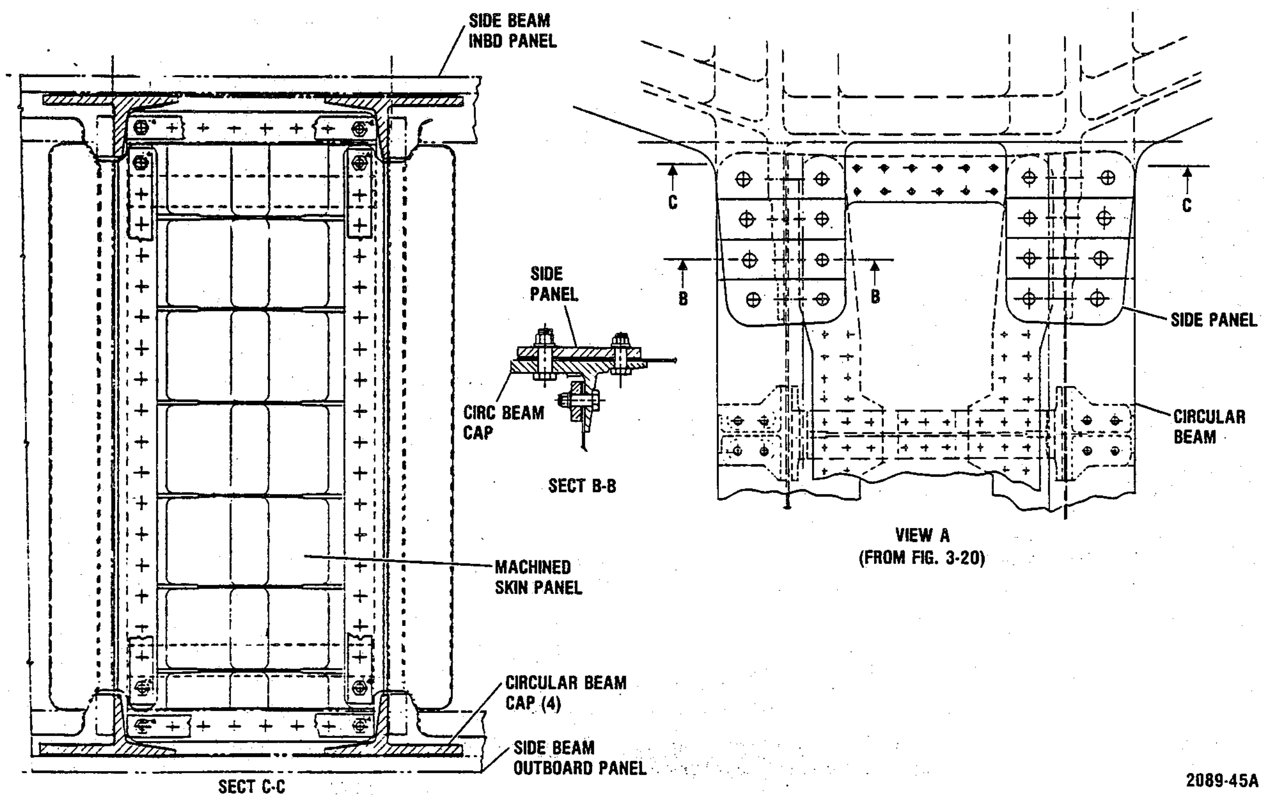

Figure 3-22. Circular Beam-Side Beam.

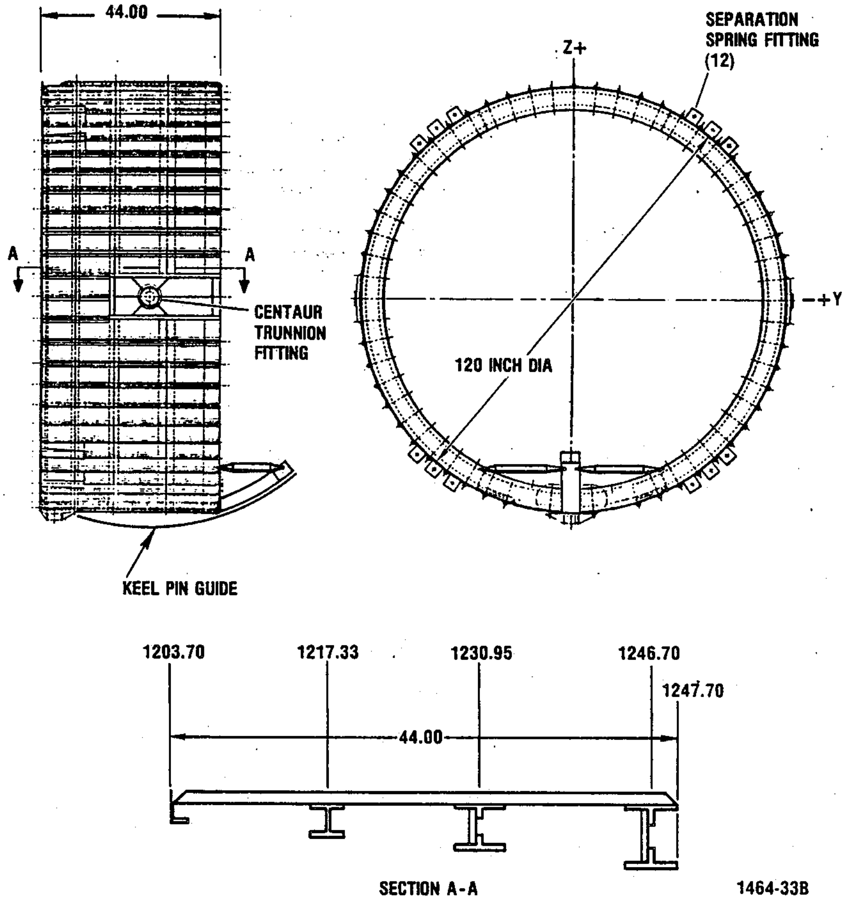

Figure 3-24. Centaur G Deployment Adapter.

rings; the two forward rings are machined, and two aft rings are web, cap, and stiffener assemblies. The skin thickness is variable with stringers spaced at six degrees.

The adapter rotates about the CSS trunnion support pins during deployment. The machined aluminum fittings that interface with these pins also transfer Centaur vertical and axial loads during flight. A semicircular channel on the adapter interfaces with the aft lower keel guide pin on the CSS to react lateral loads during flight and deployment.

The deployment adapter supports the two fluid disconnect panels, the electrical disconnects, Centaur engine support structure, numerous valve panels, and deployment actuator fittings.

3.3.2.2.3 Centaur G Engine Support Structure — The engine support structure (Figure 3-25) is a lightweight boron-aluminum tube truss arrangement that supports the Centaur engines cantilevered from the aft bulkhead and aids in load redistribution by the deployment adapter. The truss mounts on the aft end of the deployment adapter. The aft end of the truss is an extruded aluminum support frame that provides for attachment of two engine supports. These support cones slip inside the engine bells and support them through nonmetallic bearing pads and a sealing ring. Centaur forward motion during deployment will separate this passive support system.

3.3.2.2.4 Centaur G Spring Thrust System — The Centaur G spring thrust system consists of 12 spring-loaded push-rods on the deployment adapter that bear against reaction gussets on the aft adapter (Figure 3-26). The springs provide the thrust to separate Centaur from the Orbiter at a Centaur-to-Orbiter separation velocity of one foot per second.

3.3.2.2.5 Centaur G Equipment Mounting Provisions — Several subsystems have mounting provisions on the deployment adapter. The avionics packages are conveniently mounted on the accessible upper side of the adapter on a strut-supported mounting shelf (Figure 3-27). Other systems mounted on the deployment adapter and aft adapter are the fluids (lines and valves), electrical (wiring), insulation (radiation shields), and gas conditioning (lines) systems.

The CSS provides mountings for 12 helium bottles. The bottle support structure is a thin-walled, 22-inch-diameter tubular support with upper and lower rings and adjustable trunnion attach-

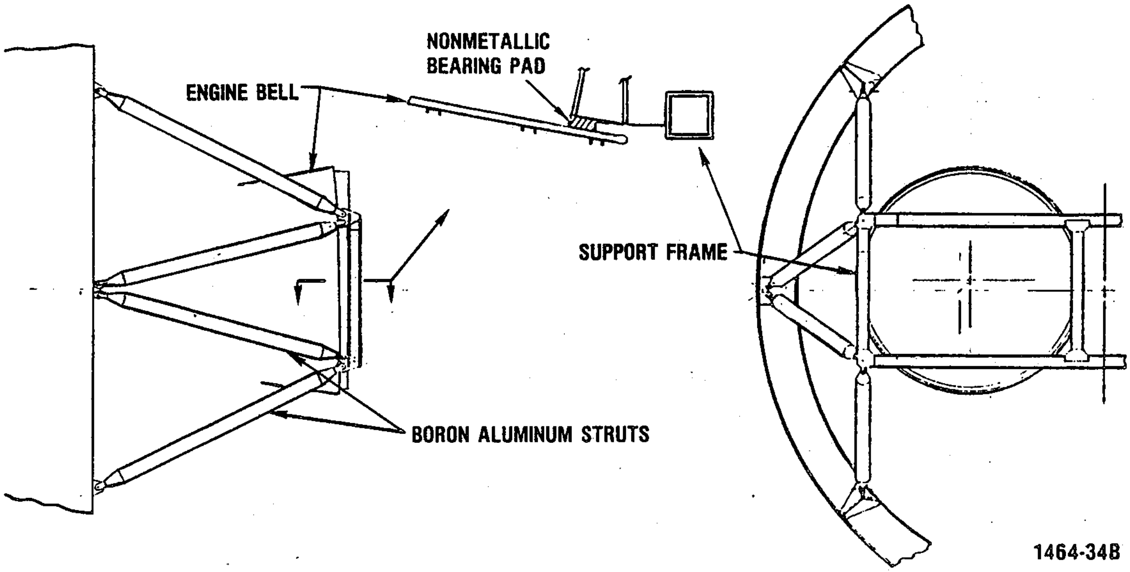

Figure 3-25. Centaur G Main Engine Support Structure.

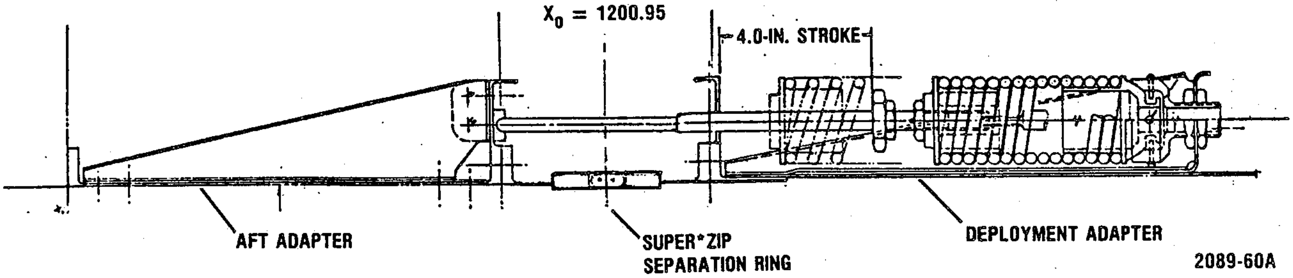

Figure 3-26. Centaur G Separation System.

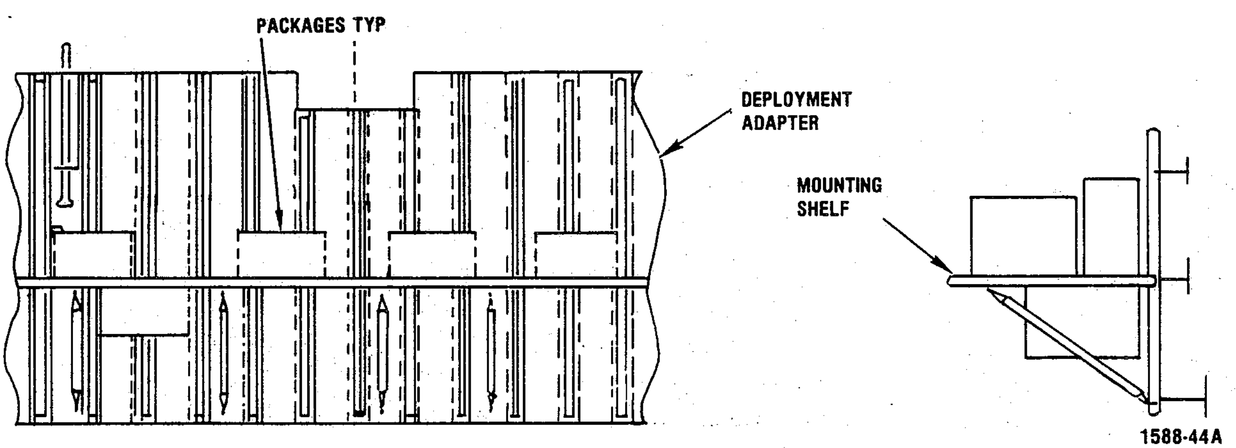

Figure 3-27. Deployment Adapter Shelf.

ment fittings (Figure 3-28). The CSS also supports fluid lines, the deployment drive system, and electrical packages.

3.3.2.2.6 Centaur G Gas-Conditioning Duct (Aft End) — A six-inch-diameter duct extends forward from the CSS (Figure 3-29) and butts with a new Orbiter

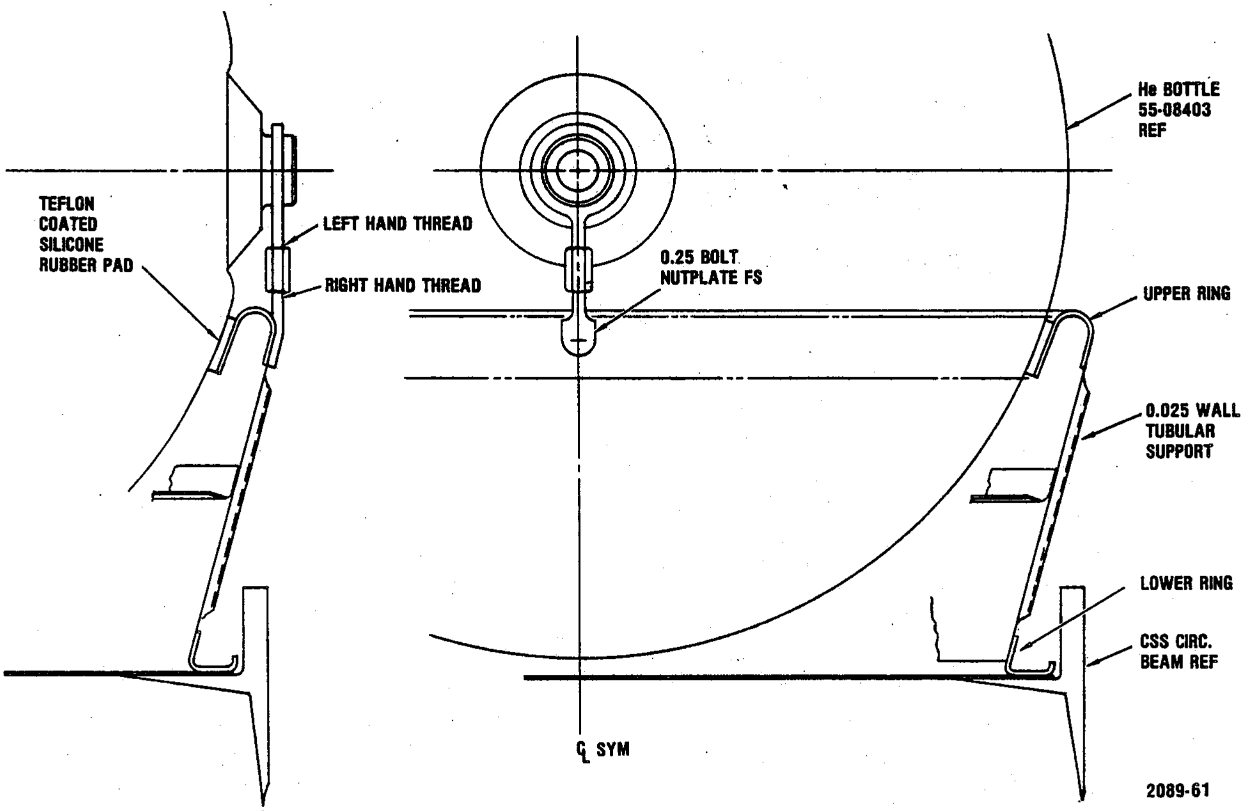

Figure 3-28. GHE Bottle Support Structure.

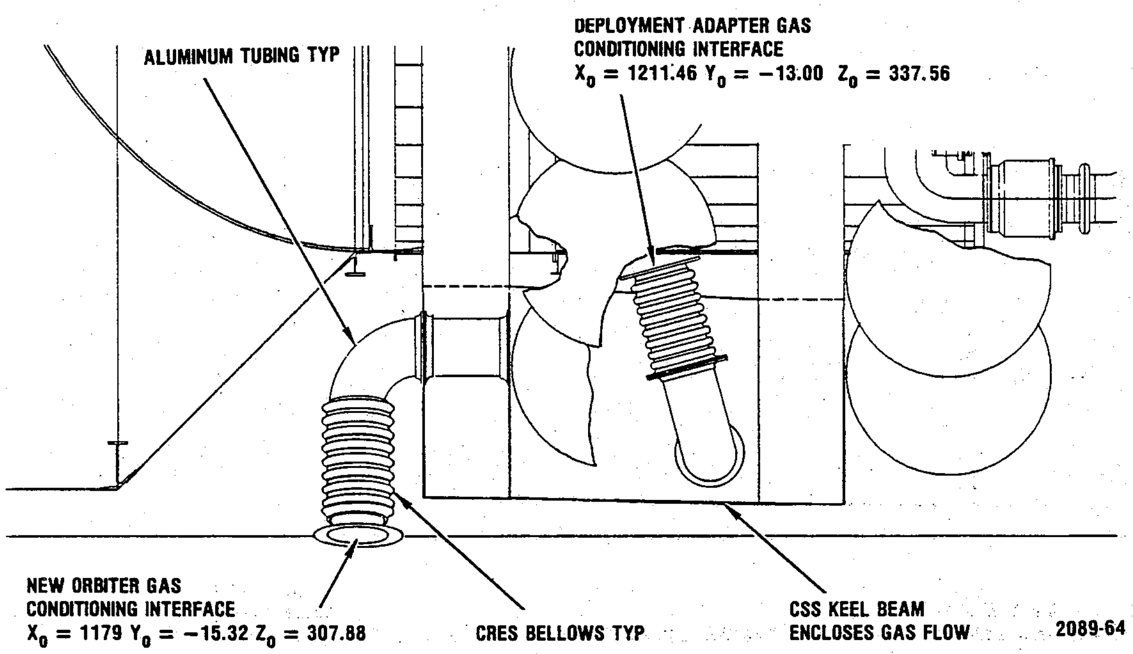

Figure 3-29. Centaur G Airconditioning System Interface.

interface at X_O = 1179 through a compressed bellows. The gas is routed through the CSS keel beam and interfaces with the deployment adapter through a rise-off bellows disconnect.

3.3.2.2.7 Orbiter Interfaces with Centaur G — Centaur and Centaur support structure will be contained within the 15-foot-diameter payload thermal and dynamic envelope throughout all operational phases. CSS attachment fittings will extend beyond this envelope at five locations and Centaur attachment fittings will extend beyond this envelope at three locations to mate with the Orbiter attachment fittings, which will be outside of the envelope.

CSS Interface — Two aft retention pins at the Orbiter sill longeron at $X_O = 1273.53$ share the aft pitch load. Two forward retention pins at $X_O = 1202.73$ share the vertical load with the aft pins, and react all axial loads from the Centaur with its payload. The Orbiter latches for these four pins are of the passive type. The two latches at $X_O = 1202.73$ are slightly modified to provide an adjustment capability to center the forward end of the Centaur vehicle during installation in the Orbiter (Figure 3-30). The keel pin at $X_O = 1226.33$ will react a portion of the yaw load.

GN_2 conditioning ducts, with bellowed ends to accommodate relative motion, interface with the Orbiter; Figure 3-31 illustrates this interface.

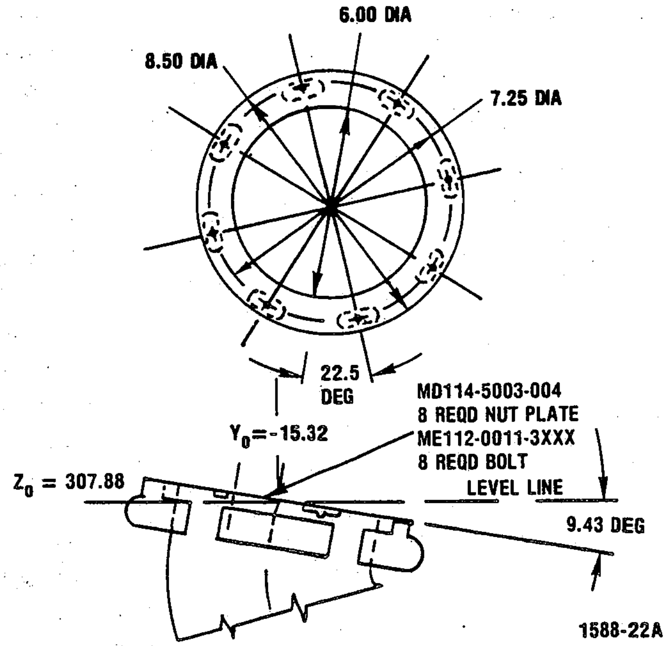

Figure 3-31. Orbiter GN_2 Conditioning Interfaces.

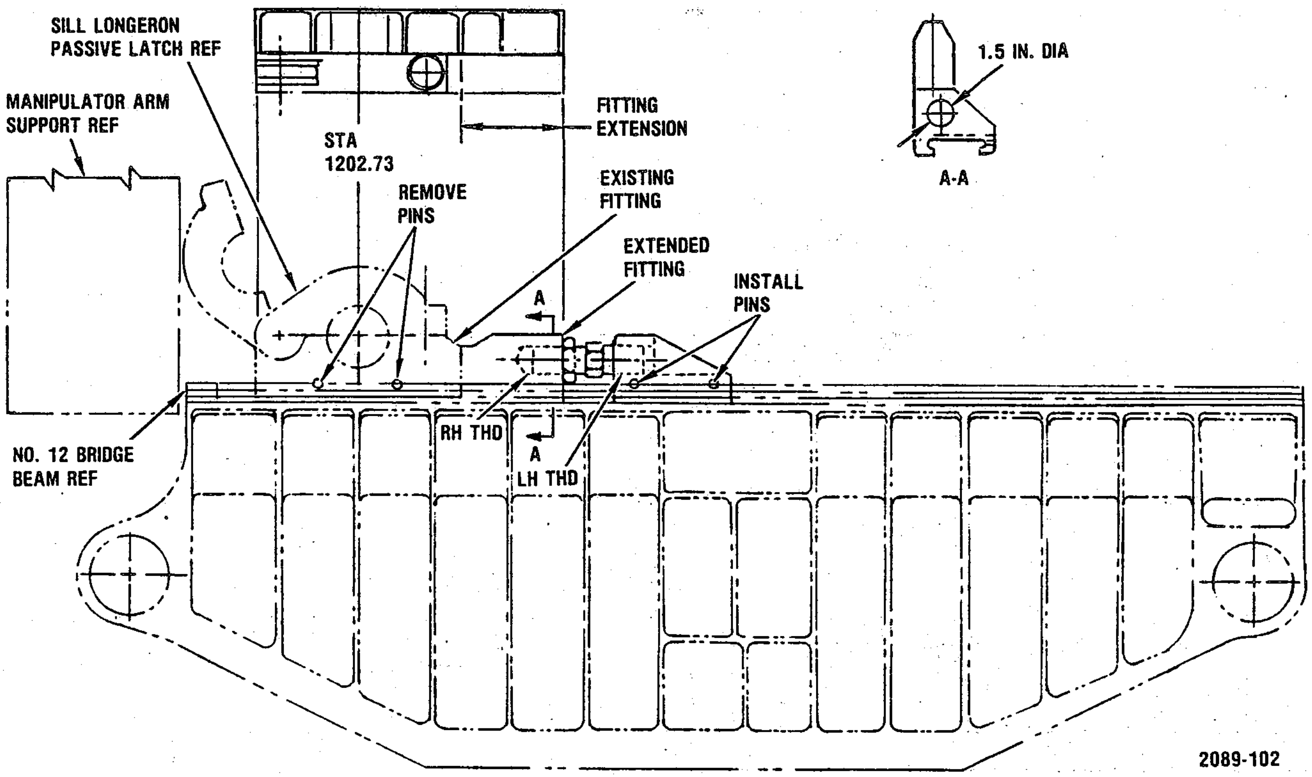

Figure 3-30. Adjustable Primary Longeron Fitting Elements.

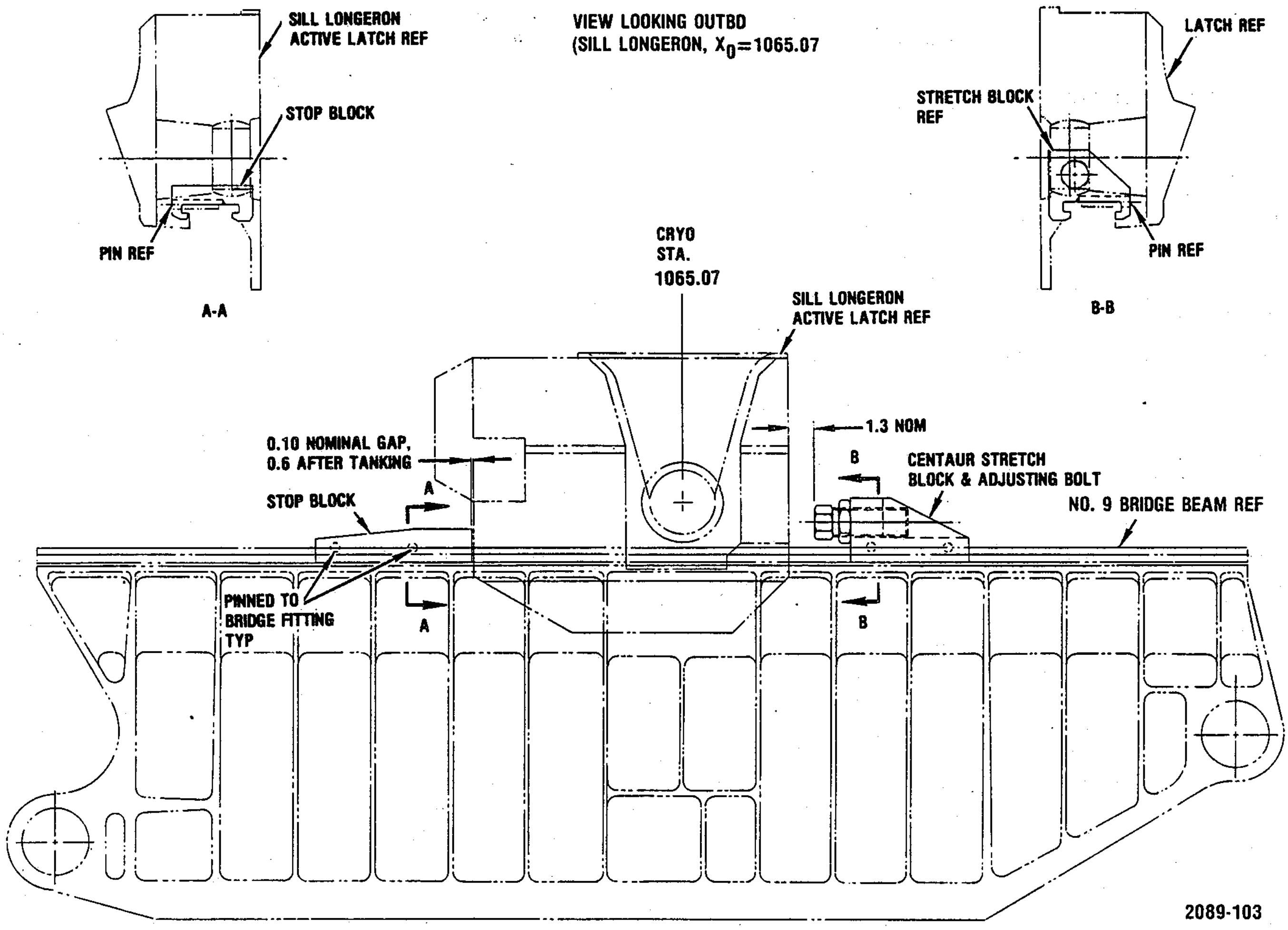

Figure 3-32. Active Sill Latch Stop and Stretch Fittings.

Equipment Module Interface — The two retention pins on the Centaur equipment module at the Orbiter sill longeron share the pitch load with the CSS pins. They are located at $X_O = 1065.07$ and interface with Orbiter active attach fittings for deployable payloads. The bridge beams for these latches are modified slightly to add latch stops for Centaur/spacecraft vehicle support should it be necessary to depressurize the tank (Figure 3-32). The keel pin on the Centaur equipment module at $X_O = 1065.07$ shares the yaw load with the CSS keel pin. This pin interfaces with an active keel fitting on the Orbiter. The bridge beam for this latch is modified to add a latch stop to act with the longeron latch stops in case the tank is depressurized (Figure 3-33).

3.3.3 MECHANISMS — The Centaur G mechanical systems (Figure 3-34) consists of an identical primary and backup deployment adapter rotation system. These systems meet the intent of the two-failure-tolerant requirements without the use of EVA. Both the primary and backup system are tolerant to single failures and either can rotate the deployment adapter under maximum loading conditions.

The deployment adapter primary rotation system shown in Figure 3-35 consists of a deployment-adapter-mounted power drive unit, a clutch, a crank, and a link connecting the crank to the Centaur support structure. Counter-clockwise rotation of the crank causes the deployment adapter to rotate clockwise about the trunnion and pivot the Centaur/ spacecraft out of the payload bay.

To start rotation, the primary rotation system clutch is engaged, the Orbiter forward keel and sill latches are released and electrical power from two

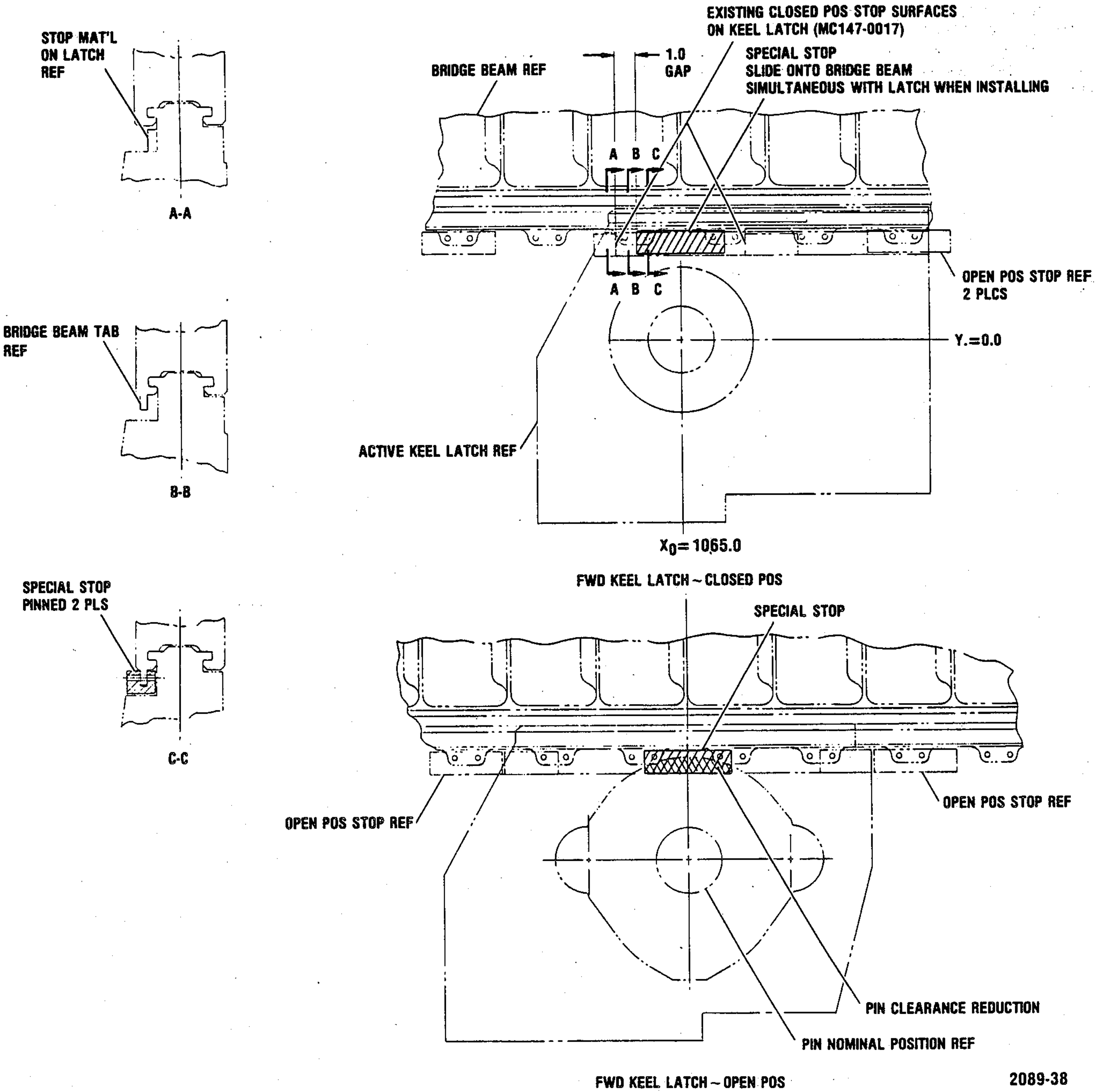

Figure 3-33. Active Keel Latch Stop.

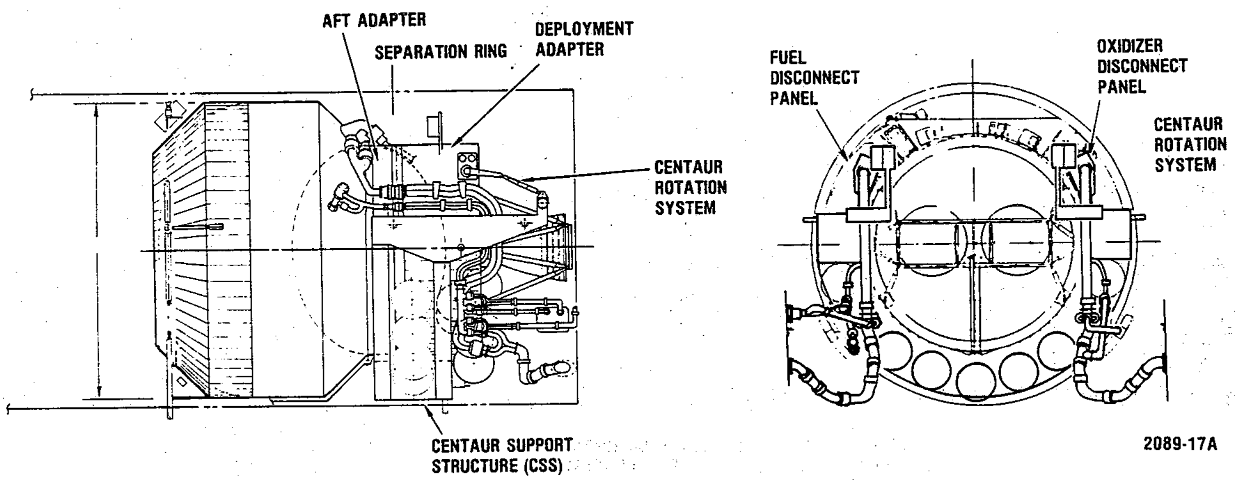

Figure 3-34. Centaur G Mechanisms.

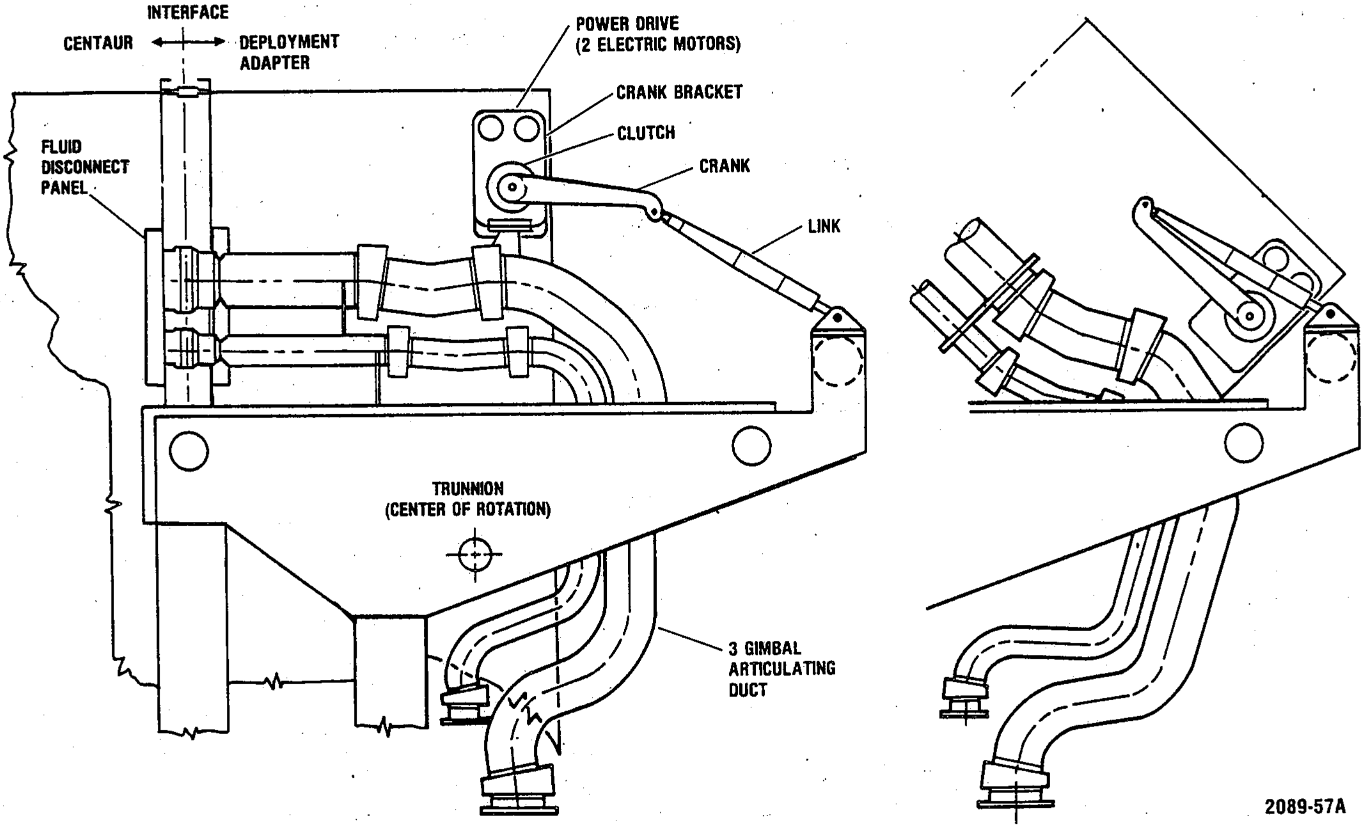

Figure 3-35. Centaur G Deployment Adapter Rotation System.

different Orbiter 400 Hz, 115 volt, three-phase buses is applied to the two drive unit motors (see Figure 3-36). Both brakes release, both motor clutches engage, and torque is transmitted and multiplied via the differential, planetary gear train and output clutch to the crank. This design provides single-motor failure tolerant operation. If one motor should fail to operate, its brake keeps it from turning and permits the remaining motor to drive the load at half normal speed. The double-gear reduction ratio, that occurs when one side of the differential is locked, doubles the output torque of the single driving motor and results in full torque delivered to the load.

With both motors operating, the deployment adapter rotates 45 degrees in approximately five minutes. Once rotated, redundant limit switches signal the controller to remove power from the drive unit, causing the brake to set and the motors to stop. The deployment adapter is held in the rotated position by the deenergized drive unit brakes and requires no separate latch.

Following Centaur deployment, the payload bay doors may be closed with the deployment adapter in any position between 0 and 45 degrees.

Should deployment be aborted, the Centaur is rotated back to the 0-degree position by reversing the drive unit. Redundant ready-to-latch limit switch signals, from the Orbiter sill latches (not shown), are used to stop the rotation-system power drive unit. The Orbiter latches are then relatched and propellants are dumped for reentry and landing.

The backup rotation system is identical to the primary. The backup system is mounted symmetrically on the opposite side of the deployment adapter.

During normal primary system operation, the crank of the backup system is disconnected from its drive unit by the disengaged clutch and the linkage merely follows the rotation. Should both primary motors fail, the crankshaft clutch on the backup system is automatically engaged and the primary clutch disengaged. Rotation then continues in either direction using the backup power drive. Manual engagement/disengagement capability of the output clutch will be provided for ground checkout but is not required to be two-failure tolerant.

3.3.4 FLUID SYSTEMS — The Centaur G vehicle fluid systems, consists of hydraulic, pneumatic, main propulsion/propellant supply, hydrazine, reaction control, vent, and fill/dump.

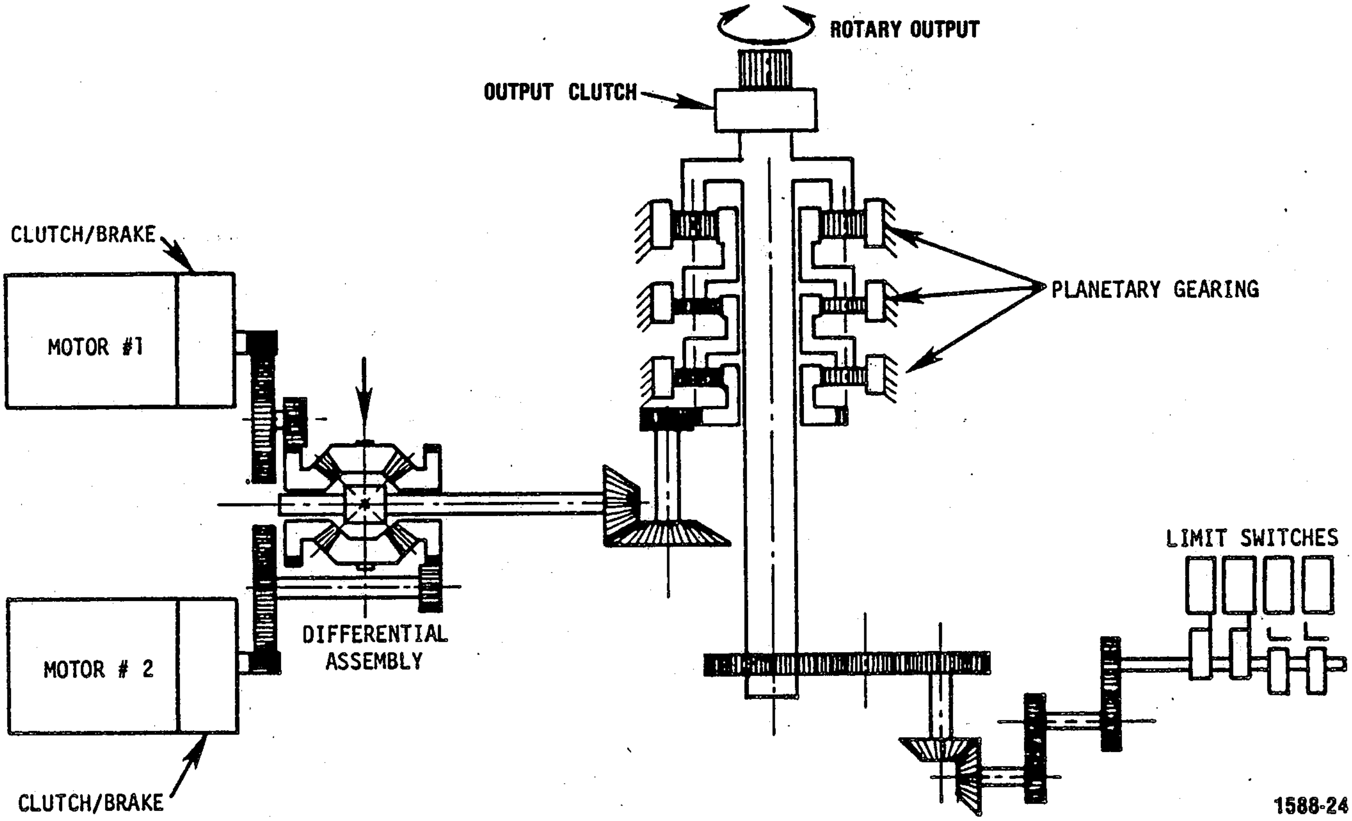

Figure 3-36. Rotation System Schematic.

3.3.4.1 Centaur Vehicle Fluid Systems

3.3.4.1.1 Hydraulic System — The Centaur systems consist of identical independent systems for each main engine, as shown in Figure 3-37. Each system supplies the hydraulic power for the two closed-loop, servo-controlled engine gimbal actuators that provide thrust vector control. Major assemblies of each hydraulic system are the power package assembly, containing an engine-driven main pump and an electric-motor-driven recirculation pump; and two servo cylinder assemblies that react in accordance with guidance and flight control system commands.

The hydraulic system is inactive in the payload bay except for operation of the low-pressure recirculation motor during liftoff and abort landing and intermittent operation on-orbit for thermal conditioning. Hydraulic system fluid is MIL-H-5606. A helium purge of the electric recirculation pump motors provides explosion-proofing.

3.3.4.1.2 Pneumatic Systems — The pneumatics system consist of the propellant tank pressurization system, pneumatically actuated valve control system, purge systems, helium supply, and the intermediate bulkhead relief system (Figure 3-38). These systems are all discussed in the following sections. Note that they are interconnected and function as a single system, except for the bulkhead relief system, which is completely autonomous.

Pressurization System (Figure 3-38) — The pressurization system consists of solenoid valves, tubing, and associated components for pressurizing the propellant tanks, using either the 12 valves located on Centaur or via CISS valves. During the Centaur mission, a parallel set of two series solenoids for each tank are cycled upon command from the Centaur digital computer unit (DCU) to provide helium pressurant control before engine starts and also for the LO_2 tank during engine burns.

An additional parallel set of two series solenoid valves and bypass orifice are used to control the LH_2 tank pressure during engine burns by using gaseous hydrogen bleed from the main engines. The DCU determines the respective propellant tank pressures by monitoring outputs from three redundant transducers in each tank. Preprogrammed logic defines the desired pressure levels and sequences throughout the mission. These propellant tank pressurization techniques have been demonstrated through testing, and have been thoroughly analyzed for all configurations of the Atlas/Centaur.

Before deploying the Centaur from the Orbiter, the quad set of helium pressurization

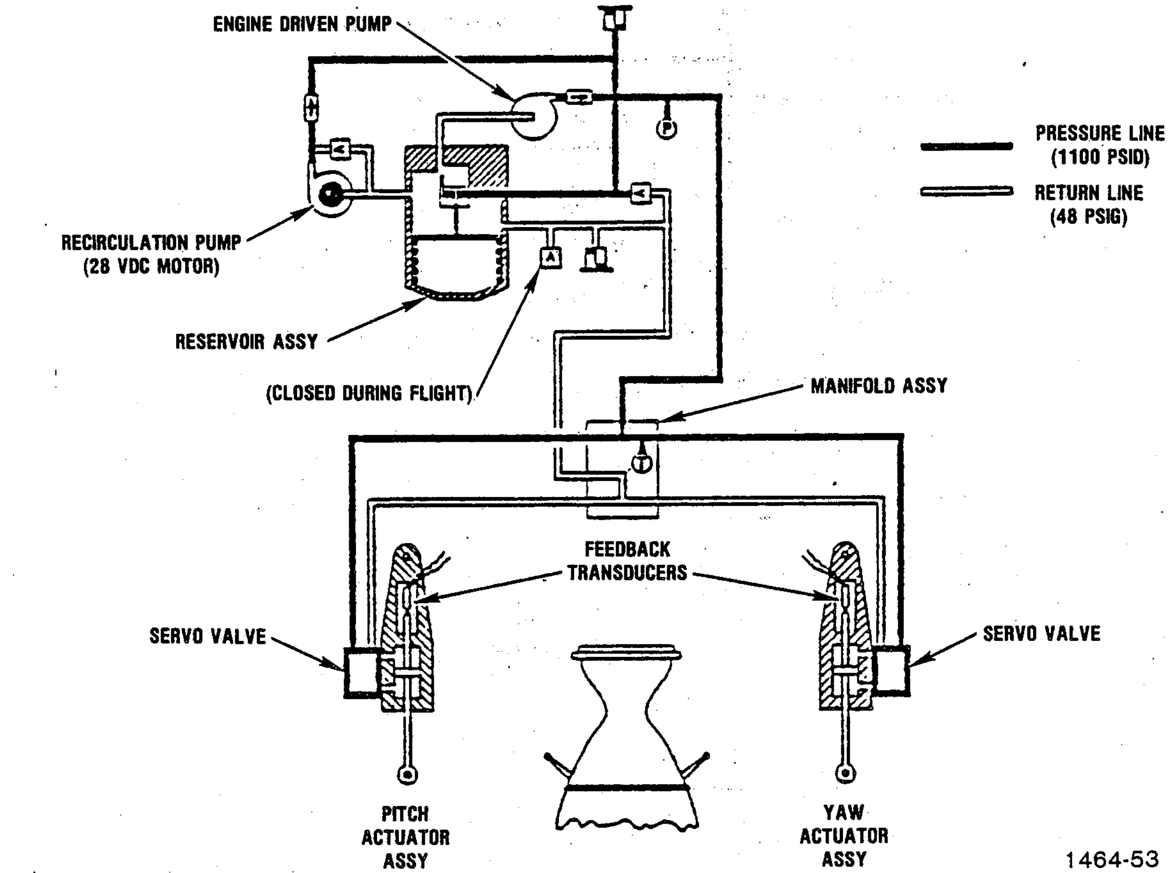

Figure 3-37. Hydraulic System.

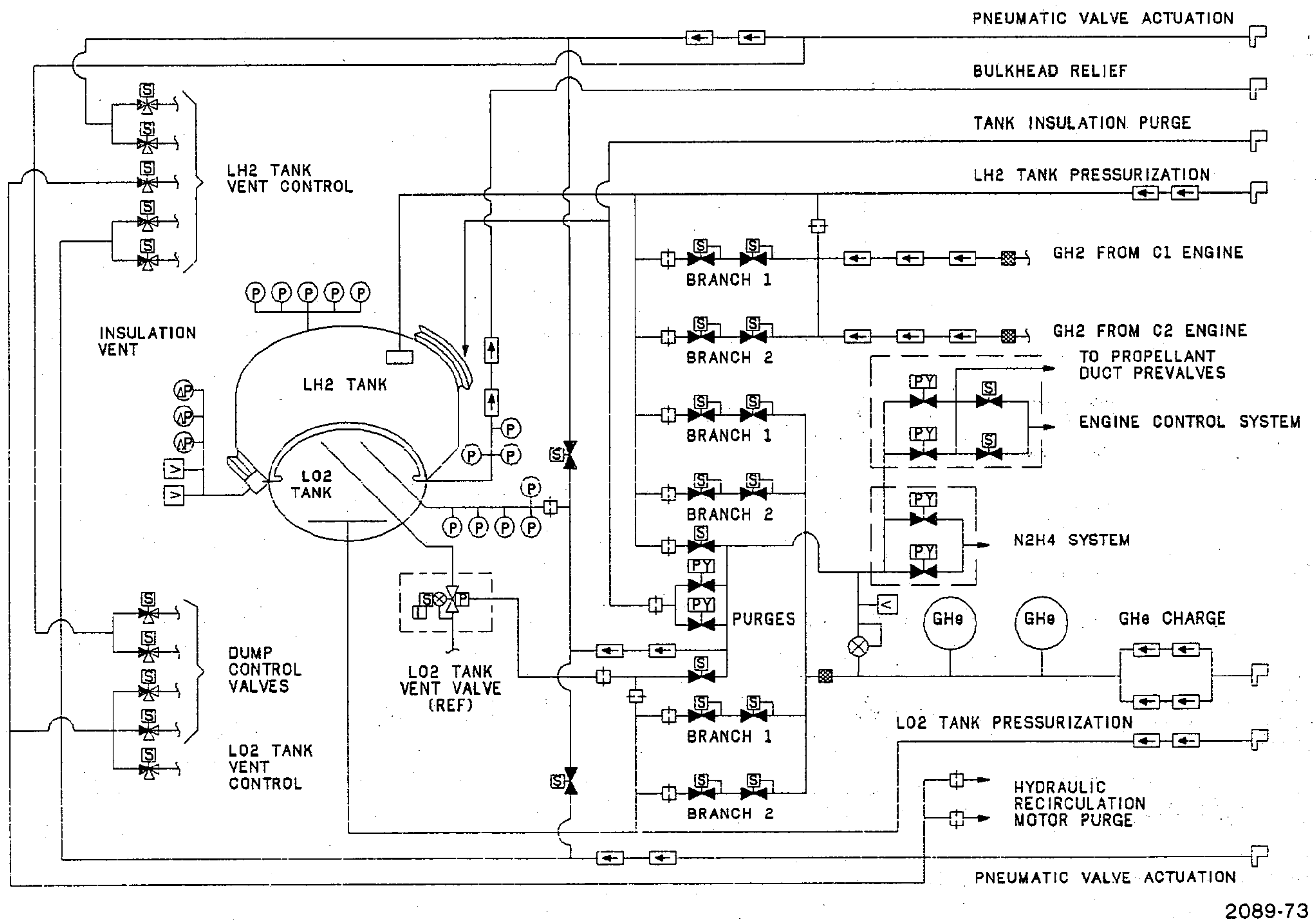

Figure 3-38. Centaur Pneumatic Systems.

valves for each propellant tank are controlled by the five control units located on the CISS, using outputs from five redundant pressure transducers in each tank, to provide the third method of pressurizing the propellant tanks (two methods are provided by the CISS system) to ensure a two-failure-tolerant system for propellant dump and pre-liftoff propellant tank pressurization.

Pneumatically Actuated Valve Control System (Figure 3-38) — The pneumatic valve actuation system consists of two parallel sets of tubing, check valves, and solenoid valves that provide a nominal 450 psig supply pressure for actuation of the four propellant tank fill/dump valves, the backup ground/ascent vent valve in each tank, and the four LH_2 tank zero-g vent system valves. One supply line is connected to a disconnect in the Centaur/CISS oxidizer umbilical panel. The other parallel line connects to a disconnect in the Centaur/CISS fuel umbilical panel.

Actuation pressure is supplied from the two-failure-tolerant pressure regulation system on the CISS. One line supplies actuation pressure to one valve in each parallel set of fill/dump and vent valves. The other line supplies the mating valve in each parallel set. Two solenoid valves provide the capability to supply either or both parallel branches from the 450-psig pressure regulation system on Centaur or to supply the LO_2 tank pressure transducer line purge from the supply system on the CISS. Check valves isolate the sections of the system going to the dump valves and backup ground/ascent vent valves after Centaur deployment.

Purge System (Figure 3-38) — The purge system consists of solenoid valves, flow control orifices, tubing, and components to direct helium purges to various locations on the vehicle at various times during the missions. One line routes from a disconnect in the Centaur/CISS fuel umbilical panel to supply helium purge to the LH_2 tank insulation system.

The insulation system is purged with helium gas introduced at ambient temperature and at 20 to 60 pounds per hour before launch. A Kapton/glasscloth/Kapton laminate containment membrane maintains internal helium during prelaunch operations. Three ΔP transducers sense the insulation system purge pressure for proper control of purge supply via valves located on the CISS. Two relief/check valves also help maintain proper insulation system pressure.

There is no insulation system purge flow requirement during boost phase. Instead, two dual-position vent doors are opened to enable rapid evacuation of the helium-purged blanket to achieve inflight radiation shielding of the LH_2 tank sidewall. In the event of an abort, the vent doors will close to permit blanket repressurization during the reentry sequence. The three ΔP transducers will be employed to maintain blanket pressure control during this period. The transducers coupled with redundant vent doors and controls make the system single-failure tolerant.

A pyro valve provides capability to supply insulation purge from the Centaur helium storage bottles during a post-abort landing. The remainder of the purge system is supplied from the nominal 450 psig pressure regulator in the Centaur helium supply system.

A continuous purge is supplied to the LO_2 tank pressure transducers sensing line. A single solenoid valve provides control of purges going to the LO_2 tank vent standpipe (through the LO_2 ground/ascent vent valve) and the LO_2 tank pressurization line. One additional solenoid valve controls purge to the LH_2 tank pressurization line. A purge is supplied to the two hydraulic system recirculation pump electric motors from the pneumatic valve actuation system supply coming from the Centaur/CISS oxidizer umbilical panel.

Helium Supply System (Figure 3-38) — The helium supply system consists of the two Kevlar overwrapped helium storage spheres and a charge line connected to a disconnect in the Centaur/CISS oxidizer umbilical panel through a quad set of check valves. An analysis has determined that the two 26-inch-diameter helium spheres will contain the helium mass required. The helium charge is controlled by valves located on the CISS. The system also contains a regulator to provide the various purge systems with a nominal 450-psig supply. A relief valve provides protection from overpressurization in the 450-psig portion of the system.

Intermediate Bulkhead Relief System (Figure 3-38) — The bulkhead relief system consists of a single run of tubing connecting the intermediate bulkhead cavity to a disconnect in the Centaur/CISS fuel umbilical panel. A capped test port and two series check valves allow the cavity to be vacuum-purged and backfilled with GN_2. When the propellants are tanked, the GN_2 cryopumps the bulkhead cavity to the required vacuum, providing the desired insulation between the LH_2 and LO_2 propellant tanks.

3.3.4.1.3 Main Propulsion/Propellant Supply — The main propulsion system consists of two Pratt & Whitney RL10A-3-3A engines rated at 15,000 lbf nominal thrust, each operating at a nominal 6:1

mixture ratio of oxidizer to fuel. A silver throat results in a nominal specific impulse of 442.4 seconds. A minimal number of tests will be conducted to verify engine capability at the 6:1 mixture ratio under shuttle-imposed conditions. This will be followed by a formal qualification test program. The net positive suction head (NPSH) required by the engine turbopumps is provided by pressurizing the vehicle propellant tanks. Propellants are delivered to the main engine turbopumps through feed ducts from the vehicle propellant tanks. The feed ducts contain flex joints to accommodate engine gimbaling and are overwrapped with a three-layer, double-aluminized Kapton radiation shield.

Pneumatically actuated prevalves located at the propellant tank outlets provide series redundant backup for the engine inlet shutoff valves (Figure 3-39). A parallel set of pyro valves and solenoid valves upstream of the pneumatic actuation control solenoid valves provides two-failure-tolerance against inadvertent opening of the engine inlet shutoff valves. The pyro valves will be fired open after Centaur is deployed a safe distance from the Orbiter.

3.3.4.1.4 Reaction Control System — The system consists of twelve 6-lbf thrust units, a positive expulsion tank with 170-lbm hydrazine capacity, two sets of parallel pyro valves, one fill/drain and two pneumatic checkout valves, and heated feed lines (Figure 3-40). All feed line joints, including those that interconnect components, are welded to provide a leak-proof, contamination-free system.

The fill/drain and pneumatic checkout valves (with redundant pressure sealing caps) are required to maintain a positive system GN_2 standby pressure, facilitate component functional checkout, and load the hydrazine tank. A set of parallel pyro valves are used in the hydrazine tank inlet and outlet lines to provide positive isolation of the hydrazine tank. The downstream set of parallel pyro valves and thruster series solenoid valves provide two-failure tolerance against inadvertent thruster operation. The pyro valves will be fired open, pressurizing the system and allowing hydrazine flow to the thrusters, after Centaur is deployed a safe distance from the Orbiter.

Inflight thermal control of the system is provided by an aluminized vapor deposit on the tank shell, periodic thruster warming firings, and spiral-wrapped, redundant line heaters. The reaction control system is tolerant of a thruster valve failure to open. Failure to close is protected against by series redundant solenoid valves on each thruster.

The DoD geosynchronous mission reaction control system is identical to that of the baseline Centaur G, except for adding a 2nd hydrazine bottle and associated lines.

3.3.4.1.5 Vent Systems (Figure 3-41) — Each propellant tank contains a mechanical self-regulating vent valve, with solenoid lockup capability, for controlling ground and ascent venting. The valve is the same as that used on all previous Centaur vehicles. A pneumatically actuated open and spring-loaded closed ball valve provides backup ground and ascent vent capability.

LH_2 tank valves are mounted on a standpipe that penetrates the LH_2 tank through the aft conical section. The standpipe continues upward inside

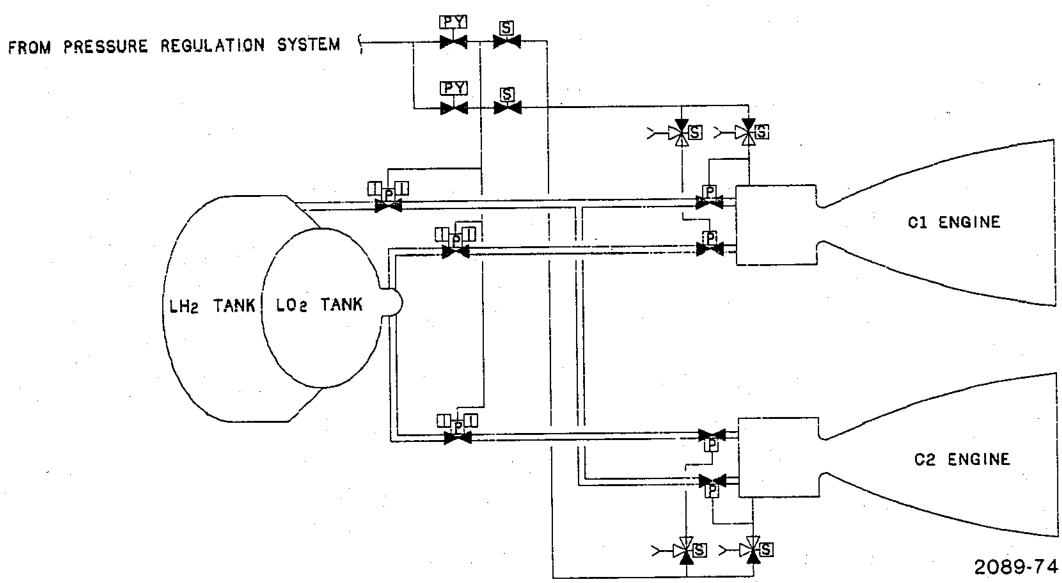

Figure 3-39. Propellant Feed and Main Engine Valve Actuation Control.

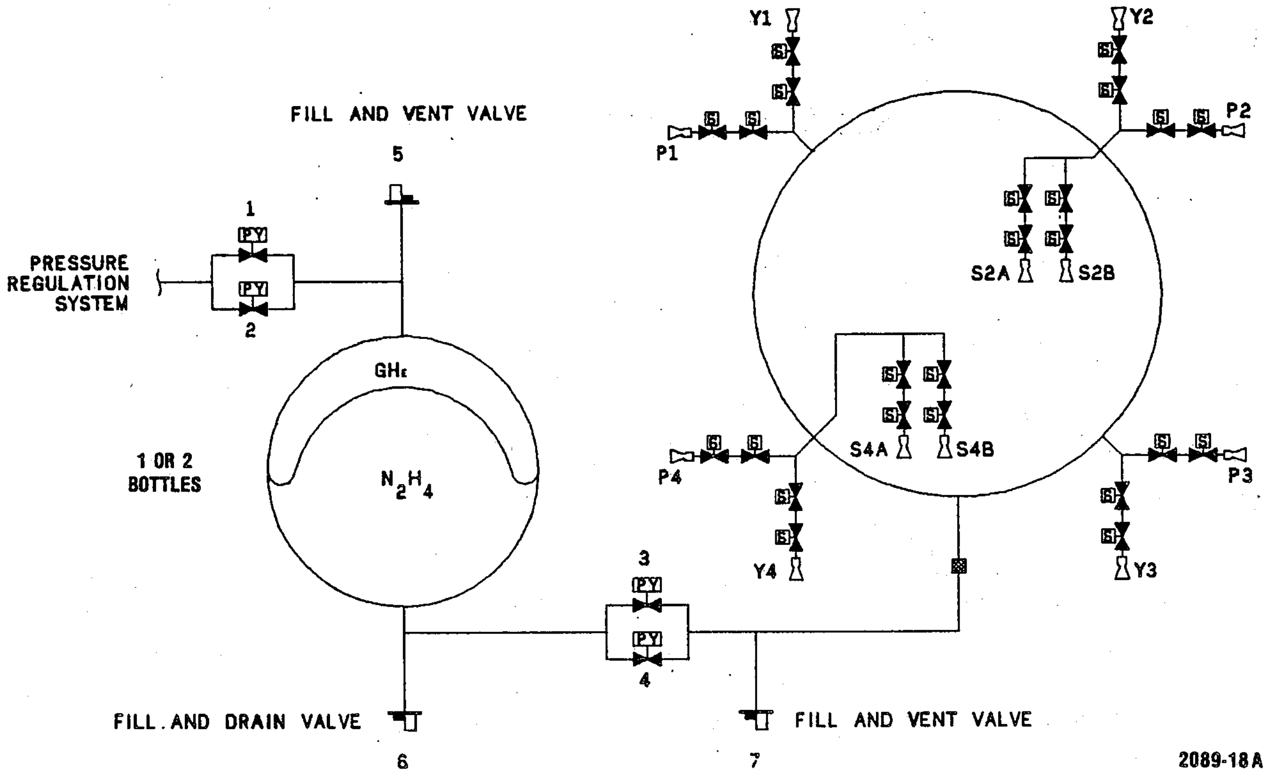

Figure 3-40. Hydrazine Reaction Control System.

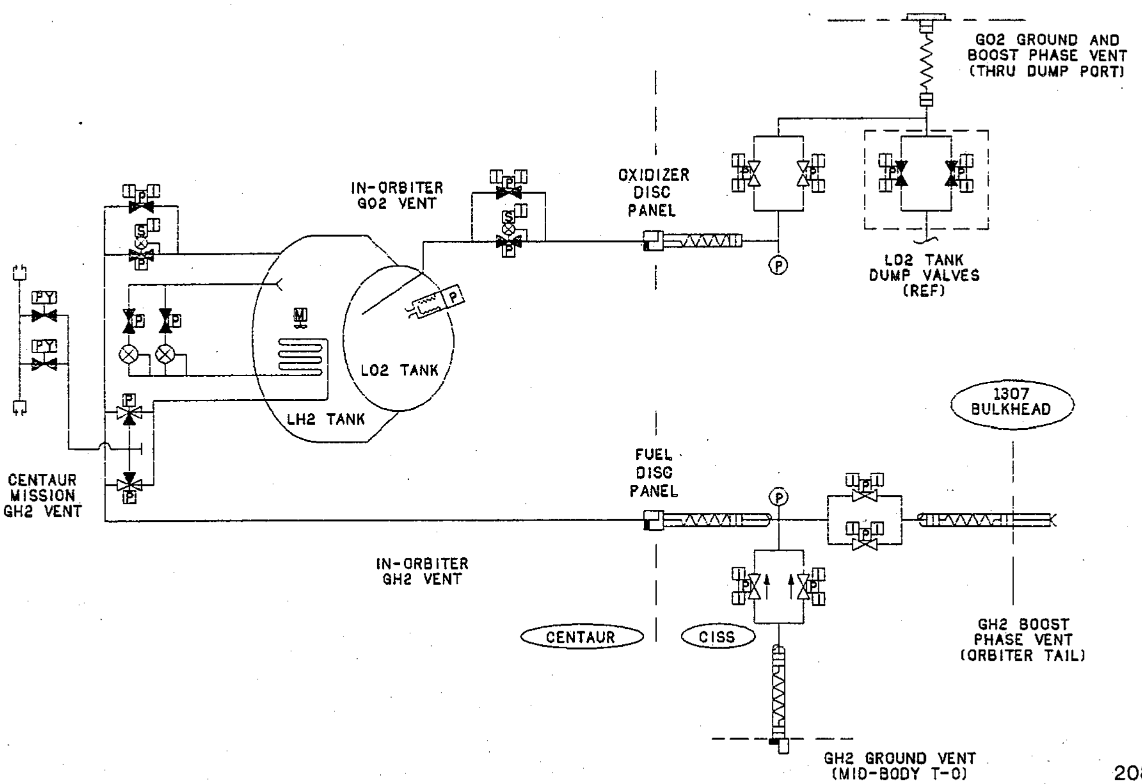

Figure 3-41. Centaur G Vent Systems.

the LH_2 tank to the underside of the forward bulkhead. The duct inlet will be covered with a baffle device to prevent liquid ingestion. The outlet of the valves are connected to a common duct that runs directly aft to a disconnect in the Centaur/CISS fuel umbilical panel. The disconnect contains a self-sealing poppet to provide backup shutoff capability after disconnect panel separation.

The LO_2 tank valves are mounted on the outlet flanges of the LO_2 tank vent standpipe and connect to a common duct that connects to a disconnect in the Centaur/CISS oxidizer umbilical panel. The disconnect contains a self-sealing poppet to provide backup shutoff capability after umbilical panel separation.

The LH_2 tank vent system contains an additional thermodynamic vent system for vent control while in a zero-g environment. The system consists of a heat exchanger with a parallel set of throttling regulators and shutoff valves at the heat exchanger inlet and a parallel set of three-way, pneumatically actuated valves downstream of the heat exchanger.

The three-way valves route the GH_2 through a balanced thrust vent system that also contains normally closed pyro valves to preclude venting into the Orbiter payload bay before Centaur deployment. The thermodynamic vent system also contains an electrically driven pump to circulate propellant through the heat exchanger and to maintain the LH_2 propellant mixed to minimize the need for venting. This vent system is single-failure tolerant and has been sized to maintain propellant tank pressure control while in the closed door payload bay environment, which represents the maximum boiloff condition for Centaur G.

The thermal energy storage potential of the LO_2 is such that the LO_2 tank (in the payload bay environment) can absorb all energy input, if the propellant is adequately mixed. The LO_2 tank will contain a mechanical jet-type mixer.

3.3.4.1.6 Fill/Dump System — The fill/dump system is designed to ensure Centaur G compatibility with all Shuttle abort modes that occur before vehicle deployment. The system has been sized to provide single-failure-tolerant propellant dump capability within 300 seconds, or within 250 seconds with no valve failures — the minimum time allowed during a return-to-launch-site abort. With this system, a simultaneous dump of LH_2 and LO_2 can be accomplished safely while the Orbiter is above 100,000 feet altitude, which corresponds to an ambient pressure less than 0.1 psia. Extensive testing has demonstrated that a hydrogen-oxygen mixture will not ignite at pressures below 0.1 psia.

The fill/dump system is shown in Figure 3-42. This high flow capability, foam-insulated duct system and a parallel set of "normally closed" pneumatically actuated dump valves interconnect the LH_2 and LO_2 propellant tanks to a self-sealng disconnect in the respective Centaur/CISS fuel and oxidizer umbilical panels. Propellant loading and draining are accomplished through the same system during preflight operations. The self-sealing disconnects provide single-failure tolerance against inadvertent dumping after Centaur separation.

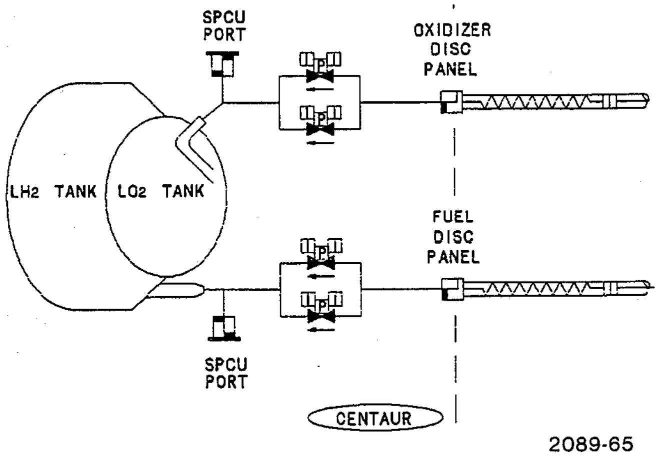

Figure 3-42. Fill/Dump Systems.

A small quick-disconnect is provided in each tank dump line to allow connecting the standby pneumatic control unit for manual and/or mechanical regulation of tank pressures when the automatic avionics control system is not in operation. The ports are sealed with dual-seal caps for launch.

3.3.4.1.7 Rise-Off Fluid Disconnect System — There are two fluid system disconnect panel pairs — one in Quad I containing the hydrogen lines and one in Quad II containing the oxygen lines. The use of rise-off disconnects ensures fluid system continuity for venting or dumping until separation from the Orbiter. The asymmetrical separation impulse from the disconnects, although small, is considered in the deployment spring design. Figure 3-43 shows the general arrangement of the panels with the disconnect sizes and fluid system functions indicated.

The five-inch fill/drain/dump disconnects and the 2.5-inch tank vent disconnects will be identical on both panels and will be qualified for liquid hydrogen or oxygen service. A conceptual sketch of the five-inch disconnect is shown in Figure 3-44. The 2.5 inch disconnect is of similar design. The inner bellows provide the initial sealing force on the spherical seat and provides for misalignment and relative motion during ascent. The outer bellows provides a chamber for helium purge and leakage containment. The remaining disconnects are not cryogenic. (Figure 3-45).

To deploy the Centaur, the Super*Zip is fired and deployment springs accelerate the vehicle away from the deployment adapter. This motion separates the disconnect halves mounted on the Centaur panel from the mating halves mounted on the deployment adapter panel.

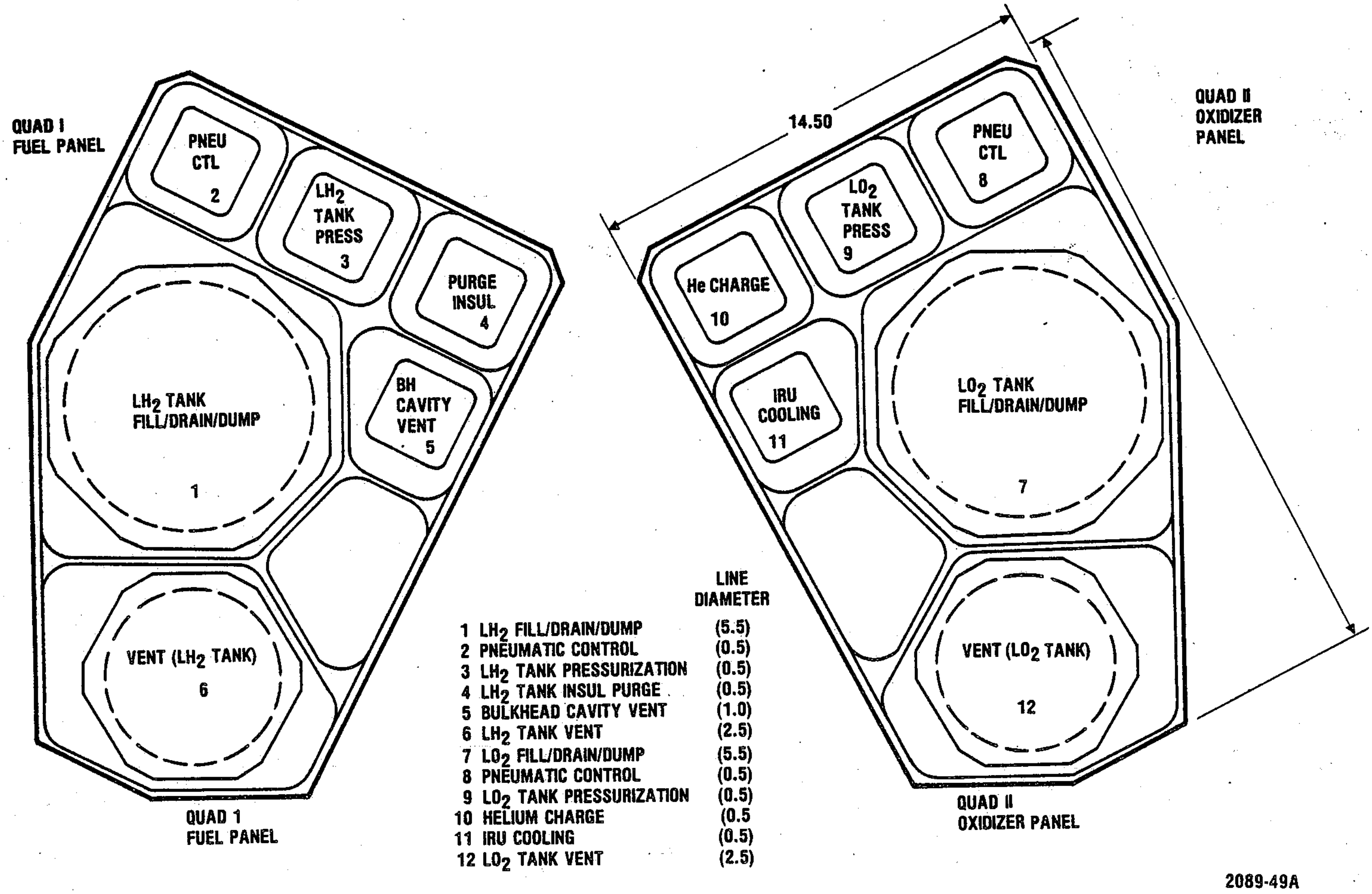

Figure 3-43. Fuel and Oxidizer Disconnect Panels.

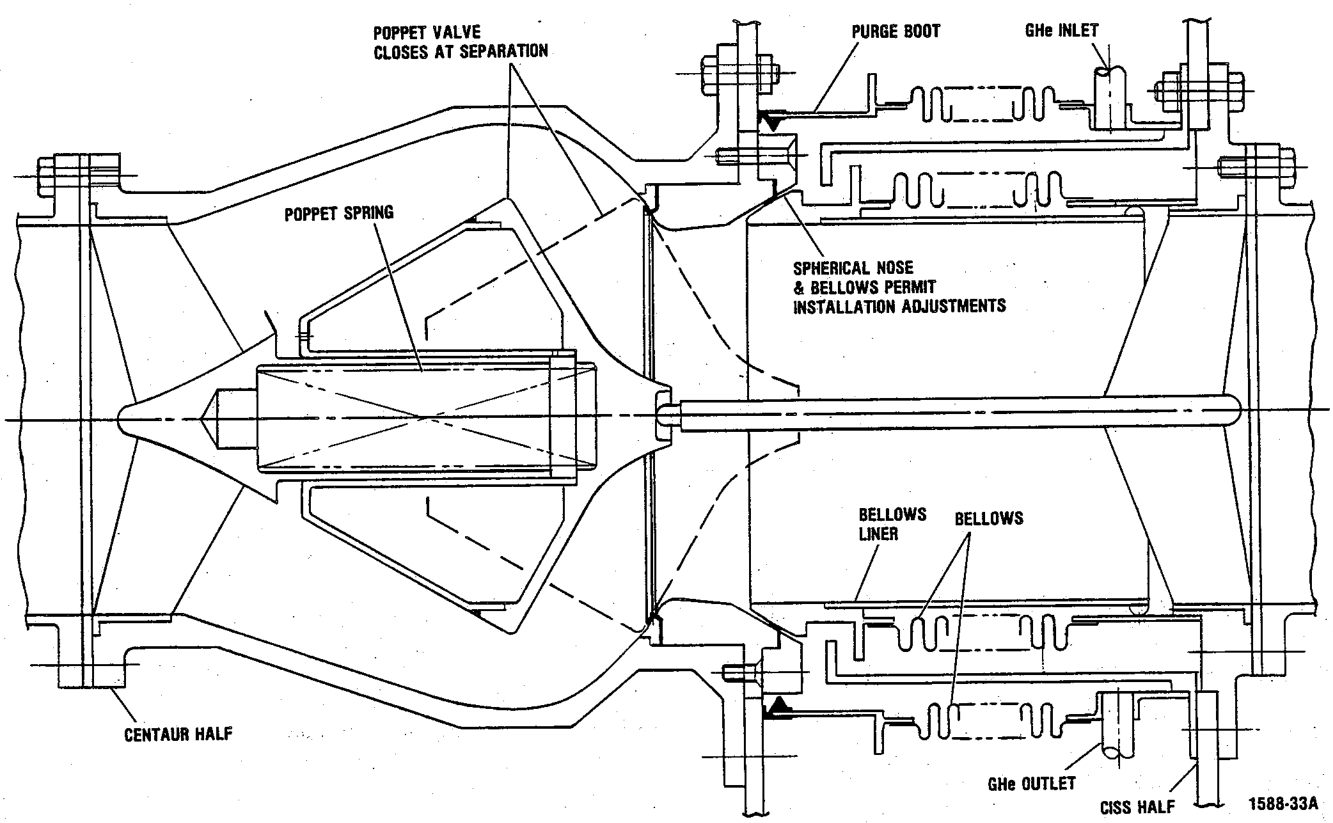

Figure 3-44. Five-Inch Disconnect.

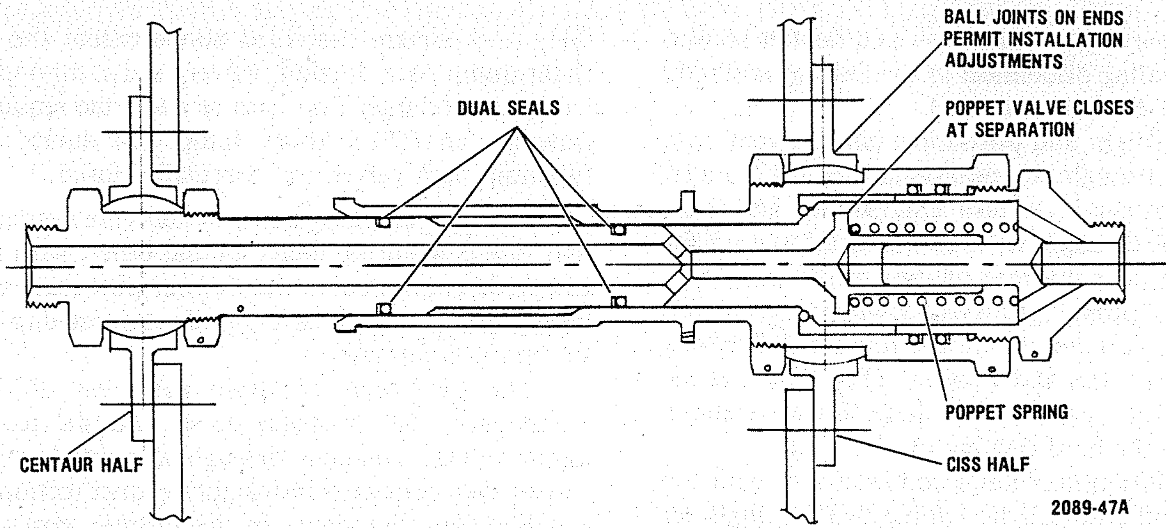

Figure 3-45. Half-Inch Disconnect.

3.3.4.2 CISS Fluid Systems — Major elements of the CISS fluid systems required to interconnect the Centaur vehicle and the Orbiter interfaces, and the systems required to provide the necessary safety requirements are described in the following sections.

3.3.4.2.1 Propellant Tank Vent Systems (Figure 3-46) — The vent systems consist of disconnects, valves, and ducting connecting Centaur/CISS fuel and oxidizer disconnect panels and the associated Orbiter overboard ports. Both the GH_2 and GO_2 vent systems use similar ducting containing three gimbals to connect the CISS half of the disconnects in the fuel and oxidizer panels to the hard-mounted ducting on the CISS. These gimbal duct sections allow the Centaur to be rotated 45 degrees to the deployment position with the vent systems still connected and fully operational, maintaining the required vehicle safety controls.

The GH_2 system branches on the CISS to two Orbiter overboard paths. The ground vent path branches through a parallel set of normally open and pneumatically actuated closed ball valves, then

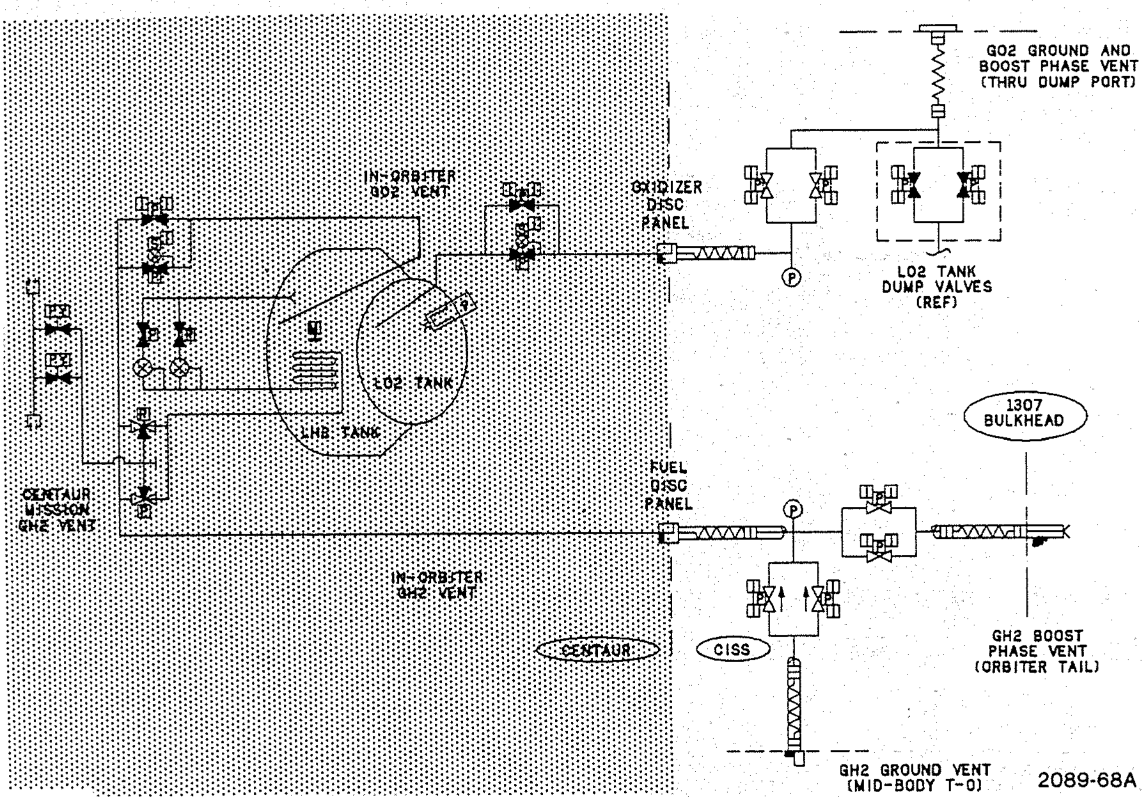

Figure 3-46. CISS Vent Systems.

continues through a single duct and flexible section to a self-sealing disconnect in the Orbiter midbody port-side T-0 umbilical panel.

The inflight and post-abort landing vent path branches through an additional set of parallel valves, then continues into a single duct and flexible sections through the 1307 bulkhead to an overboard port near the base of the Orbiter tail.

These gimbal sections downstream of the CISS valves accommodate the relative deflections between the CISS and Orbiter. The CISS/Orbiter interface is the point where these flexible sections connect to the hard ducting on the CISS.

The GO_2 system has a common vent path for both ground and inflight venting, with a single set of parallel valves identical to the GH_2 side. The duct downstream of the valves connects into the overboard duct for the LO_2 propellant dump system.

The set of "normally open" valves in the CISS vent paths provided the second method of vent control for both tanks during all vent operations, making the vent system fully single-failure tolerant. They also allow the Centaur-mounted mechanical self-regulating valves to maintain proper tank pressure after loss of avionic control.

3.3.4.2.2 Fill/Dump Systems (Figure 3-47) — CISS fill/dump systems are similar in concept to the GH_2 vent system described above except the inflight dump path ducting, valves, and components have a much larger flow area to allow the required flow for an RTLS abort dump. All dump and fill/drain path valves are "normally closed."

The LH_2 and LO_2 dump systems are similar in that one is a mirror image of the other, with the LH_2 side connected to the Orbiter port-side midbody dump port and the LO_2 side connected to the starboard dump port.

The LH_2 tank fill/drain path tees off the dump path just upstream of the parallel set of dump valves, branches through a parallel set of valves, then continues into a gimbal duct section to a self-sealing disconnect in the Orbiter port-side midbody T-0 umbilical panel. The LO_2 fill/drain section on the CISS is a mirror image of the LH_2 side, except the gimbal section connects to ducting that penetrates the Orbiter 1307 bulkhead through the starboard payload oxidizer panel and continues to the Orbiter aftbody starboard T-0 umbilical panel. As with the vent systems, the CISS/Orbiter interface is where the gimbal sections between the CISS and Orbiter connect to the hard ducting on the CISS.

The CISS system, in conjunction with the Centaur system, is fully single-failure-tolerant in providing inflight dump, ground filling and drain-

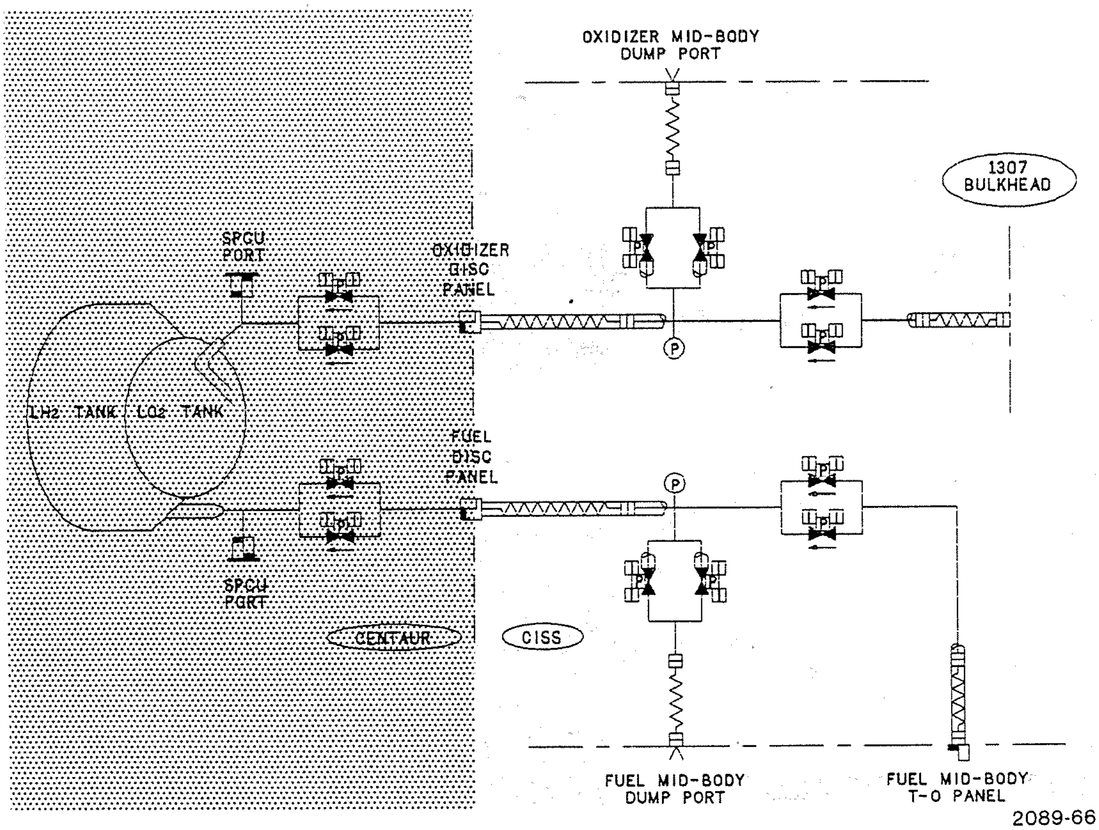

Figure 3-47. CISS Control of Fill, Drain, and Dump System.

ing, and tank shutoff capability. The dump system provides the third path for tank pressure relief (venting) and, in conjunction with the basic vent system, ensures two-failure tolerance for relieving tank pressures.

3.3.4.2.3 Pneumatic Systems — CISS pneumatic systems consist of the propellant tank pressurization system, pneumatically actuated valve control system, helium purge systems, helium supply system, and intermediate bulkhead relief system.

The systems are described individually in the following section; however, they are interconnected, except for the bulkhead relief system, which is completely autonomous.

Pressurization System (Figure 3-48) — The pressurization system consists of a valve module containing three parallel legs of three solenoid valves in series for each propellant tank. Two legs will contain flow control orifices sized so that one leg will provide minimum ullage flow requirements and the two legs combined will provide maximum ullage flow requirements. The third leg orifice will contol flow at a high rate equal to combined flow of the other two legs.

The system will be fully two-failure-tolerant against inadvertent pressurization and in providing low-flow and high-flow when combined with the Centaur system. The valve modules will be mounted on the interior surface of the deployment adapter with a supply line connecting the respective valves to disconnects in the Centaur/CISS fuel and oxidizer umbilical panels. All system permanent tube joints will be welded and all separable connections will use either welded or brazed "Dynatube" fittings. A quick-disconnect port with a manual shutoff valve and dual sealed cap permits connecting the standby pneumatic control unit to the helium supply line whenever the CISS avionics is not in operation and to provide helium supply for system checkout.

Pneumatical Actuated Valve Control System (Figure 3-49) — A network of three regulators and eight solenoid valves will provide a nominal 450-psi helium supply to two separate supply branches that route to each of the pneumatically actuated ball valves in the four parallel sets in the fill/dump system and three parallel sets in the vent system. Each valve in a parallel set will be actuated by a three-way solenoid valve connecting to a different supply branch. The third regulator can be switched to supply either branch, or any one of the three regulators can supply both branches, ensuring two-failure-tolerance capability in providing 450 psi actuation pressure to at least one of the branches

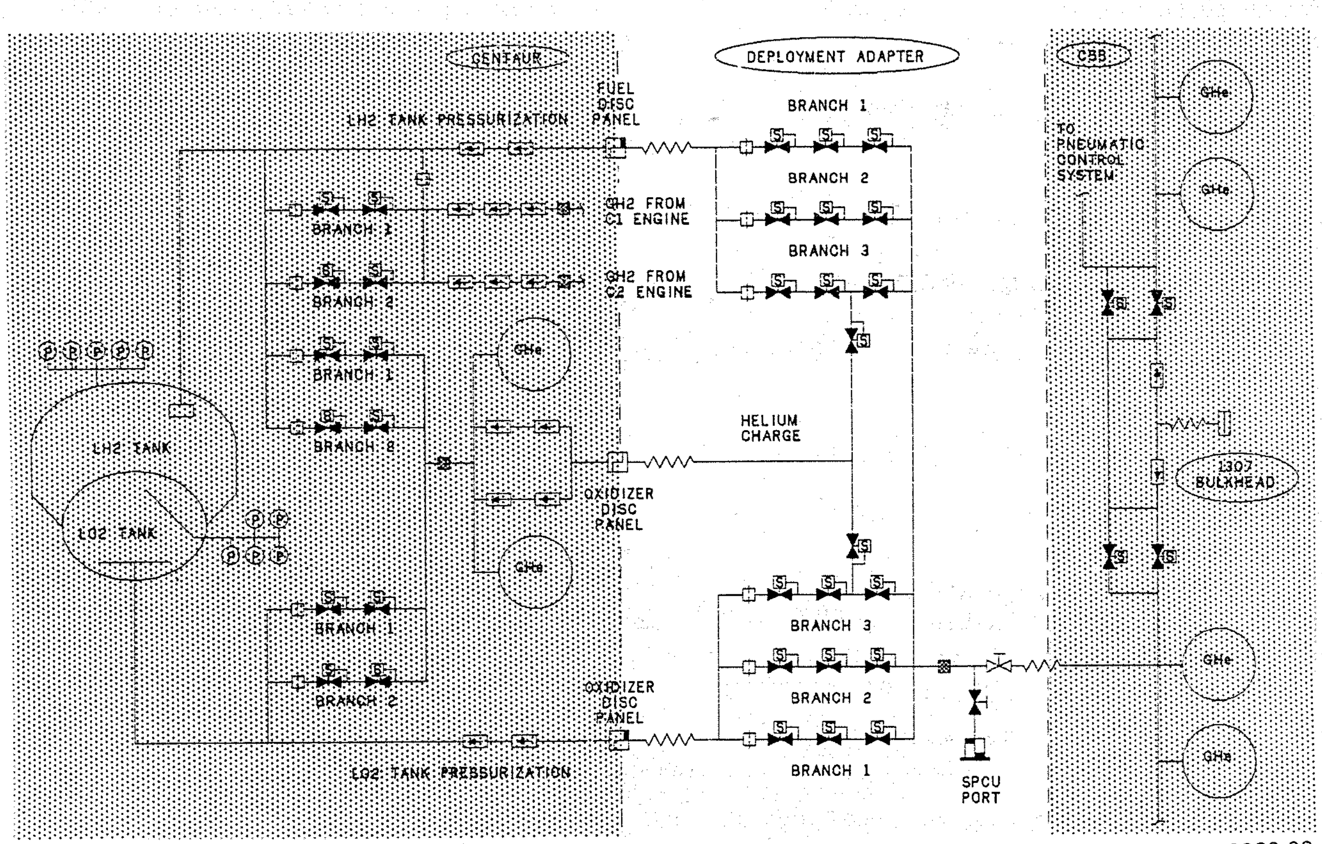

Figure 3-48. Propellant Tank Pressurization System.

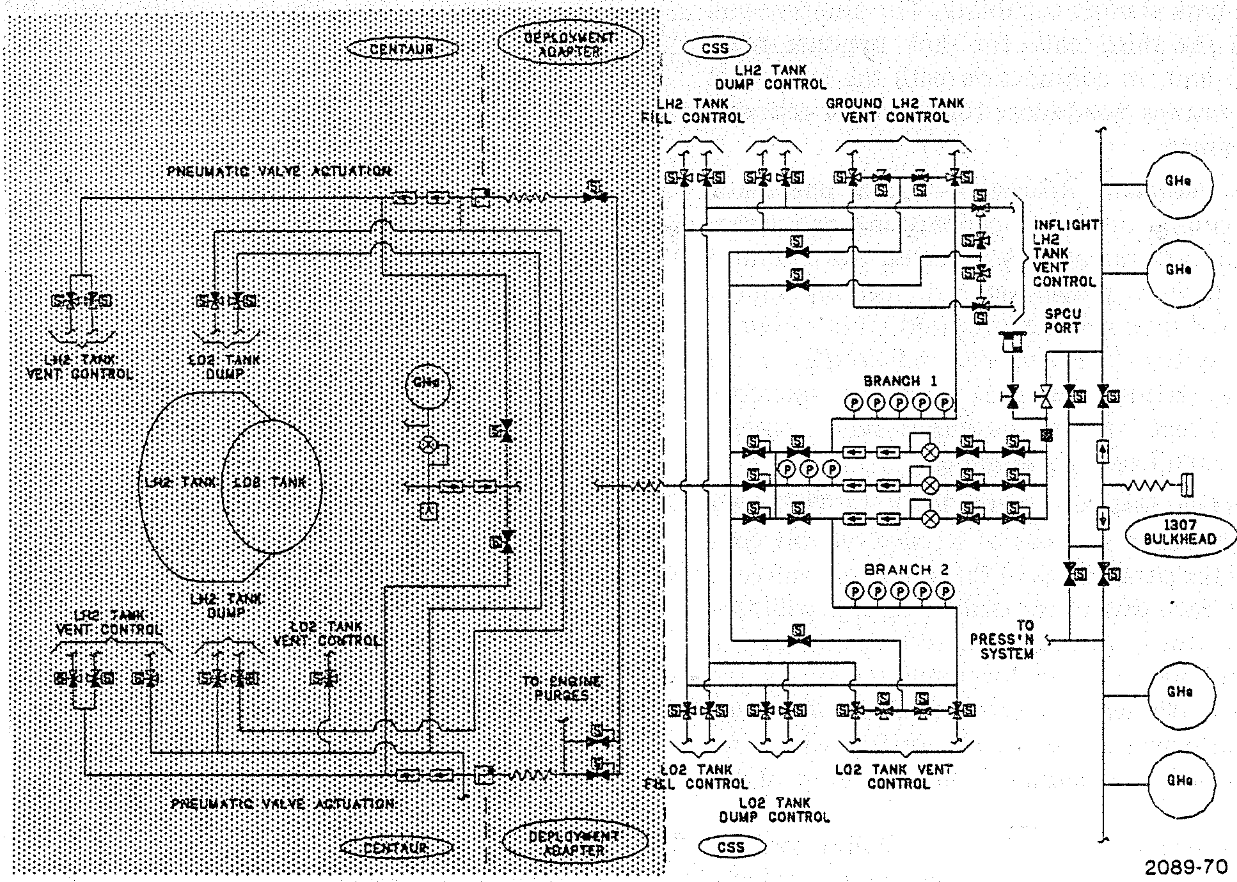

Figure 3-49. Pneumatical Actuated Valve Control System.

serving the parallel valve sets. Pressure transducers in each branch will provide output to each of the CISS avionics control units for determining proper regulator operation and required solenoid valve control.

The output from the center third regulator normally supplies a third branch through a set of three parallel solenoid valves. In similar fashion, any one of the three regulators can serve the third branch, which supplies the purge systems, the pneumatically actuated valves on Centaur, and backup actuation pressure for the three sets of parallel "normally open" CISS vent valves. Each parallel set of vent valves can be commanded closed by actuating solenoid valves supplied from the third branch if for some reason either branch No. 1 or 2 is inoperative.

The supply line to the valve actuation and purge systems on Centaur branches on the deployment adapter. One leg goes through a disconnect in the Centaur/CISS fuel umbilical panel; the other leg goes through a disconnect in the oxidizer umbilical panel. One leg is controlled by a single solenoid valve and the other leg by a parallel set of solenoid valves to ensure the system is two-failure-tolerant in supplying 450-psig actuation pressure to at least one of the two Centaur actuation supply lines.

A quick-disconnect port with a manual shutoff valve and a dual-sealed cap permits connecting the standby pneumatic control unit (SPCU) to facilitate system checkout and to allow the SPCU to connect into the helium storage system for its supply when not at a facility.

Purge System (Figure 3-50) — The purge system is supplied from the two-failure-tolerant pressure regulation system described above.

A network of six solenoid valves located on the interior surface of the deployment adapter provides two parallel systems, each of which can provide three different purge rates to the Centaur LH_2 tank insulation blanket through a disconnect in the Centaur/CISS fuel umbilical panel. An additional network of four solenoid valves located on the deployment adapter provides either a low or high flow rate to the Centaur engine systems. Another five solenoid valves control purges to the LO_2 and LH_2 fill/drain system and the LH_2 vent system. A purge is provided to each leakage containment chamber around the Centaur/CISS umbilical panels. Vent lines route the helium purge and any LO_2 or LH_2 system leakage to respective over-

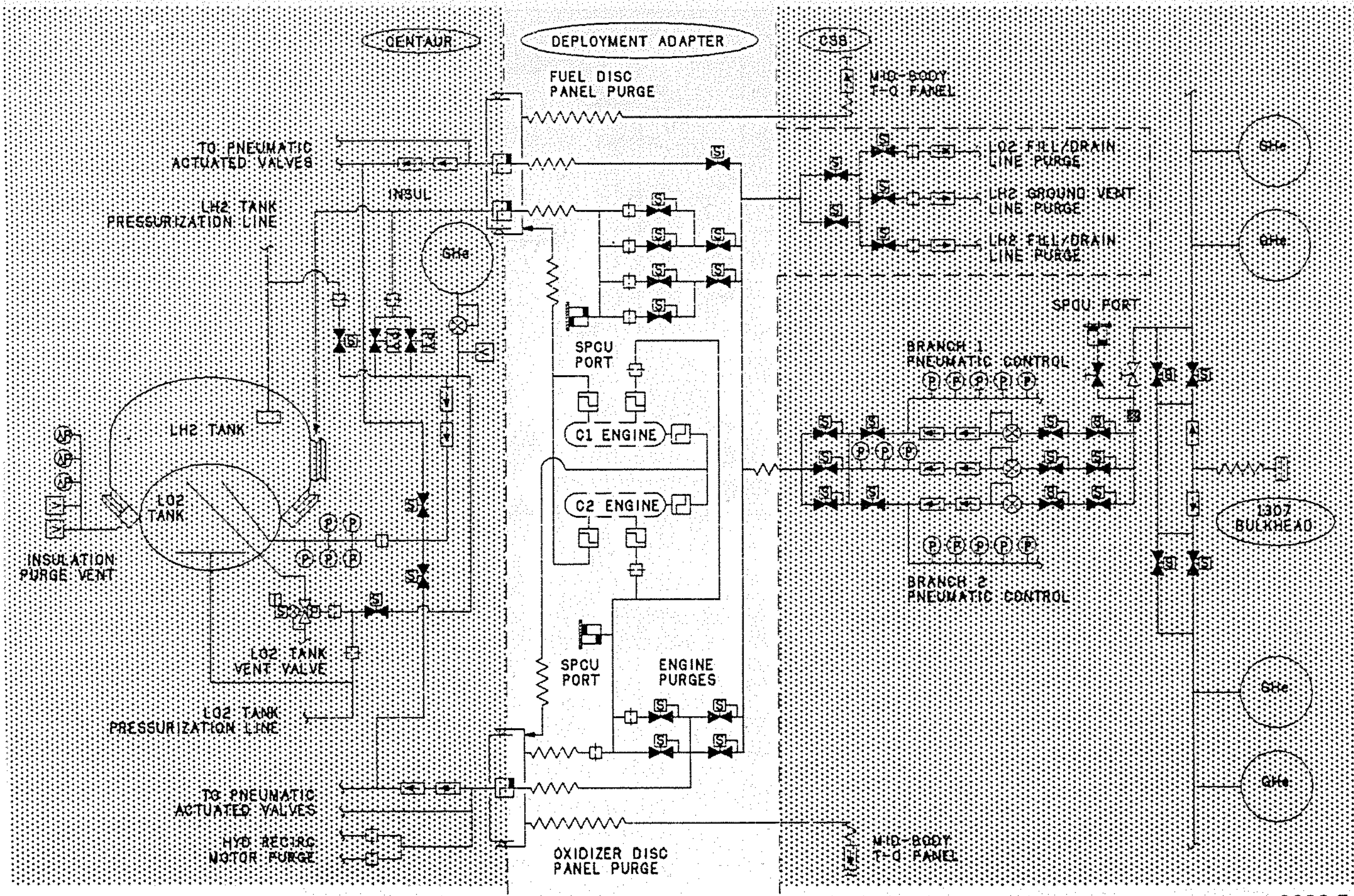

Figure 3-50. Purge System.

board vent ports in the Orbiter midbody fuel T-0 panels and the starboard OMS ΔV panel.

The lines supplying the engine purges and LH_2 tank insulation purge contain a capped quick-disconnect port to permit connecting the standby pneumatic control unit to supply these purges when the automatic avionics control system is not in operation.

Helium Supply System (Figure 3-51) — A network of twelve 4,650-cubic-inch (22-inch diameter) Kevlar-overwrapped helium storage spheres is mounted on the CISS structure to provide all Centaur G helium requirements. The network is divided by a set of quad solenoid valves to separate the normal mission requirements from those required for a mission abort. The valve arrangement permits crossflow from either half of the network.

The network is initially charged to 4,000 psig through a self-sealing disconnect in the Orbiter aftbody fuel T-0 panel. Flex hoses connect the inflight abort supply to the pressurization system and the normal supply to the valve actuation pressure-regulation system. Each supply line to the two systems incorporates a manual shutoff valve to permit system checkout without the need to pressurize the total CISS supply.

Intermediate Bulkhead Relief System (Figure 3-52) — This system consists of a single line from a disconnect in the Centaur/CISS fuel umbilical panel to a vent port in the Orbiter midbody port-side (fuel) T-0 umbilical panel. A GN_2 purge is supplied from the environmental conditioning system on the CISS (supplied from the Orbiter) to provide a positive GN_2 backpressure to the check valves on the Centaur to preclude helium ingestion.

3.3.5 AVIONICS SYSTEM

3.3.5.1 Centaur Vehicle Avionics — This section describes the baseline Centaur G avionics system and how it will be modified for DoD missions to satisfy requirements for:

- SGLS-compatible telemetry, tracking, and command (TT&C).
- Secure communications (COMSEC).
- Spacecraft interfaces.

Figure 3-53 shows the major functional elements of Centaur G avionics. Figure 3-54 indicates the sub-

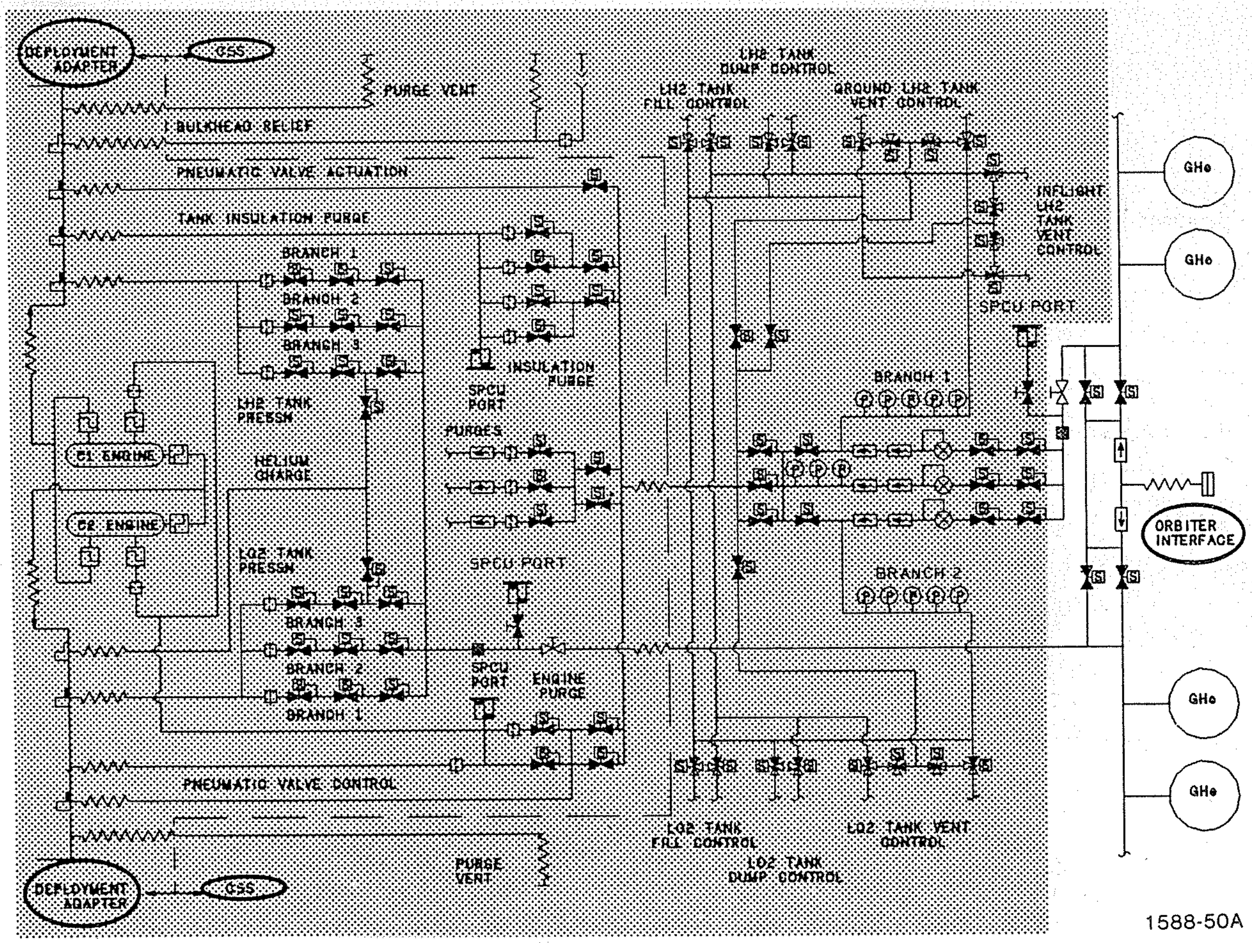

Figure 3-51. CISS Helium Supply.

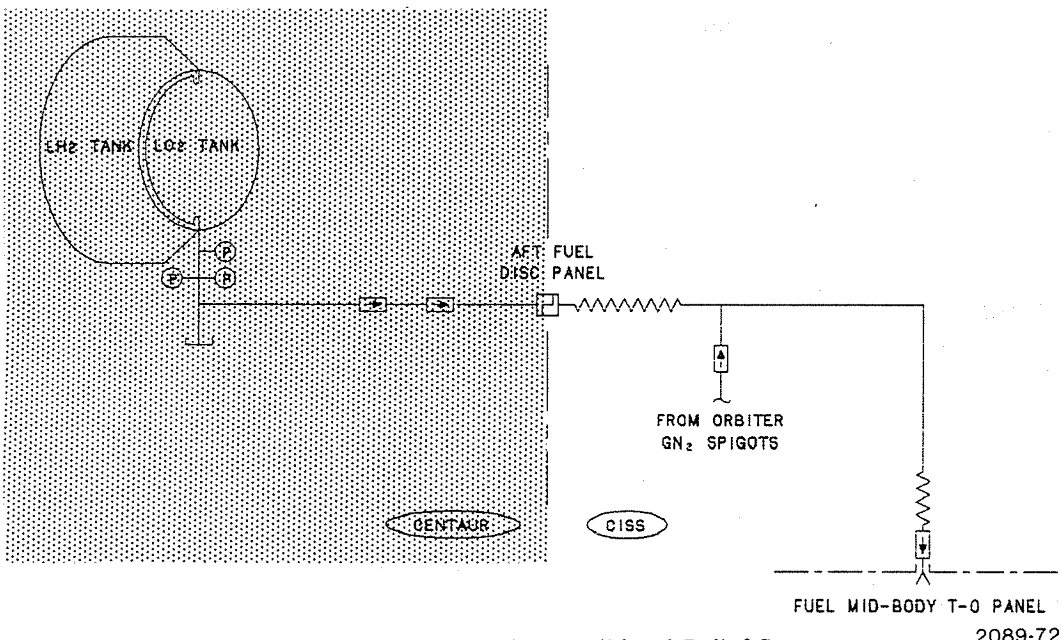

Figure 3-52. Intermediate Bulkhead Relief System.

systems to be modified for Centaur G to comply with DoD requirements.

The avionics system selected by NASA and Convair for the Shuttle/Centaur program is a minimum modification to the current Centaur (D1) configuration. The D1 configuration, a second-generation Centaur avionics system, was developed in 1971 and 1972 to NASA high-reliability standards and has compiled a perfect record of 33 operational successes in performing 33 geosyn-

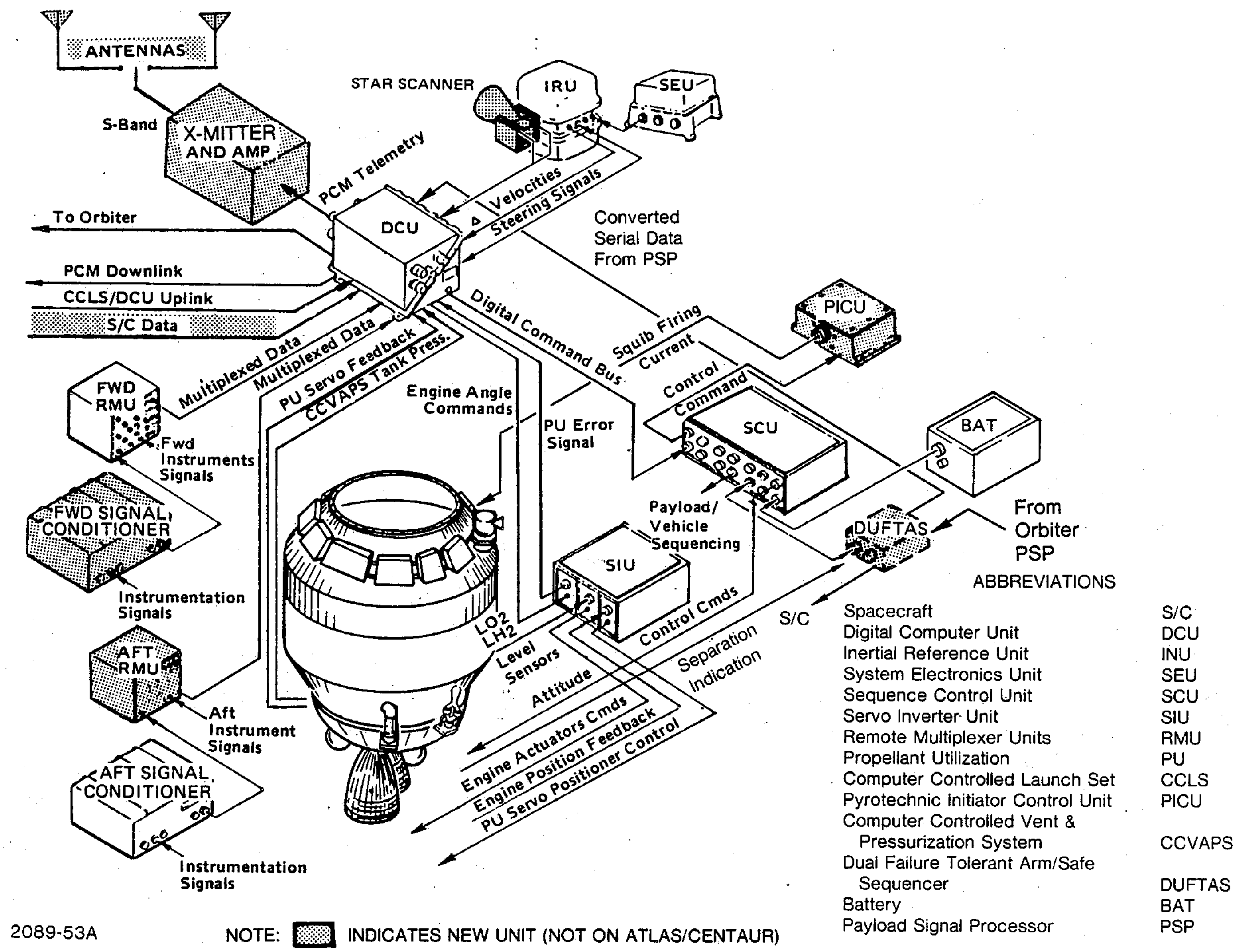

Figure 3-53. Centaur G Baseline Avionics.

chronous and interplanetary Atlas/Centaur and Titan/Centaur missions.

The decision to continue use of the single-string D1 avionics system configuration for Shuttle applications rather than to integrate a dual-redundant system was based on a comparison of the D1 demonstrated reliability to the calculated potential increase in mission reliability offered by a new, redundant configuration. The D1 avionic system benefits are that the D1 system:

1. Is mature with flight-proven hardware and software.
2. Minimizes front-end program risk in both hardware and the software development areas.
3. Minimizes development and recurring costs.
4. Minimizes the payload weight penalty.

3.3.5.1.1 Digital Computer Unit (Figure 3-53) — The Teledyne Systems Co. digital computer unit (DCU) is a 16,384-word, 24-bit, random-access, core memory computer. Its memory is divided into 12,288 words of non-alterable memory and 4,096 words of alterable memory. The DCU receives incremental time and velocity pulses from the inertial measurement group, converts analog dc to digital form, receives formatted data from remote multiplexers and external sources, responds to discrete inputs, and acts on priority interrupts.

The DCU output converts digital values to both ac and dc analog signals, formats PCM data, and provides parallel discrete commands.

The input/output capability provides hardware compatibility with Orbiter differential inputs, communication with the Orbiter or the ground and star scanner compatibility for guidance and navigation functions, in addition to input/output interfaces with other Centaur GN&C functions.

The Centaur G DCU incorporates minor modifications to the Atlas/Centaur unit to accommodate a TT&C system and to add a star scanner.

3.3.5.1.2 Guidance and Navigation — The guidance and navigation functions are implemented using a

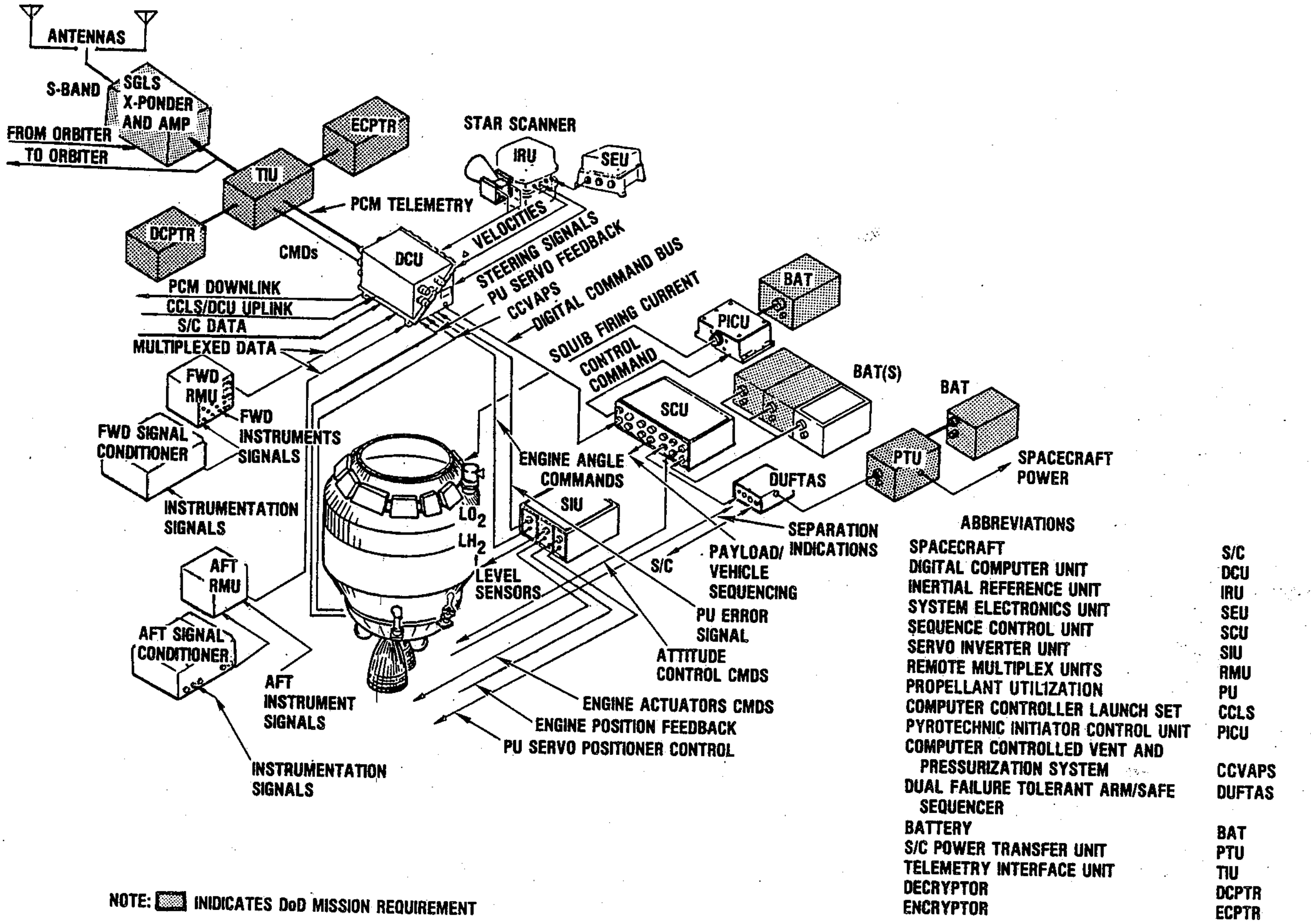

Figure 3-54. Centaur G Avionics To Meet DoD Requirements.

Honeywell inertial measurement group (IMG) for measurement of vehicle accelerations (ΔV pulses) and the DCU for computation of vehicle position and velocity and generation of the required steering signals. The IMG is composed of an inertial reference unit (IRU) and its associated power supplies housed in the system electronics unit (SEU). The IRU contains a four-gimbal, gyro-stabilized platform that supports three orthogonal, pulse-rebalanced accelerometers.

A gyrocompassing mode will be used for initial azimuth alignment of the inertial element for Shuttle missions.

Although IRU accuracy is sufficient to meet the Galileo mission requirements by navigating from the ground up without external navigation or attitude assist, extended periods in the Orbiter payload bay may necessitate navigation and attitude updates. Navigation update will be provided from the Orbiter via the PSP interface. The attitude update will be accomplished by a Ball Aerospace Systems Division star scanner.

The Centaur G inertial measurement group (IMG) is a slightly modified Atlas/Centaur IMG to improve gyro torquing command accuracy to accomplish the attitude update and azimuth alignment.

3.3.5.1.3 Control — The control functions — Centaur main engine thrust vector control and coast phase attitude control — are performed on the basis of analog vehicle attitude errors received by the DCU from the IMG. The main engine thrust vector control signals are generated by the digital autopilot software in the DCU, which accepts the IMG attitude errors, differentiates them to obtain vehicle rates, and computes the desired engine actuator commands. The analog engine actuator commands are sent from the DCU to the servo inverter unit (SIU), where they are power-amplified and the engine position control loop is closed by a position feedback signal from an actuator transducer. The attitude control signals during coast phase are also generated by DCU computations, which use the IMG attitude errors as inputs. The coast phase attitude engine commands are digital on-off commands, which are sent from the DCU to the sequence control unit (SCU). SCU relays provide the attitude control engine switching.

A timing mechanism provides dual-failure tolerance against inadvertent initiation of all safety-related functions until deployment of the Centaur is complete and the separation distance is sufficient. The timing mechanism contains series timers initiated by discretes from the separation mechanism. Figure 3-55 indicates the functional mechanism for providing two-failure tolerance.

In addition to flight controls and safety functions, the Centaur avionics provides command outputs based on a serial uplink from the orbiter (Figure 3-56). This command link is only available during the attached mode and must: (1) initiate discrete commands through the Centaur DCU/SCU to the spacecraft, (2) initiate computer controlled star scanner sequences.

3.3.5.1.4 Sequencing — The sequence control unit (SCU) contains the logic to decode a 22-bit parallel DCU sequencing command and 96 magnetic latching relays. The SCU provides all sequencng commands to vehicle systems and 16 discrete commands to the spacecraft.

3.3.5.1.5 Propellant Utilization Management — This system increases vehicle performance by propellant residual management and by controlling the engine mixture ratio.

For Centaur G, the Atlas/Centaur capacitance probe used to sense liquid levels will be changed to conform to the modified tank shape and part value constants in the bridge detector circuits will be changed to provide 6:1 mixture ratio control. The LO_2 tank probe will be the same as that used on Atlas/Centaur. The LH_2 probe will be modified to accommodate the new LH_2 tank geometry.

3.3.5.1.6 Computer-Controlled Vent and Pressurization System (CCVAPS) — This system controls pressurization of the Centaur LH_2 and LO_2 propellant tanks, optimizes helium use, and provides failure detection and corrective action for the redundant tank pressurization components. Five redundant sensors in each tank supply independent inputs to the CISS control units. Predeployment pressurization and venting are controlled by the CISS computer system.

After Centaur deployment, four other pressure transducers in each tank are monitored by the DCU. The DCU selects valid signals, compares pressure levels to predetermined values, commands actuation of appropriate valves through the SCU, and provides commands to actuate redundant pressurization solenoid valves should a primary solenoid valve fail.

After deployment from the Orbiter, Centaur G pressurization control is principally the same as for Atlas/Centaur. Before deployment, the CISS avionics provides two-failure-tolerant control of pressurization and vent valves.

3.3.5.1.7 Instrumentation — The Centaur G instrumentation system (Figure 3-57) collects data and conditions and converts it to a PCM bit stream. The system provides this information before launch and throughout all phases of shuttle and Centaur flight phases. The instrumentation system consists of vehicle transducers, harnesses, signal conditioners, remote multiplexer units (RMU), and the PCM central control unit (CCU), supplied with and located in the digital computer unit (DCU).

The system is portioned into two remotely located, groups of equipment: (1) a set of transducers, a signal conditioner and a RMU on the forward end of the Centaur; and (2) an identical set at the aft end of the Centaur.

The signal conditioner produces transducer excitation voltages and normalizes the measurement signals to acceptable ranges for the RMU.

RMU addressing is under format control of the CCU. The CCU also integrates PCM data from the spacecraft payload with internal Centaur vehicle data.

The composite PCM data is sent over the following links:

- Prelaunch data to CCLS.
- Attached data to data interleaver.
- Detached data to orbiter or ground via TDRSS compatible transmitter.

Safety function transducers (insulation blanket, differential pressure, and tank pressure) are directly excited by the 28 vdc bus and hardwired directly to the Centaur Integrated Support System (CISS) safety control system. Each safety function transducer output is independently signal conditioned.

All elements of the system are similar to the Atlas/Centaur instrument system.

3.3.5.1.8 Telemetry — The baseline Centaur G telemetry system (Figure 3-58) is used to communicate to the ground and Orbiter from the Centaur, both in the attached and deployed modes. Downlink transmissions are required for 16 kbps of PCM data to the Orbiter or to the ground.

Major telemetry elements are the transmitter, antenna system for full spherical coverage, an RF

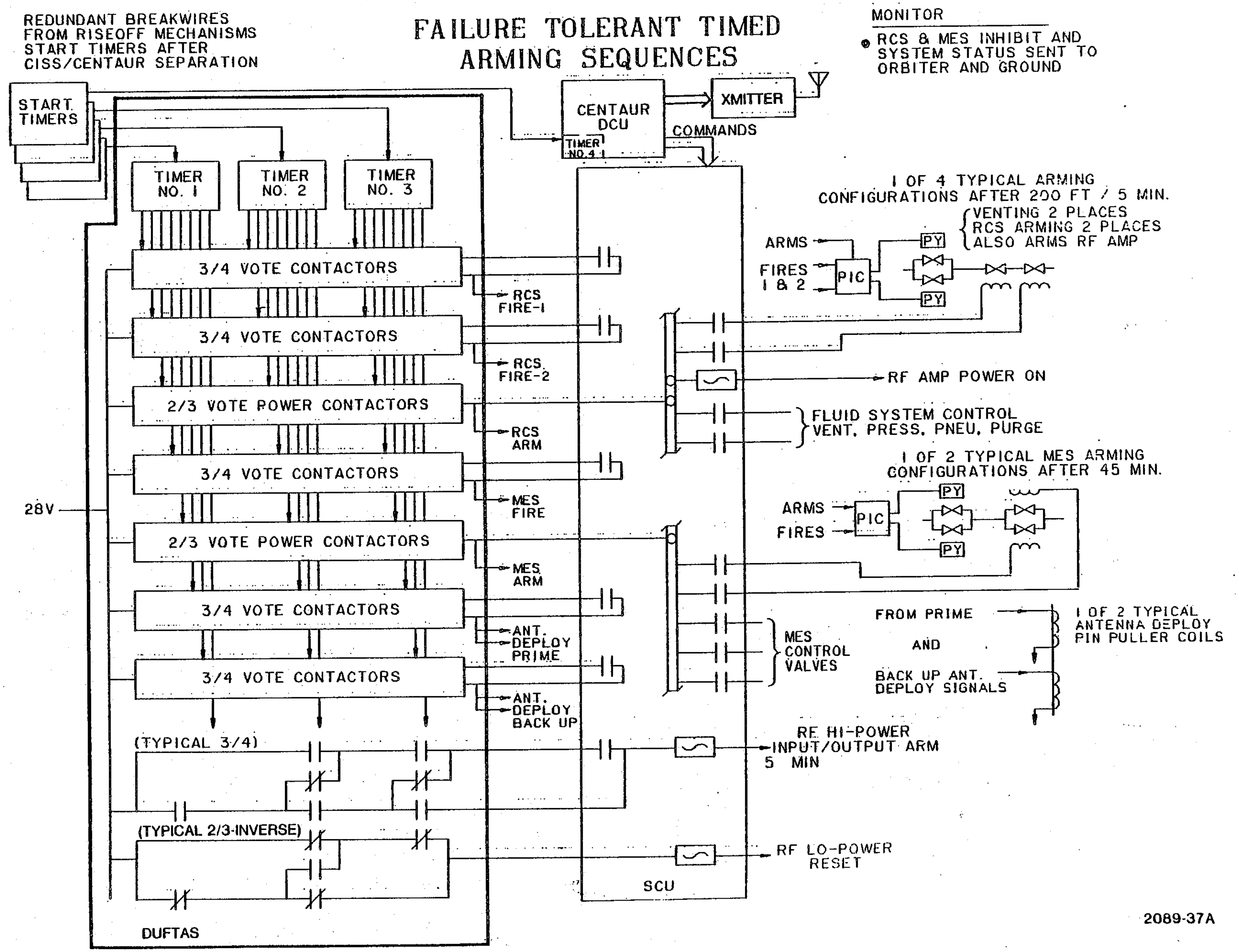

Figure 3-55. Failure-Tolerant Timed Arming Sequences.

amplifier for long-range communications, and RF switches for signal routing.

The telemetry system is compatible with the Orbiter payload interrogator, and the NASA tracking and data relay satellite system.

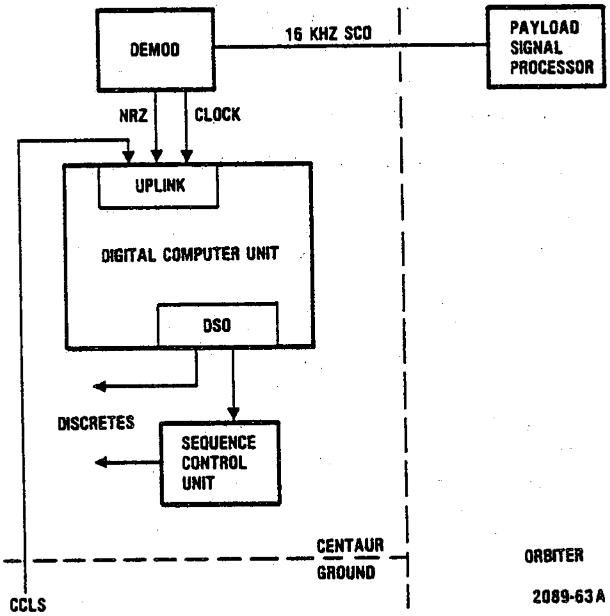

Figure 3-56. Baseline Centaur G Command Link Paths.

The transmitter responds to commands from the Centaur SCU to reconfigure its mode of operation and provides self-monitoring status signals to the instrumentation system. The transmitter is switched to the appropriate S-band antenna, under DCU control, to achieve the best link margin. DCU decisions are based on known terminal locations. The amplifier is switched into the signal path based on time from Centaur/Orbiter separation, to provide adequate return signal performance margin as required. Higher data rates and/or extended mission ranges require addition of a directional antenna.

The Centaur G telemetry system for DoD applications differs from the baseline configuration in several respects. An RF uplink capability has been added by replacing the transmitter with a transponder. This transponder can also provide turn-around of ranging signals as required. Thus the baseline telemetry system is replaced by an integral Telemetry Tracking & Command (TT&C) system.

The transponder is Space Ground Link System (SGLS) compatible. The SGLS trans-

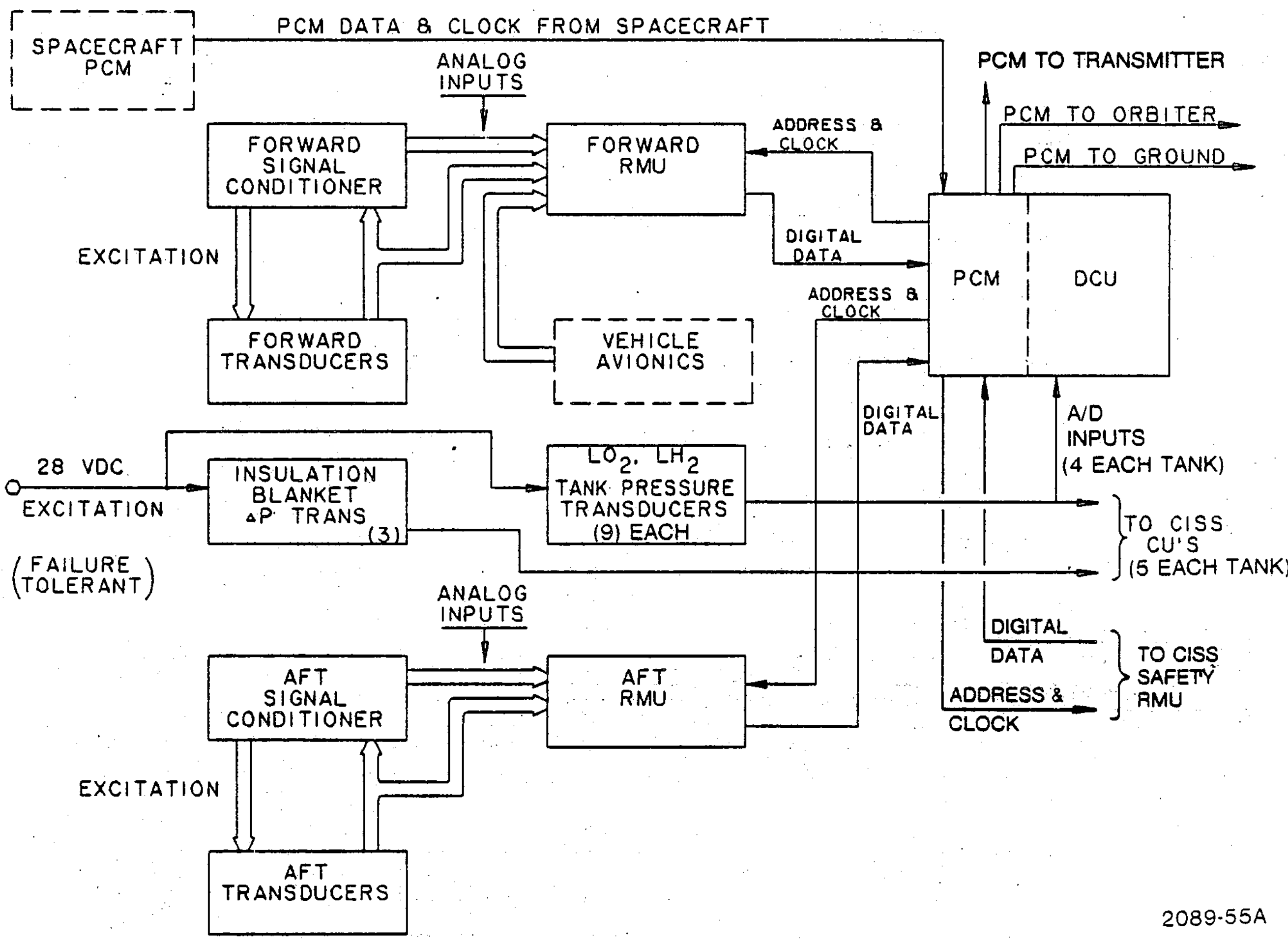

Figure 3-57. Centaur G Instrumentation System.

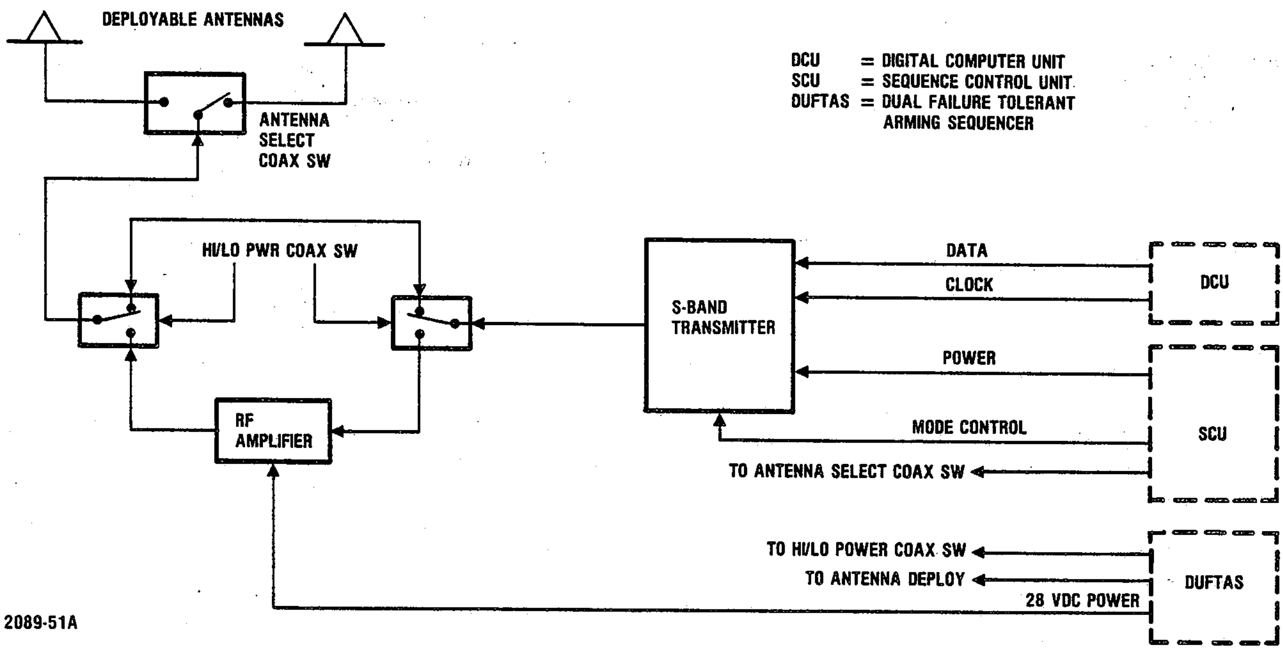

Figure 3-58. Baseline Centaur G TT&C System.

ponder satisfies the requirement to interface with the Satellite Control Facility (SCF) ground stations. Commands are transmitted via the SGLS ternary command system.

Certain classified missions may require communication security equipment on the command and telemetry RF links to safeguard sensitive data. We have incorporated mounting provisions and electrical isolation in our basic design for easy installations of a COMSEC kit consisting of an encryptor, decryptor, and associated cables.

General Dynamics Convair Division has established the TEMPEST (secured communications) boundaries as the red/black interface shown in Figure 3-59 and will provide the required isolation on all signal and power lines crossing this interface to preclude compromising the secured data. These isolation networks will be housed in the telemetry interface unit (TIU). All signal and clock lines will have isolation buffers consisting of two TTL inverters connected in series with low-pass passive L-C filters at the input of the inverters to provide high-frequency isolation. Similarly, filters will be used on all power distributed within the black zone. The filter package within the TIU will be completely shielded and all cable assemblies penetrating the black zone and within will have outer shields with circumferentially bonded connectors at both ends.

The secure communications system will be designed and tested to ensure compliance with TEMPEST requirements of NACSEM-5100.

Centaur G has the capability of accepting spacecraft telemetry data for interleaving with the Centaur telemetry data, subsequent encryption if required, and transmission to the ground via the TT&C system or via the Orbiter communication systems while in the Orbiter payload bay. At the 16 kbps Centaur data rate, up to 1 kbps of data from the spacecraft will be interleaved into the Centaur telemetry format.

The DoD communication interface unit mounted on the aft flight deck provides the capability to convert and format binary commands to SGLS ternary format and verify and authenticate command signals, including crew generated selected commands and hardline commands to the Centaur G transponder.

3.3.5.1.9 Electrical Power — The Centaur G electrical power and distribution system consists of a silver-zinc primary battery, a power changeover switch to select between Centaur internal (battery) and external power, rise-off umbilicals located on Centaur/CISS, military specification wire and connectors comprising the distribution system. This is the flight-proven system flown successfully on Atlas/Centaur. The principal changes accommodate the larger equipment mounting ring and new equipment. A functional diagram of the system Centaur and CISS power and distribution system are shown in Figure 3-60.

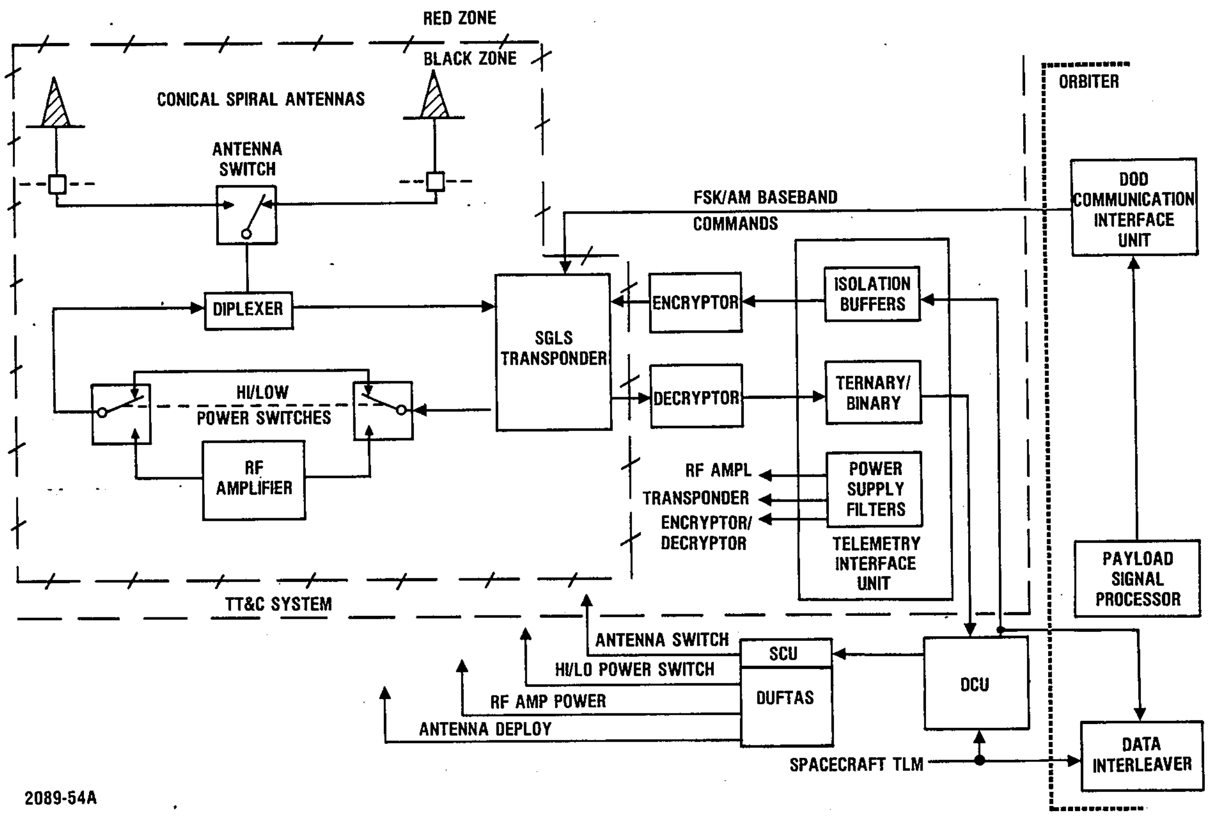

Figure 3-59. Centaur G TT&C System for DoD Missions.

The Centaur G power and distribution system for DoD missions is identical to the baseline Centaur G except for adding batteries and equipment to; provide (1) spacecraft electrical staging, (2) a spacecraft separation system, (3) a unique spacecraft power and control system, (4) a much expanded spacecraft electrical interface, and (5) revised and new harnesses to interconnect the systems.

3.3.5.2 CISS Avionics — Five control processors with majority voting ensure compliance with Orbiter safety requirements. Control of the systems at the functional level with voting at the output plane simplifies the redundancy management (Figure 3-61).

The CISS provides all electrical interfaces between Centaur and the Orbiter. CISS also provides:

- Computer control for operational sequencing of all systems requiring multiple-failure tolerance.
- Electrical power and power control.
- Instrumentation and telemetry.
- Pyrotechnic control for Centaur separation.
- Centaur propellant-level tanking indications.

All harnesses that provide Orbiter services to and from the Centaur cargo element, including the spacecraft, will interface through the CISS. Standard Orbiter-provided interfaces are used for all uplink command and downlink data services, for crew monitor and control, and for hardwires to ground support equipment through the T-0 umbilical.

3.3.5.2.1 Control System — The CISS control subsystem controls the safety functions on CISS and Centaur (from preflight until separation) at a two-failure tolerant level for critical functions. All systems are controlled at the functional level to eliminate extensive feedback networks required to detect failures at the component level.

The control system executes a majority vote at the output of each of the five independent control units. The vote is achieved at the output plane by interconnection of relay contacts, as shown in Figure 3-62. Voting at the power/load interface eliminates the necessity for failure detection within the electronic strings. This approach permits straight- forward functional control laws for subsystem functional control and fault detection.

A Centaur DCU located on the CISS provides PCM data from all control units to the ground and

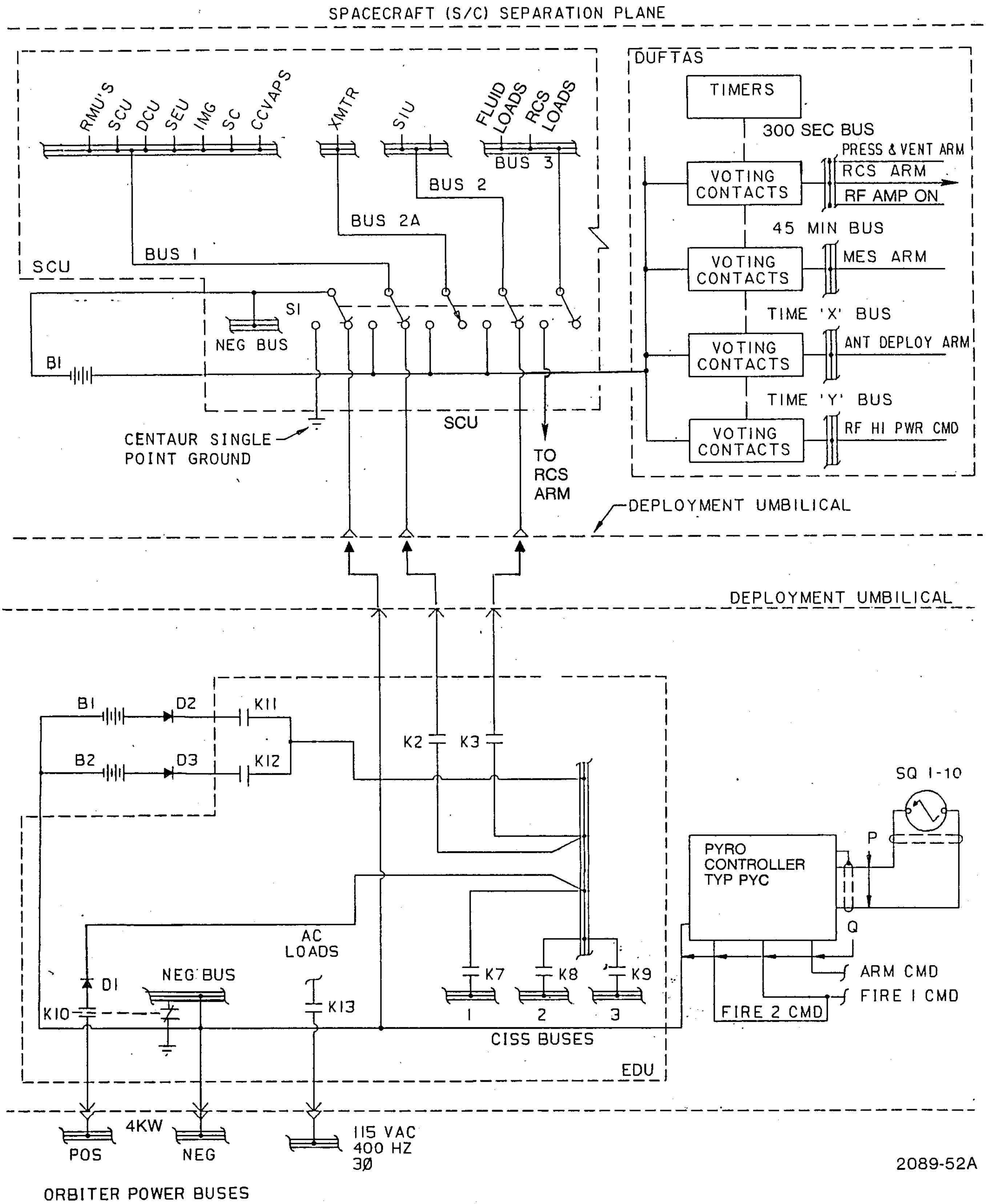

Figure 3-60. Centaur G Electrical Power System.

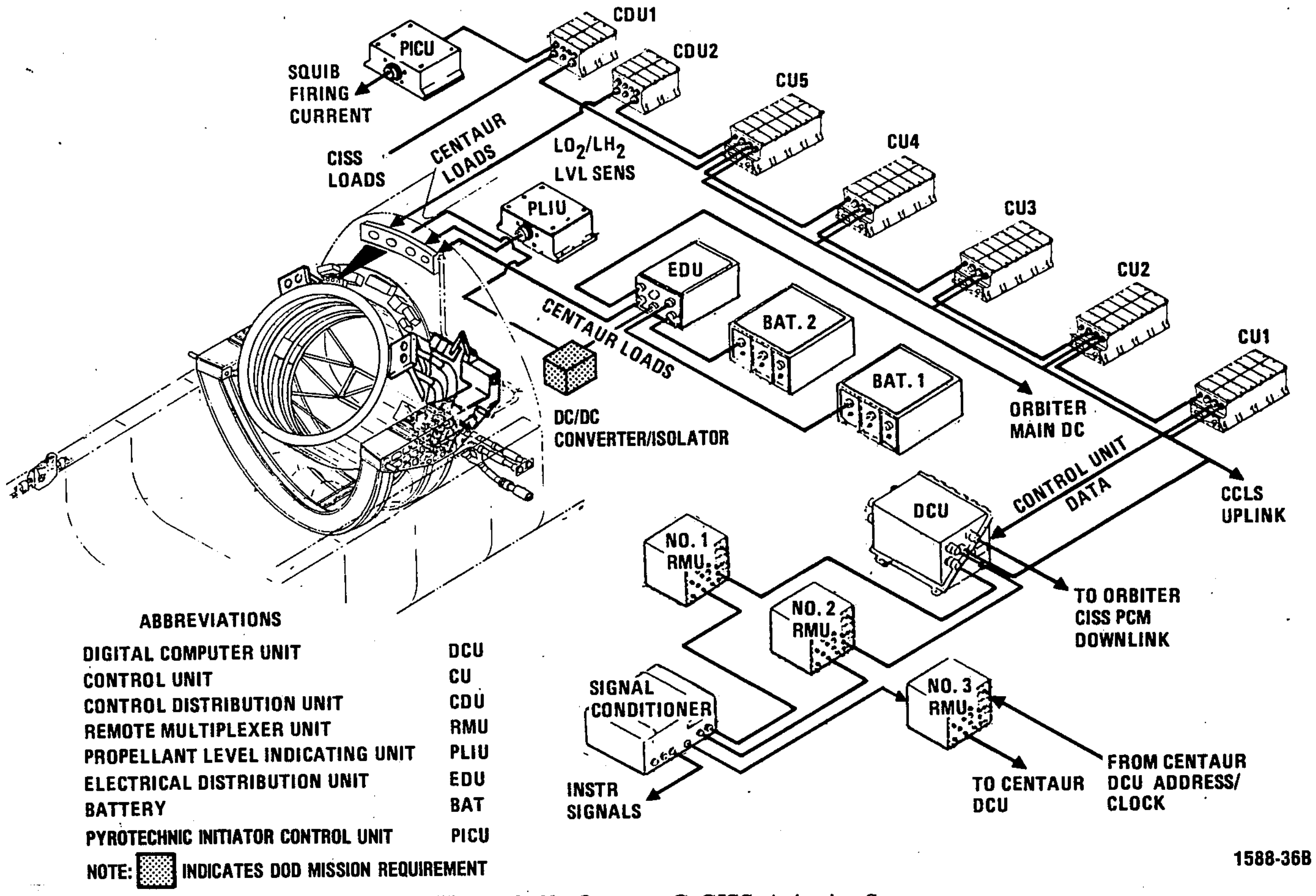

Figure 3-61. Centaur G CISS Avionics System.

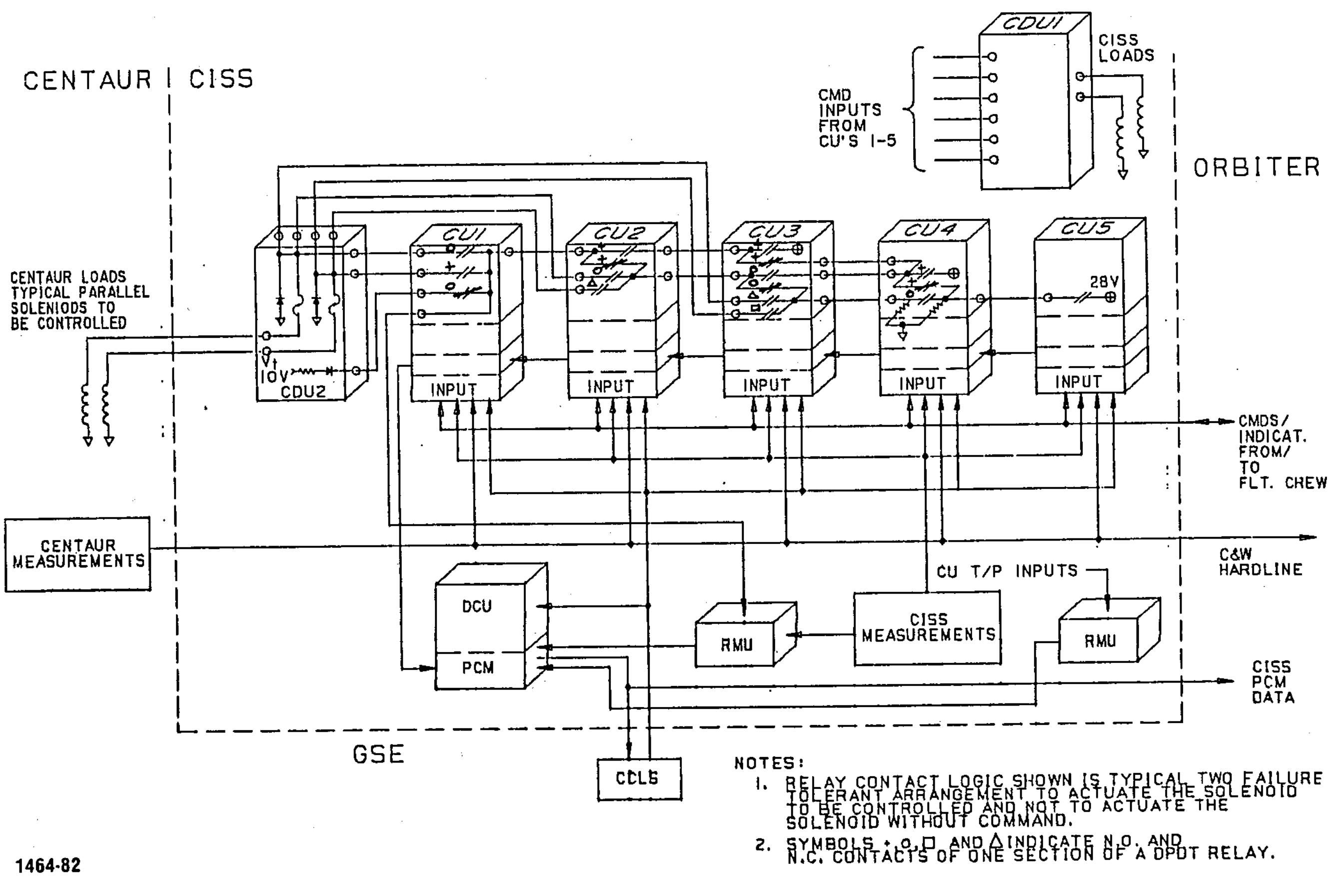

Figure 3-62. Five-String Voter Control Units.

to the Orbiter. The DCU is also used in the instrumentation and telemetry subsystem.

The relay networks are designed to provide individual load control from the CCLS. Test points and instrumentation permit verification of proper functioning of individual control units (CU) and relay networks during all operations.

Command and data communication links provide individual control and monitoring of the CUs. Commands to the CUs during ground operations originate at CCLS and are used to load flight-dependent constants, initiate ground operations, and execute prelaunch checkout programs. During flight, discrete commands originating at the switch panels will initiate in-line automated sequences such as the on-orbit deployment sequences. The abort dump of propellants is initiated by discretes from the commander.

Downlink PCM data paths will be provided to the CCLS and to the Orbiter for visibility into the state of the CISS.

Two data paths, one from the CISS and one from Centaur, provide monitor capability for closed-loop ground checkout operations with the computer-controlled launch set (CCLS). A third, abbreviated set of data is made available through the Orbiter only for manual detanking. The status of all systems will be available to the Orbiter and to the ground after liftoff via the three data paths. The data will be used to verify proper system operation while some data is fed into the Orbiter caution and warning system.

3.3.5.2.2 Electrical Power System — The CISS electrical power and distribution system consists of two fully rated silver-zinc primary batteries, redundant with Orbiter power to provide two-failure-tolerant power to CISS/Centaur in the attached mode. Power control, diode isolation, and bus excitation for both Centaur (external) and CISS loads are provided by the electrical distribution unit (EDU). The Centaur umbilical are zero-force (nominal) rise-off disconnects. Military specification wire and connectors are used in the harnesses. All of these assemblies/components are space flight proven or direct derivatives thereof.

The CISS electrical power system for DoD applications is identical to the above except for adding batteries and equipment to provide (1) spacecraft-peculiar power, via dc/dc converter/isolator as shown in Figure 3-61, (2) the control/ selection of spacecraft power, (3) an expanded spacecraft-to-Orbiter interface, and (4) revised and new harnesses to interconnect the systems.

3.3.5.2.3 Instrumentation and Telemetry System — The Centaur G CISS instrumentation system, (Figure 3-63), follows the operating hardware, installation and general practice philosophy currently used on Atlas/Centaur. A signal conditioner and two remote multiplexer units (RMU) support the CISS measurements. A third RMU provides a redundant path for selected CISS measurements to the Centaur G vehicle digital computer unit (DCU), pulse code modulation (PCM) system. The CISS DCU provides a PCM stream independent of the Centaur G vehicle PCM to the Orbiter payload data interleaver, payload recorders, and the CCLS. The CISS PCM also interleaves the control unit data.

3.3.5.2.4 Pyrotechnic System — Pyrotechnic devices required for Centaur G deployment from the Orbiter will be initiated by NASA standard initiators.

3.3.5.2.5 Propellant Level Indicating System — A propellant level indicating unit supplies power to the tanking level sensors and will detect wet/dry condition of the sensors. Indications are provided to the propellant loading control system via the telemetry system.

3.3.5.3 Orbiter Interfaces — This system is designed to minimize avionics interfaces with the Orbiter. The interface requirements are met using only elements of the standard Orbiter services plus two small cables. Orbiter services used are:

- Telemetry and data services to monitor the status of the Centaur cargo element (CCE) in the attached and detached modes.
- Command interfaces for controlling on-orbit deployment functions.
- Displays and controls for crew status monitoring and safing interfaces.
- Power and cable interfaces.

The extent of the Orbiter services required is discussed in the following paragraphs.

3.3.5.3.1 Telemetry and Data Services — The Orbiter interleaves PCM data from two spacecraft channels, one Centaur, and one CISS. In the attached mode, three individual payload data interleaver channels receive serial data and select specific preprogrammed words to be interleaved with Orbiter data transmitted to the ground; 6.4 kilobits of Orbiter S-band downlink data is available during ascent and 32 kilobits during on-orbit operations.

On-orbit data service is augmented by the Orbiter through the use of the KU-band system

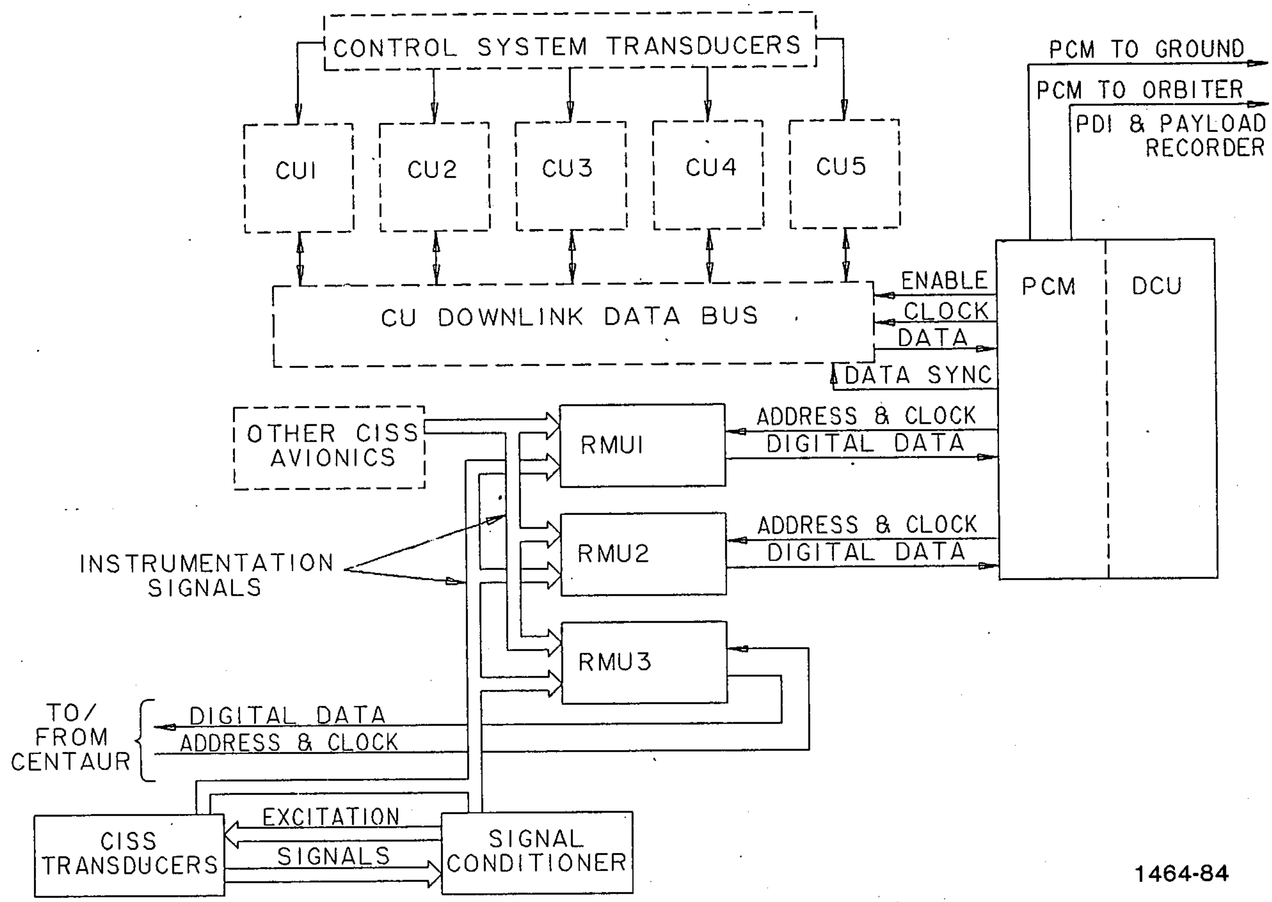

Figure 3-63. CISS Instrumentation System.

which enables 64 kilobits to be interleaved and sent to the ground.

In the detached mode, CISS continues to send data to the data interleaver; however, Centaur/spacecraft data will flow to the Orbiter through the payload interrogator. Two payload recorder channels and the Orbiter bent-pipe downlink mode supplement the Orbiter's real-time downlink data capability.

Modification of the interfaces necessary for Centaur G to accommodate spacecraft requirements and to permit processing secure communications are presented in Section 3.3.5.1.8.

3.3.5.3.2 Command, Display, and Control Interfaces — Command inputs from the crew are required for on-orbit deployment functions and abort operations. Commands are initiated via the standard switch panel, commander's safing panel, or standard software functions controlled by the keyboard. Safety inputs for monitoring will be read in through the payload data interleaver and/or the payload interrogator in the attached or detached mode and through direct measurements wired into the multiplexer-demultiplexer caution/warning inputs, or from the five channels of the caution/warning electronics assembly.

During predeployment sequences, keyboard commands initiate RF operations through the payload interrogator and send a navigation update to Centaur via the payload signal processor. Commands and feedback responses at the standard switch panel initiate and monitor Centaur Cargo Element (CCE) automated deployment functions. Safety information is brought to the crew's attention by the caution/warning electronic assembly or by data under analysis by standard Orbiter system software. The data will be displayed on cathode ray tubes (CRTs). Safety abort dump commands are initiated via the commander's safing panel, keyboard, or GPC with commander initiation of Orbiter abort.

The command, display and control interfaces for DoD applications will be the same as for the baseline Centaur G, except some modifications to interface harnessing and crew procedures may be required to accommodate spacecraft requirements and processing of secure communications.

3.3.5.3.3 Electrical Power and Cabling — The CCE uses Orbiter power to supplement its two banks of silver-zinc batteries. No direct ground support cabling is necessary. During ground operations, the CCE uses the 4 kW of allocated power. During prelaunch, ascent and on orbit, the CCE will use the 4 kW provided by the Orbiter as its primary power source.

Cabling that supplies power and all other electrical interfaces consists of four sections of standard mix cargo harness (SMCH) and two smaller, CCE-unique cables. Cable interfaces afford the CCE the full complement of T-0 umbilical wires allocated for the Orbiter cargo. Unique harnessing will provide the mix of payload services — both avionic and from the flight deck — to meet system requirements and reduce weight. A physical connection is located on the port and starboard sides of the CISS. Attach points are at the forward end of the CISS.

Additional spacecraft power requirements for DoD missions may require addition of a payload-chargeable reactant kit to the Orbiter power system. Interface cabling will be modified to accommodate spacecraft requirements.

3.3.6 SOFTWARE SYSTEMS

3.3.6.1 Vehicle DCU Software Systems

3.3.6.1.1 Centaur G DCU Software Baseline — Centaur vehicle software supports ground checkout, launch, and flight operations. It is defined as the software that executes within the Centaur vehicle DCU.

The software is divided into two basic operational categories: preflight and flight.

Preflight software covers ground checkout and operations up to launch. Flight software covers all vehicle DCU activities from launch to mission completion.

Safety-related vehicle functions, while Centaur is attached to the Orbiter, are excluded from DCU responsibility; they are performed by an independent set of Centaur integrated support system (CISS) avionics and software. This approach greatly reduces vehicle software requirements related to single and dual-failure-tolerant operations. The flight DCU software, although operating in a "single string" avionics system, employs software and hardware backups that make the flight-program operation as forgiving as possible of critical hardware failures.

DCU preflight software operations are closely integrated and augmented with the CCLS ground-launch computer software. This minimizes the software burden on the DCU during ground operations. The preflight software uses storage overlays and limits itself to the 4,096 words of alterable memory to minimize core requirements.

Major functions that the preflight operations support are:

- Centaur and spacecraft systems checkout
- Centaur IRU calibration and alignment
- Communications between the Centaur DCU and the CCLS ground computer
- Terminal-count sequencing and testing

Flight modules are stored in the 12,288 words of DCU nonalterable memory, but also use most of the alterable memory for scratchpad and data storage after vehicle liftoff. Major functions of the flight software are:

- Vehicle sequencing
- Vehicle guidance
- Navigation
- Vehicle control
- Propellant utilization
- Vehicle-tank-pressure control
- Telemetry formatting
- Star-scanner operations
- Communications to and from the Orbiter.

Centaur flight software operates in a passive mode through deployment from the Orbiter. The CISS remains in full control of all vehicle safety-related functions during this period. The only DCU programs that will be operating before deployment, other than the resident control system, are:

- Navigation
- Telemetry
- Star-scanner operations
- DCU self-test
- System checkout
- Vehicle sequencer.

The software is structured in a modular concept where each module performs a unique function and represents a convenient and manageable segment of instructions and/or constants individually coded, checked, documented, and maintained in a program library under configuration control. Individual software modules selected from the library are integrated to satisfy the program requirements for a mission and undergo integrated program checkout. Table 3-4 (software preflight and flight modules) lists the software modules in each category that were selected to satisfy the Centaur G program requirements.

Table 3-4. Software Preflight and Flight Modules.

Preflight Modules	Flight Modules
Preflight Resident Control	Attitude Error and DDR
DCU Alterable Memory Test	Arm/Inhibit
DCU Non-Alterable Memory Test	Coast Autopilot
Ramp Output Generator	Coast Guidance
Sawtooth Output Generator	Permanent Constants
Sine Wave Output Generator	Centaur Star Scanner
SCU Switch Test	Computer Controlled Vent and Pressure
Gimbal Angle Test	Flight Initialization
IRU Calibration & Alignment	Powered Guidance
DCU Memory Dump	Hydrazine Monitor
Vehicle End-To-End Steering Test	Non-Duplicate Literals
DCU SKD Test	Navigation
IMG Steering Chain Test	Powered Autopilot
PU Test	Predeployment Checks
Gimbal Slew Test	Vehicle Telemetry Program
DCU Instruction Test	Post Injection
Combined Function Generator	Platform Torquing Test
Terminal Count Sequencing	Propellant Utilization
DCU Interrupt Check	Discrete Priority
DCU I/O Driver	Resident Control System
Communications Link Test	Steering Interface
Spacecraft Test	Slack Time Task
Avionics Test	Mission and Vehicle Peculiar Telemetry
	Vehicle Sequencer
	Antenna Selection

1464-86

Each DCU module is coded in machine-assembly language unique to the DCU instruction set. The library of modules so coded is extensive and flight-proven and includes software programs from Atlas/Centaur and Titan/Centaur missions. All modules, because of their machine language coding, are highly efficient and optimized for minimum DCU core usage and/or duty cycle, as the case demands.

3.3.6.1.2 Software Changes Relative to the Baseline — DCU software existing for the baseline Centaur G/Galileo mission will be adapted with minor modifications to perform the DoD geosynchronous mission. The majority of the flight software will be identical for both the DoD and NASA missions. The following modifications have been identified as required to support the DoD missions.

1. Extend the guidance related modules to support the two-burn mission box.
2. Add mission-peculiar coast phase pointing for passive thermal control and telemetry orientations.
3. Modify the vehicle sequencing software to support two-burn missions.
4. Support unique mission-peculiar telemetry requirements.
5. Modify preflight tenants to support mission-peculiar spacecraft checkout, as required.

These items are amplified below.

The baseline guidance equations are nearly optimum, highly flexible and modular designed for both planetary and earth-orbit applications, and are derived from our existing Atlas/Centaur and Titan/Centaur software library. To support the DoD mission box, the Galileo guidance equations will be modified only to the extent of initializing the target orbit and adding a coast phase (MECO-1 MES2) guidance module, and the exchange of yaw steering subroutine. The initialization subroutine, which is mission peculiar, will be modified to delete parameters of the Galileo hyperbolic orbit (such as asymptote and orbital energy), which are not applicable to the DoD missions, and replace the target orbit definition with parameters descriptive of the mission box. These parameters, which will be input directly to the guidance equations, can be selected from the following:

- Apogee
- Perigee
- Eccentricity
- Argument of perigee
- Inclination
- Ascending node

The target orbit constants are loaded into the DCU from a constants tape and are not part of the DCU program, non-alterable memory load. (Rapid targeting is discussed in Section 3.3.6.1.6.) This capability permits the generalized guidance equations to accomplish all missions within the mission box simply by specifying the appropriate targeting data. The coast phase guidance module is added to the baseline software to provide mission-peculiar coast phase pointing to satisfy passive thermal control and telemetry requirements. Alignments relative to the nadir or ecliptic plane are selected from prestored options. Roll rates are part of the existing baseline software.

The guidance module is constructed of approximately 15 subroutines. This design facilitates the construction of the guidance module from the software library to satisfy mission-peculiar requirements while retaining the basic structure and algorithms across a mission set that may include both one-burn and multi-burn missions, as well as planetary and earth-orbit missions. One of the mission-peculiar options is to select the yaw steering mode appropriate to the mission requirements. The baseline Galileo program employs an option that optimally steers in yaw so that the orbit plane at MECO contains the outgoing asymptote of the hyperbola. For geosynchronous missions, this subroutine will be replaced with one that will control node and/or inclination. These options have been flown on our current Atlas and Centaur programs.

DCU software functions are sequenced by a software sequencing module that acts as the master controller of the system. It performs such functions as:

- Program synchronization to major events.
- Starting and stopping execution of software modules.
- Issuing time-related discretes for both hardware and software.

The sequencing module relates closely to the specific requirements for a mission. It therefore requires software modification to perform those discrete time- and event-related functions. The sequencer design within the Centaur G flight software is such that the majority of modification required from mission to mission may be accomplished mainly by a change of constants maintained in a sequencer table. This design has proven both desirable and convenient during previous Centaur missions by requiring a minimum of software logic changes to accomplish a wide range of mission-sequencing requirements. This greatly reduces cost of software checkout and establishes a degree of consistency within the software for varying missions.

Centaur vehicle data and DCU computed data are organized and selected for telemetry by a mission-peculiar software module and a software-telemetry-format routine. The mission and vehicle-peculiar telemetry software will be modified to be compatible with the trajectory-data telemetry requirements. This will include the predicted post MECO1 and MECO2 state vectors.

A minimum of change is required to the preflight software, the majority of which is common. The ground testing and launch support performed by the preflight software is largely directed toward the Centaur vehicle system and avionics testing and calibration. The exception would be any special spacecraft testing unique to DoD applications that would be required while on the ground after the spacecraft is mated with the Centaur vehicle.

The structure of the preflight software design (modular concept and overlay techniques) results in a minimum interface between the baseline Centaur G preflight software and any unique Centaur G preflight spacecraft software required in the vehicle DCU. Any such unique software modules are easily integrated into the library of preflight modules.

3.3.6.1.3 DCU Resource Summary — The Centaur vehicle DCU memory is adequate to accommodate the Centaur G software. Of the 16,384 memory cells available in the DCU, the Centaur G software will require up to 13,742 leaving 2,642 unused and available for additional requirements. Table 3-5 (estimated Centaur vehicle DCU memory re-

Table 3-5. Estimated Centaur Vehicle DCU Memory Requirements.

FLIGHT MODULE	Centaur G Core Storage Required
Attitude Error and DDR	137
Arm/Inhibit	70
Coast Autopilot	339
Coast Guidance	504
Permanent Constants and Sequencing Data Table	547
Centaur Star Scanner	2500
Computer Controller Vent and Pressure	702
Flight Initialization	159
Powered Guidance	1584
Hydrazine Monitor	69
Non-Duplicate Literals	110
Navigation	652
Powered Autopilot	258
Predeployment Checks	250
Vehicle Telemetry Program	1488
Post Injection	31
Platform Torquing Test	55
Propellant Utilization	189
Discrete Priority	208
Resident Control System	1937
Steering Interface	734
Mission and Vehicle Peculiar Telemetry	786
Vehicle Sequencer	323
Antenna Selection	110
INFLIGHT PROGRAM TOTALS (WORDS)	13,742

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quirements) lists the flight program modules, the baseline memory requirements. Previous experience in performing numerous mission-peculiar changes to the DCU flight software for Atlas/Centaur and Titan/Centaur programs has developed the expertise as well as the software structure and techniques to readily and efficiently incorporate a wide class of mission-peculiar changes into the basic Centaur vehicle software.

Approximately five modules, including constants, will require some degree of modification to support DoD missions. These modifications are estimated as a 4% increase in the software memory requirements over the baseline Centaur G. This will still leave a 2,000 memory-cell margin for future contingencies.

Peak duty-cycle requirements on the existing Atlas/Centaur flight software are 80% of capacity. Since this peak occurs during the Atlas ascent phase, the peak duty cycle required for the Centaur G is expected to be less than 80%. The 20% spare capacity is considered more than adequate due to the maturity of the baseline software and the small amount of changes required for Centaur G.

3.3.6.1.4 Software Documentation and Configuration Control — General Dynamics Convair Division will prepare a software development plan that will define the software development process. This plan will be in accordance with existing software control procedures.

General Dynamics will prepare functional requirements documents (FRD) to define the software requirements to support Centaur G. These documents will serve as the software specifications for the software development.

General Dynamics will begin coding the software after the requirements are documented. General Dynamics will develop, check out, and control the software initially on a module-level basis, expanding to program levels as the module checkout is completed.

The major software configuration control tool is the check figure, a number that is generated by adding the computer instructions within a module or program, carrying to the low-order bit in the event of overflow. The check figure changes not only when instructions within a module change, but also when the sequence of the instructions changes. General Dynamics will use source-code check figures to control the module source programs, object-code check figures for the object code, and total-load check figures to control the entire DCU memory load. Computer load is inhibited in the event of a check-figure discrepancy. The check-figure control is used for both the flight program and constants load tapes.

3.3.6.1.5 Security — General Dynamics Convair Division's large-scale computer processing facility, including a Cyber 172 computer, is designed to secret security requirements. The Cyber is the host for our analysis and simulation computer programs. General Dynamics Convair uses the Cyber in its secret mode when necessary to generate the operational mission trajectory during the targeting process. This facility is currently used to perform classified targeting validation. General Dynamics Convair uses the Cyber in its unclassified mode for analyses and mission box trajectory simulations.

General Dynamics Convair will perform software and simulation tests for the telemetry encryption software on our classified mission analysis facility. This facility is designed to Top Secret security requirements and consists of a TEMPEST data processing room and an operations center.

3.3.6.1.6 Deployment Delays — The Centaur DCU is synchronized to real time (GMT) through the GSE before liftoff. Since the system is navigating from the ground up, the Centaur is insensitive to delays in deployment of the Centaur from the orbiter. This permits the mission to be accomplished on any deployment opportunity. For those missions that have a time-dependent target condition (such as ascending node), the appropriate target-orbit data can be selected from prestored options within the DCU, once the deployment time is established. This feature is also a part of the baseline Galileo software, in which the planetary targeting is performed on board the DCU after deployment, using prestored trajectory data (in this case, the desired hyperbolic asymptote and orbital energy). The synchronization of DCU time and GMT thus makes the Centaur system autonomous, and obviates the need for crew-initiated functions to initialize the software or communicate the deployment time.

3.3.6.1.7 Rapid Targeting — The baseline guidance equations are a simple modification of the existing Atlas/Centaur and Titan/Centaur guidance equations (the modifications are primarily the deletion of Atlas- and Titan-peculiar functions). These equations are an explicit formulation of the two-point boundary value problem and, as such, require a minimum of targeting data and no *a priori* trajectory shaping information. This permits the targeting process to be extremely simple, and enables the target orbit to be selected very close to launch.

The guidance software will be validated over the entire mission box, using representative target orbits. The validation is intended to test the guidance equations and airborne implementation using nominal, 3σ and abnormal ($> 3\sigma$) environments, but not necessarily the particular guidance constants of a specific mission. Targeting, which is the generation of the target orbit guidance constants, proceeds as follows:

1. The target orbit parameters are selected anywhere within the range of the previously validated mission box. The target parameters include apogee, perigee, eccentricity, argument of perigee, inclination, and ascending node.
2. The selected parameters are input to the closed-loop guided simulation and a set of test cases (nominal and 3σ environments) is executed in the general purpose, non-real-time simulation to verify targeting accuracy.
3. A constants tape is written with the parameters of the target orbit, and firing tables are generated. (Firing tables are an aid to the launch site personnel to verify the contents of the flight constants tape.)
4. The constants tape and firing tables are transmitted to the launch site.

The current targeting ten weeks before launch of Atlas/Centaur FLTSATCOM and INTELSAT missions is typically accomplished in less than five days. Since there is no design work in this targeting process, it can be automated and carried out comfortably 48 hours before launch.

3.3.6.1.8 Software Validation — The analysis and validation of the flight software is performed on three levels and with three simulation tools. The three levels of testing and validation are:

1. Design, analysis and evaluation of the flight algorithms
2. Module-level checkout of the flight software
3. Integrated systems level checkout of the flight software.

The design, analysis, and evaluation of the flight algorithms — e.g., guidance, navigation, etc. — is performed on the Cyber-172 general-purpose computer, using Fortran replicas of the flight software in a nonreal-time mode. The software is tested using nominal, 3σ, abnormal ($> 3\sigma$) and failure-mode environments for the complete range of target conditions, i.e., the complete mission box. Compliance with software accuracy requirements is established with these tests, with the exception of inaccuracies caused by the flight-computer truncation.

Module-level tests are performed using the interperative computer simulation (ICS). The ICS is discused in Section 3.3.6.5. These tests are designed to validate the airborne code of each module in the flight program. The outputs from these module-level tests are compared to the outputs from the Fortran replicas driven by identical inputs. This establishes truncation errors due to the flight DCU. The ICS also provides scaling evaluation of the fixed-point DCU code, and timing analysis of each module.

Integrated software checkout is also performed with the Cyber ICS. In this mode, the ICS is run closed-loop in conjunction with the general-purpose trajectory simulation and executes all, or subsets, of the flight modules. This simulation validates interfaces between the software modules, and provides timing data at the integrated systems level. The ICS in this mode is nonreal time.

The integrated systems-level validation is performed in the SIF with the actual-flight DCU code executing in a flight configuration DCU, in real time, in a closed-loop guidance mode in conjunction with a general purpose vehicle simulation. This simulation, the flight analogous software test (FAST), is discussed in Section 3.3.6.5, and provides all the external I/O to the flight program. The FAST tests provide a complete system-level software interface validation, and a final evaluation of DCU truncation and timing. The output from this test is orbital data, analog traces of significant DCU parameters, and a telemetry tape of all DCU data for post-processing analysis.

This validation procedure is the same as that employed on the current Atlas/Centaur program. For DoD missions, the validation results could be augmented with those obtained by an independent validator.

3.3.6.2 CISS Software — The CISS software is defined as that software that executes within the five CISS control units (CUs) plus the CISS DCU. The major purpose of the CISS software is to control in a one or two failure-tolerant system all safety-related functions while the Centaur vehicle is attached to the orbiter. This design relieves the burden which would otherwise be placed on the Centaur vehicle avionics to control these functions in a two-failure-tolerant mode. The CISS software supports:

- Ground testing at the factory, Complex 36, Shuttle Payload Integration Facility, Vertical Processing Facility, and Complex 39

- Ground and launch support operations, including Centaur vehicle tanking
- Predeployment testing and operations of Centaur and CISS
- Prelanding and postlanding operations, including abort.

During ground operations, the software is closely monitored and controlled by the CCLS ground computer. The CCLS can communicate to any of the five CISS CUs or CISS DCU. After liftoff, the CISS software is controlled via internal CU software sequencing and via discrete commands from the orbiter.

3.3.6.2.1 CISS Control-Unit Software — The software basic design approach for the CUs is similar to that employed so successfully for the Centaur DCU. The software uses the same modular concept and is operationally controlled by a software task scheduler. The CUs are coded in a machine-assembly language. The software is being developed on the General Dynamics Software Engineering System (SES). It is documented and under configuration control similar to that for Centaur DCU software.

Table 3-6 (microprocessor functional control modules) lists the functional control modules for each of the five control units. A minimum amount of system checkout and control-unit self-testing is planned. This simplified test approach is made possible by the avionics system design, whereby control of a system is at the functional level and the five control-unit outputs are voted on at the relay level. These concepts greatly simplify both the magnitude and complexity of the software, which otherwise would have to address itself to the problems of fault detection and system reconfiguration. The microprocessor memory for each control unit is 8K of eight-bit programmable read-only memory (PROM) and 1K of eight-bit random access memory (RAM). This is considered adequate to maintain sufficient margin for contingencies.

Table 3-6. Microprocessor Functional Control Modules.

FUNCTION	
Computer Control System	**Functional Control System**
Telemetry	Sequencer
Task Scheduler	Tanking
I/O	Testing
Exec. Control	Press. & Vent Cont.
Uplink Control	ΔP Control
Interrupt Logic	Dump Logic
Initialization	Power Monitor & Cont.
	Purge
	Pneumatics
	Deployment

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Among significant features of the CU software design are:

- Each control unit operates independently to avoid single-point failures.
- Time synchronization of each control unit's functional program operation is not required.
- Downlink data from each control unit is synchronized at the start of a data cycle to avoid double-decommutation of PCM data.
- Software in the programmable read-only memory (PROM) of all microprocessors is identical to maintain control-unit interchangeability.
- CISS control units actively control all safety-related Centaur vehicle operations up through deployment; e.g.:
  - Sequencing
  - Pressurization and vent control
  - Abort operations
  - Purge-system control
  - Pneumatic-system control
  - Deployment operations
- CCLS will be able to communicate independently with each control unit.
- Control units will not be required to communicate with one another or communicate with the Centaur DCU.

3.3.6.2.2 CISS DCU Software — As its main function for both preflight and flight operations, the CISS DCU will downlink PCM data gathered from the two CISS RMUs and the five control units. The only software required is a resident control system similar to that used by the Centaur vehicle DCU and one or more unique PCM formats to satisfy data downlink requirements.

The CISS software is fully mission independent and will support all Centaur G operations with no changes.

3.3.6.3 CCLS Software — CCLS ground software supports vehicle checkout and tanking and verifies the launch readiness of the Centaur cargo element. Checkout is performed by communicating test instructions to the Centaur DCU and CISS CUs which, in turn, provides test stimuli to the vehicle avionics. CCLS, in turn, monitors vehicle responses via PCM telemetry and verifies proper conditions and tolerances.

The basic requirements for CCLS software are:

- Control and monitor Centaur and CISS avionics systems.
- Control and monitor Centaur tanking operations.
- Adequately exercise systems for thorough problem isolation.
- Maintain flexible operator command and control.
- Generate accurate historical-data records.
- Perform testing safely with minimum chance for human error.

The CCLS software is divided into modules, which perform system and executive functions, and applications programs, which perform validation, airborne testing, and vehicle functional operations. All CCLS software is documented, released, and under configuration control.

The only area that will require modifications for DoD mission will be the uplink processor software, which will handle the transmission of secure data to the DCU.

3.3.6.4 Computer-controlled Test Equipment (CCTE) Software — CCTE software is composed of three software groups to allow checkout and evaluation of Centaur avionic packages and their associated cards and modules. These three software groups are:

- The circuit card and module software associated with the Hewlett Packard HP1000 computer to checkout analog boards. These programs are written in FORTRAN.
- The circuit card and module software associated with the HP1000 computer to checkout digital (TTC) boards. These programs are written in Test Aid III.
- The package level checkout software associated with the Harris H100 computer to perform functional, temperature and vibration package testing. These programs are written in Fortran.

There are no known modifications required to CCTE software for DoD missions.

3.3.6.5 Support Software — The baseline Centaur G support software is applicable to all missions without change. The DCU support software consists of the following elements.

1. Interpretive computer simulation (ICS)
2. Flight analogous software test (FAST) integrated system simulation
3. Assembler
4. Loader
5. Librarian

These tools are derived from the existing Atlas/Centaur program and are being adapted to the Centaur G program with only minor revisions. The ICS is being modified to add additional I/O functions consistent with computer modifications. The FAST simulation is being augmented with a Shuttle ascent simulation and star-scanner functions, and is being translated from a Harris/4 to a Harris/H800 computer. These support software revisions will be accomplished for the baseline Centaur G program, and will support the DoD missions without change. There are no changes to the assembler, loader, and librarian from the existing Atlas/Centaur program.

The ICS is an exact simulation of the DCU instruction set and interrupt structure. Bit-for-bit agreement has been verified between the simulation and the actual DCU hardware for all operations. The simulation contains diagnostic aids to permit the user to assess scaling of all variables, and timing of any subset of instructions, any module, or the entire integrated program. The ICS is typically used at both the module level and at the integrated system level.

For module-level checkout, special-purpose test drivers are created to execute the module under test. At the integrated-system level, the general purpose trajectory simulation is used as the executive program, and supplies the simulated external input to the ICS, which in turn simulates the DCU. All I/O is executed in this mode, including IRU outputs, tank pressures, and propellant sensors. In turn, the ICS outputs steering commands to the trajectory simulation to close the guidance and control loop. The ICS is resident on the Cyber 172 computer, and has been used for 10 years on the Atlas/Centaur and Titan/Centaur programs.

The FAST simulation is a simplified six-DOF simulation of the launch vehicle system, which operates in real time and interfaces with a DCU. The DCU is loaded with a flight program tape. This facility is used for extensive system-level validation of the integrated flight program, and exercises the actual flight-program code in both test and flight DCUs. The FAST simulation is used primarily to validate the operation of the integrated software, the external interfaces to the DCU, and the internal software interfaces in a realistic flight environment. This includes nominal, abnormal, and failure-mode environments. All external I/O and interrupt functions are exercised by the FAST simulation. These include:

1. Analog to digital inputs to the DCU
2. Digital to analog outputs from the DCU
3. Power on, power off, real-time (50 HZ), GSE, and telemetry interrupts
4. Discretes input to the DCU
5. Discretes output from the DCU

The FAST simulation outputs include trajectory and vehicle state data, analog traces of key DCU variables, and a DCU telemetry tape. The telemetry tape is processed with a companion post-processing program. The FAST simulation is resident on the Harris/H800 computer in the SIF.

The assembler for the DCU translates symbolically coded instructions (source program) into a relocatable, machine-oriented language. This assembler output is termed the object program. The source programs input to the assembler are maintained and modified under the CDC update utility. Use of the update utility provides a record or "tracks" of all changes made to a program. Finally, the assembler produces the source check figure and the loader check figure discussed under configuration control.

The loader for the DCU is a linking loader that takes relocatable object programs as input and produces an absolute load file for the target computer. The loader computes the check figure for each program module and compares it with the check figure computed by the assembler. If a miscompare is found a diagnostic is printed and the load is terminated, thus ensuring that the loader reads the object program correctly. When the load is completed, the loader computes a core load check figure for the absolute load. This core load check figure is sensitive to any change in the program, including the order in which the program modules are loaded. The core load check figure then becomes the configuration control tool used to identify the program tape used at DCU load time.

The librarian for the DCU software provides a facility for maintaining a library of object programs (assembler output) and their assembly listings. The librarian allows the user to select, by program module name, any mixture of previously assembled object programs. The librarian builds a file of object programs for input to the loader and a printed output assembly listing of each program selected. The librarian thus provides a cost-effective method of building a flight program without reassembling each module, and it assists configuration control by selecting known, previously tested, object program modules.

The assembler, loader, and librarian are all resident on the Cyber 172 computer.

The support software for the CUs is being developed on the General Dynamics Software Engineering System (SES). It uses the Harris Vulcan operating system, a multiuser, priority-structured memory-management program that concurrently maintains multistream batch processing, interactive time-sharing, data-base management, remote job-entry and real-time operations.

The support tools available with this system and used for Centaur G software development include:

- Z-80 microprocessor cross-assembler and compiler
- Zilog Z-80 simulator
- Software product management system
- Data analysis
- Software library system
- Automatic flow charting
- Documentation
- Graphic display

No changes are required to any of the CU support software development tools in order to support DoD missions

3.3.7 MASS PROPERTIES

3.3.7.1 Weights Summary — The top-level weights summary presented in Table 3-7 are used in mission analyses, the results of which are presented in Section 3.2.

3.3.7.2 Centaur/Spacecraft Weights Summary — A comparison of the major component weights of the baseline Centaur G and DoD version, each with its respective spacecraft, appears in Table 3-8. Weight differences between these vehicles are caused by mission-peculiar hardware differences.

Weight and cg will be controlled by continual analysis and reporting so that the Program Director can take appropriate action should a problem arise. In general, weight will be minimized insofar as possible and the Centaur lateral cg held within two inches of the vehicle centerline.

Although weights shown are initial estimates, the similarity in virtually all cases and actual com-

Table 3-7. Weights Summary for Centaur G Mission.

Item	Weight (lb) Centaur G (Baseline Planetary)	Centaur G (DoD GEO)
Total loaded weight	49,308	55,829
Total support weight	8,169	9,029
Spacecraft airborne support equipment	450	1,700
Centaur airborne support equipment*	7,719	7,329
Total vehicle weight	41,139	46,800
Spacecraft gross weight**	5,359	10,600
Centaur tanked weight	35,780	36,200
Centaur jettison weight	5,881	6,241
Centaur dry weight	5,460	5,687
Centaur residuals	421	556
Centaur expendables	29,899	29,934
Propellants	29,780	29,705
Main impulse	29,285	28,965
Non-propulsive	495	740
Hydrazine	117	250
Helium	2	4

* Conservatively assumed same as NASA version
** Includes mission adapter

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Table 3-8. Centaur Vehicle Weight Summary Comparison.

	Centaur G (Baseline)	Centaur G (DoD GEO)
Spacecraft System Weight	5,359	10,600
Centaur Tanked Weight	35,780	36,200
Centaur Jettisoned Weight	5,881	6,241
Centaur Dry Weight	5,460	5,687
Basic Vehicle Weight	5,206	5,433
Body Group	2,722	2,722
Propulsion System Group	1,149	1,174
Flight Control Group	310	310
Fluid Systems Group	599	628
Electrical Group	251	424
Separation Equipment — Aft	175	175
Information & Safety	254	254
GD/C Payload Adapters	0	0
Customer Payload Adapters	0	0
Launch Vehicle Mission Peculiar	0	0
Centaur Residuals	421	556
Propellants	358	433
H_2	119	189
O_2	289	244
N_2H_4	34	92
Helium	12	14
Ice	17	17
Centaur Expendables	29,959	29,899
Propellants	29,780	29,705
Main Impulse	29,285	28,965
H_2	4,131	3,934
O_2	25,154	25,031
Vent, Chill, Start & Shutdown Propellants	495	740
Hydrazine	117	250
Settling Motors	104	152
Attitude Control	13	98
Helium (PRE-MES)	2	4

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monality in many cases with current Centaur hardware lend confidence to overall weight accuracy.

Maximization of propellants available for impulse will be a design goal. This will be, and has been, accomplished by designing plumbing and tank geometry to minimize residuals. In addition, early knowledge of residuals and non-impulse propellant requirements tends to maximize propellant usage efficiency through proper tank sizing. One of the tools generated to ensure this efficiency is a tank volume computer program that calculates exact volumes based upon cryogenic, external loading, and acceleration effects. The program is currently used for both Atlas and Centaur vehicles.

Mass properties versus time of Centaur flight are calculated by an existing computer program that uses the volume program output and generates information at any time slice desired.

3.3.7.3 Centaur Airborne Support Equipment Weights — Table 3-9 lists weights of individual major components of Centaur G ASE for the baseline and DoD missions.

The CASE interface with the Orbiter, for mass properties generation purposes, has been carefully analyzed: first, by meeting the requirements of Vol. XIV as clarified by the amended Vol. X, and second by contacts with Rockwell International and Johnson Space Center personnel. The major objectives have been to ensure that:

- All items are accounted for.

Table 3-9. Centaur Airborne Support Equipment Summary Comparison.

	Centaur G (Baseline)	Centaur G (DoD GEO)
Centaur Airborne Support Equipment	7,719	7,329
Centaur Integrated Support Structure	5,510	5,510
Centaur Support Structure	2,069	2,069
Deployment Adapter	779	779
Fluid Systems — Dry	1,558	1,558
Avionics	1,104	1,104
Orbiter & CISS to Orbiter Equipment	2,107	1,717
Rockwell Supplied Fluid System Kit	223	223
Payload Support Fittings	1,028	1,028
Avionics	10	10
SMCH Cable (lighweight)	350	350
Payload Recorder	60	60
Payload Timing Buffer	3	0
Aft Flight Deck Harness	25	25
Switch Panels No. 1	21	21
ATCS Panels — RTG Cooling	387	0
Fluids	102	102
Helium	59	59
Trapped LO_2	40	40
Trapped LH_2	3	3
Payload ASE	450	1,700

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- Control has been exercised so that minimum weight results.
- Weight and cg limits have been satisfied.

The current estimate of cg station versus Orbiter limits for the various conditions of spacecraft and Centaur G is presented in Figure 3-64.

Estimates of the total mass properties effect of the mission or missions versus time of Shuttle flight and versus the various abort modes will be analyzed in detail by means of a computer program that is scheduled to become available for Centaur G this year.

3.3.7.4 Shuttle/Centaur x Center of Gravity vs. Limits — Figure 3-64 shows that all required center of gravity (cg) limits are met. The launch limit is not stated as a requirement in accordance with "Shuttle Operational Data Book." This is true because Shuttle/Centaur can dump propellants for abort. For vehicles which cannot dump propellants, the launch limit becomes a requirement because of the abort cg limit.

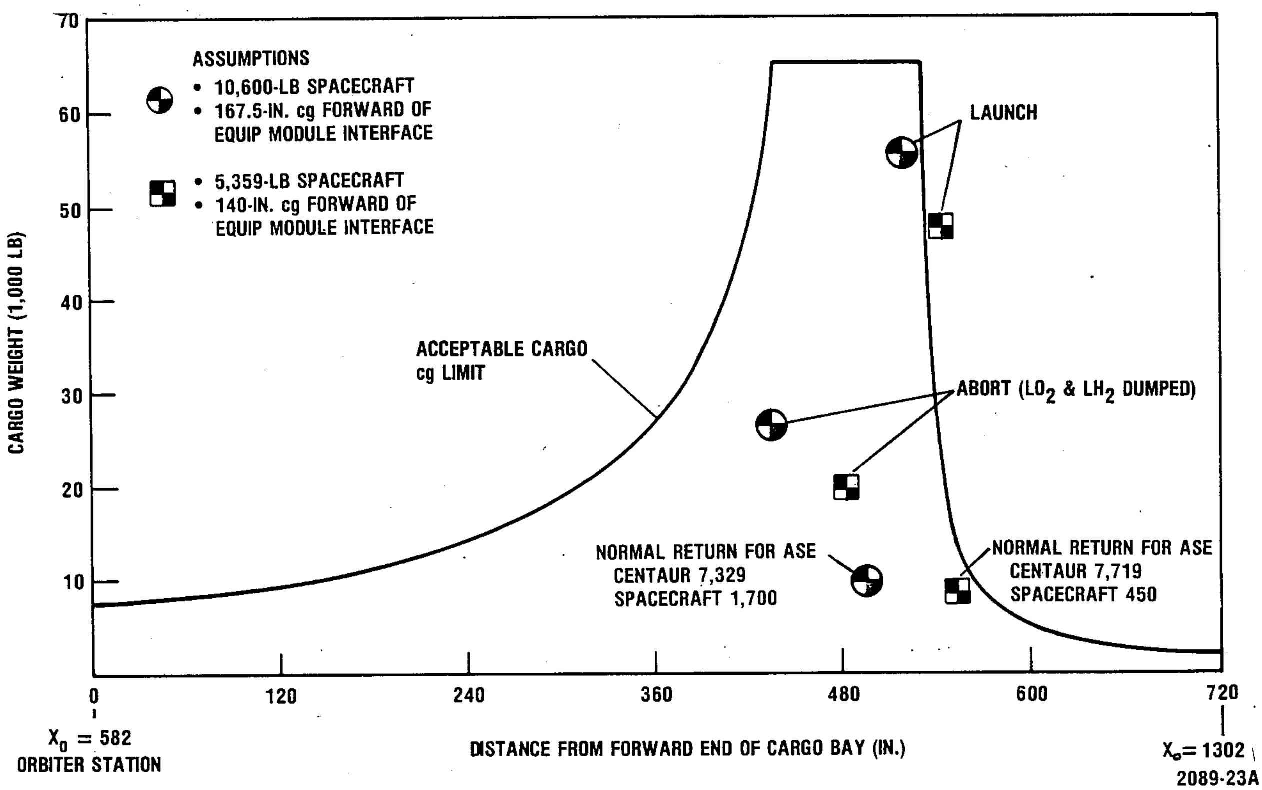

Figure 3-64. Shuttle/Centaur cg Limits for Centaur G.

3.4 SYSTEMS REQUIREMENTS

Centaur G draws upon the proven technology and reliability that successfully integrated the Centaur with many NASA and military spacecraft, two different boosters — Titan and Atlas.

3.4.1 INTEGRATION REQUIREMENTS — Integration requirements for Centaur G will be based upon a joint NASA/DoD program.

General Dynamics has successfully integrated and flown both the Atlas and Centaur on a variety of missions and with a variety of payloads. Included are the existing Atlas program at Vandenberg AFB and the Atlas/Centaur program, which includes both NASA and military payloads. The Centaur vehicle has been integrated with both Atlas and Titan boosters. We have also integrated and flown several military payloads on the Atlas SLV-3A from the Eastern Launch Site.

Centaur G is being integrated into the Space Transportation System through the efforts of the various integration panels and working groups at the NASA Johnson Space Center, Kennedy Space Center, and Lewis Research Center. The panels have been set up to review and control the integration of Shuttle-to-Centaur interfaces, as well as to handle any spacecraft-peculiar requirements. The various interfaces are being worked in conjunction with Rockwell to ensure complete compatibility with the Space Shuttle Orbiter.

Activities unique to DoD missions on Centaur G, such as secure communications or ground operations with classified payloads, will similarly be integrated into the system.

The Centaur G stage is being integrated into Shuttle in such a manner as to minimize the impact on Shuttle. Centaur G will use the standard Shuttle interfaces, as defined in JSC 07700, Volume XIV, "Space Shuttle System Payload Accommodations," which includes as an attachment ICD 2-19001, "Shuttle Orbiter/Cargo Standard Interface." Additionally, the Centaur will comply with JSC 07700, Volume X, Appendix 10.16, "Shuttle Centaur/Centaur Airborne Support Equipment." For Centaur G, no change is anticipated.

The Centaur cargo element is designed to keep the Centaur vehicle as independent as possible of the Shuttle system or operation. The Centaur integrated support system (CISS) will be used to provide interface compatibility between Centaur and the Orbiter. In addition, the CISS will control all safety-critical functions for the Centaur vehicle with the level of redundancy necessary for the identified hazards.

Servicing of the liquid hydrogen propellant will be through the port-side midbody T-0 panel; liquid oxygen will be serviced through the aft starboard T-0 panel. If mission abort is required, the Centaur propellants may be dumped any time before Super*Zip firing for Centaur separation. This will allow a safe landing for the crew and Orbiter. Propellants will be dumped upon command from either the Orbiter computers or from the crew. These activities are being integrated into Orbiter operations and timelines.

Centaur operations will be integrated into the Shuttle crew timelines and operations. The goal is to give the crew control of initiating such critical functions as rotation, separation, or abort.

The thermal environment for the entire Centaur cargo element with spacecraft will be analyzed with the Orbiter to ensure temperature compatibility. Air conditioning and purging requirements will be modified or defined. Propellant tank heating rates will be analyzed under the most severe thermal environments to which Centaur will be exposed to ensure pressure control in both tanks.

An analysis of the interface loads will be based on the load factors given in ICD 2-19001, "Shuttle Orbiter/Cargo Standard Interface." A dynamic analysis using the Shuttle model and forcing functions, as obtained from Rockwell, will be used to verify acceptability of the interface loads.

During prelaunch activities at the Eastern Launch Site, Centaur will be mated to the Centaur integrated support system at Complex 36, where it will be checked as an element before integration and test with the spacecraft and Shuttle. The Centaur/spacecraft will be installed in the Shuttle in the vertical mode. They will be capable of being removed horizontally while the Orbiter is in the Orbiter Processing Facility. These and other operations will be reviewed on a mission-peculiar basis to ensure compliance to special requirements that may exist, such as security for certain phases of the operation.

Wherever possible, systems designs and interfaces will be implemented using existing flight components and ground support equipment.

3.4.2 SYSTEM SAFETY — The system safety program for Shuttle/Centaur will ensure that Centaur will generate no hazards that will endanger the Space Transportation System.

We will achieve this level of safety by incorporating the system safety engineering discipline into the detailed design, assembly, test, and ground and flight operations of Shuttle/Centaur.

System safety requirements of both NASA and the Air Force are common and well defined in NHB 1700.7A, "Safety Policy and Requirements for Payloads using the Space Transportation System," which is the document accepted by both agencies. The systems, in most cases, are functionally identical for all missions.

The hazardous aspects of operating a cryogenic upper stage in the STS have been under analysis since the initial Space Tug studies of 1972. This analysis has determined the Centaur can safely operate as can STS element. As detailed safety requirements have been identified, the design of the current Atlas/Centaur has evolved into the Centaur G to satisfy them. Early studies led directly to the 1979 Phase 1 safety review to the requirements of NHB 1700.7. The review of the Centaur vehicle and airborne and ground support equipment was conducted by both the JSC and KSC Safety Committees. They concluded the Centaur can safely operate from the Orbiter payload bay.

The integrity of the propellant tanks to contain cryogenic fluids and the validity of the tank analyses have been demonstrated over the last 19 years with 64 launches using both Atlas and Titan boosters.

Redundancy to provide the safety necessary for Centaur G has been provided in the fluids, mechanisms, and CISS avionics systems. Appropriate parallel and series valves have been added to the tank pressurization, vent, and drain/dump functions to ensure that valve failure does not lead to a hazard. Mechanisms for erecting the Centaur G are also redundant to achieve the required failure tolerance. CISS avionics control these systems. The avionics has been designed to be fully independent of the Centaur guidance, navigation, and control system. This separation allows the critical flight functions to be accomplished by the fault-tolerant CISS system before Centaur/Orbiter separation. No matter what the condition of the basic Centaur avionics, the CISS will retain control and prevent the occurence of hazards. CISS control functions are implemented by five control units that allow 3 out of 5, or 2 out of 3 voting to accomplish the required control redundancy.

The system safety program will build on our preliminary safety studies. Hazard reports will continue to be generated as hazards are identified and closed out when, with management and customer concurrence, appropriate preventive measures are defined. Hazard identification will be accomplished using failure modes and effect analysis (FMEA), engineering analysis, and specific safety analysis. Periodic reviews of the hazard reports by customer agencies will be accomplished.

From the system safety point of view, the greatest difference between NASA and DoD systems will be the ground handling operations. The Shuttle Payload Integration Facility will be used for DoD missions and will necessitate a mission-peculiar analysis to ensure that hazards are identified.

The task of identifying all potential hazard causes and their interrelationships is a primary concern. Qualitative fault tree analysis will be performed to systematically examine the causes of hazards and their relationships. The fault trees allow confirmation that the required level of fault tolerance has been achieved, and that failure causes are, indeed, independent. The end events of the fault trees will be related to the hazard reports as a cross-check to ensure that all basic failure causes have been identified.

CISS avionics control all functions that impact Orbiter safety. To ensure unconnected events do not occur, a sneak circuit analysis of the CISS avionics will be performed. This technique has been successfully used in other programs, such as the Atlas E/F, cruise missiles, and high-performance aircraft. The analysis is typically performed using released engineering drawings so that the actual flight hardware is verified.

System safety engineers assigned to the Shuttle/Centaur program will participate in all trade studies performed on the Centaur and its support systems. They will also participate in all design and test reviews, both in-house and with the customer.

3.4.3 RELIABILITY AND QUALITY ASSURANCE REQUIREMENTS — Twenty years of reliability and quality growth have led to a mature operational system.

The Centaur G reliability/quality program meets the intent of NHB5300.4 (ID-2), as defined in the Mission Assurance Plan, Convair Report BGJ 72-006. Reliability and quality are designed into our products and ensure that there is no degradation of inherent design reliability through the succeeding steps from fabrication to end use.

During the design phase, we will translate functional and environmental requirements into functional requirements documents. General Dynamics will ensure that safety margins, derating factors, and failure effects are developed and analyzed. Physical parameters and constraints will be addressed and test requirements, including overstress tests and test quantities, will be identified.

General Dynamics' reliability effort includes failure modes and effects analyses (FMEA) and a critical items list (CIL). These efforts emphasize the identification of single-point failures at the system and subsystem level to determine possible modes of failure and their effects on mission objectives and crew safety.

A complete electronic parts control program will be implemented through the Space Parts Control Board, as defined in the Mission Assurance Plan, including parts selection in the order of precedence established by MIL-STD-143B. This includes:

- Space Programs Approved Parts List (SPAPL), GDC Report AYF-73-002
- MIL-STD-975C
- MIL-STD-1546

The parts program also includes a derating policy, qualification of piece-parts, and detailed control drawings.

Quality tasks are identified in the Mission Assurance Plan. These tasks include:

- Design assurance
- Process control
- Identification and data retrieval
- Procurement control
- Fabrication control
- Inspection
- Nonconformance control

All of these tasks are being accomplished for the Atlas/Centaur program and will be continued for the Centaur G.

3.5 MECHANICAL FACILITIES AND GROUND SUPPORT EQUIPMENT (GSE)

3.5.1 GENERAL CONCEPT — General Dynamics has twenty years of experience with the facilities and GSE required to support pressure-stabilized LO_2 and LH_2 powered space vehicles. The majority of facility and GSE design concepts for Centaur G have been proven by the Atlas/Centaur.

Integrating Centaur into the Space Transportation System requires modifications to certain Convair Division, Cape Canaveral Air Force Station, and Kennedy Space Center (KSC) facilities and some new and modified GSE. These changes are required for one or more of the following reasons.

- To allow for tank geometry differences between the Centaur G and the Atlas/Centaur configuration.
- To accommodate the Centaur integrated support system (CISS) and to facilitate its assembly with the Centaur.
- To simulate certain aspects of the Orbiter/Complex 39 installation at Complex 36A.
- To provide the necessary portable equipment to service the Centaur/CISS assembly while at KSC (Figures 3-65 and 3-66).

3.5.2 GENERAL DYNAMICS FACILITIES (SAN DIEGO) — Changes to General Dynamics facilities in San Diego are primarily modifications to accommodate the change in Centaur tank geometry. Fabrication of all versions of the Centaur tank will be performed at Air Force Plant 19. The Centaur G will be transported to the Convair Division's Kearny Mesa plant on a modified Atlas/Centaur transport pallet.

Subsystem installation and checkout will be performed primarily in Building 5 of the Kearny Mesa plant. The dock area will be modified to accommodate the new tank configuration. Changes to existing pneumatic checkout equipment for testing the Centaur and CISS will be minimal. The CISS and deployment adapter will be supported in the test and transport fixture (TTF) during checkout and transportation.

3.5.3 CAPE CANAVERAL AIR FORCE STATION (CCAFS) FACILITIES — The most significant change to the CCAFS facilities will be at Complex 36A. It will be modified to allow assembly of the Centaur, CISS, and insulation system and to perform checkout after assembly. The Atlas/Centaur launcher will remain in place and an adapter will be installed to hold the Centaur CISS assembly (CCA) in the vertical position using the TTF. An air-conditioned environmental enclosure will be provided. Where feasible, the Orbiter/Complex 39 installation will be simulated. Included in this simulation will be the Orbiter bay liner and nitrogen purge; the transfer lines connecting the LO_2 control skid, LH_2 control skid, and helium control skid to the CISS; and portions of the Centaur LO_2 and LH_2 tank ground vent systems.

For the Centaur G, General Dynamics will provide new and modified GSE and/or facility-

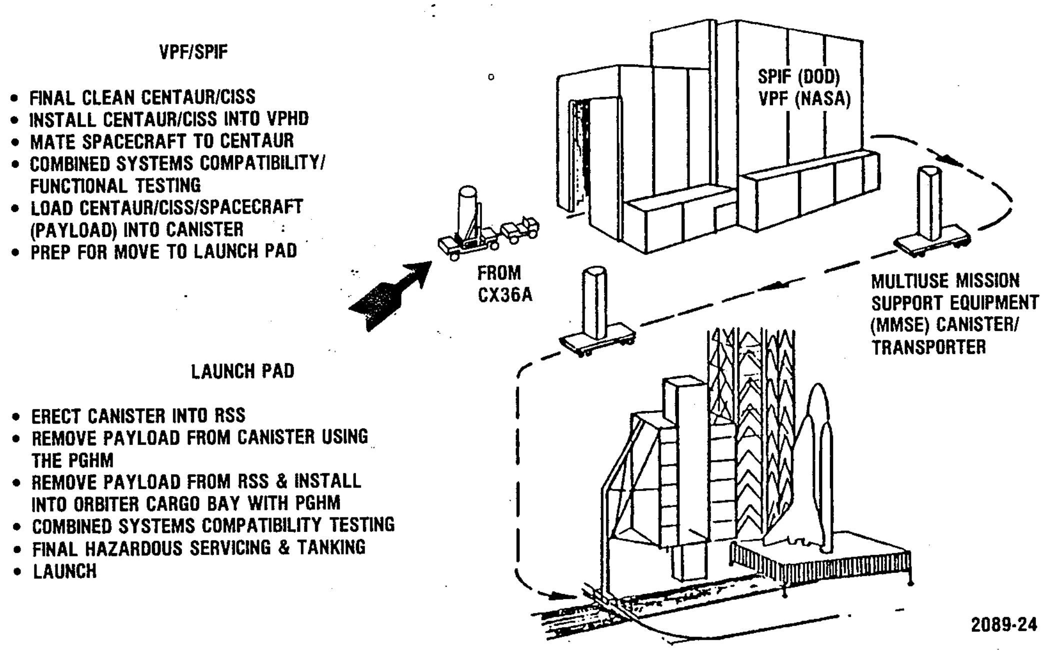

Figure 3-65. Centaur G Prelaunch Operations Flow Path.

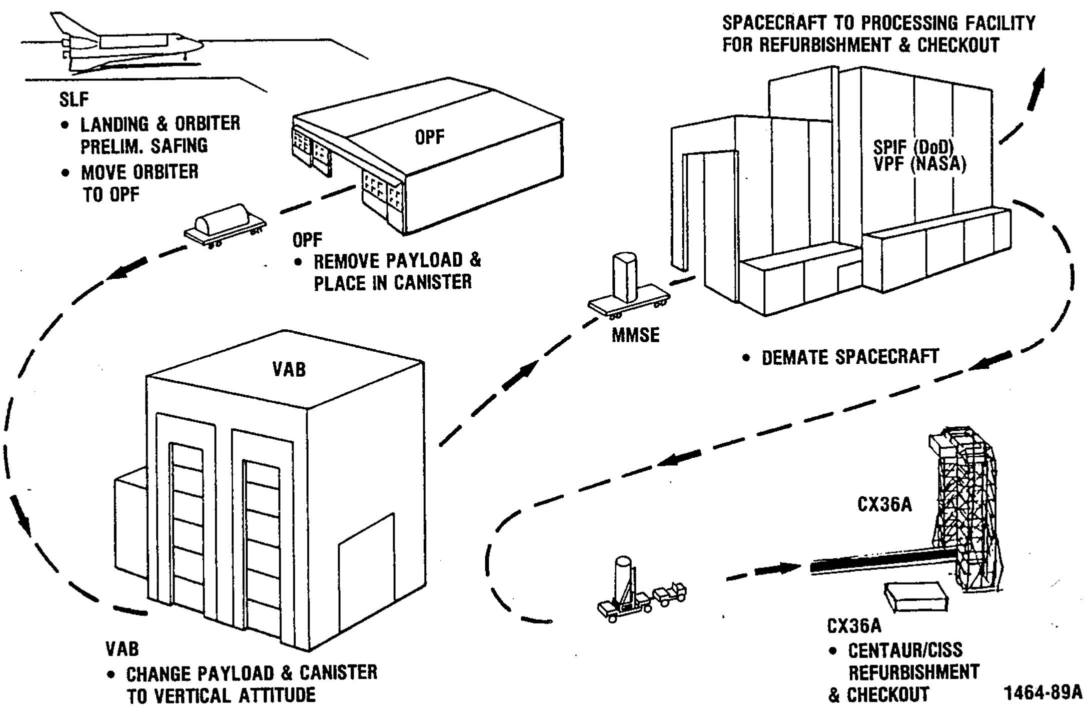

Figure 3-66. Centaur G Return To Launch Site Abort Flow Path.

type workstands as required to allow access to the shorter tank at Hangar J, Complex 36A, and the Vertical Processing Facility (VPF) or Shuttle Payload Integration Facility (SPIF).

3.5.4 KENNEDY SPACE CENTER (KSC) FACILITIES — At the Vertical Processing Facility, Rotating Service Structure, and Orbiter Processing Facility, the Centaur/CISS assembly will use existing KSC handling equipment. General Dynamics will provide the required slings and handling adapters. Access will be provided by existing work platforms with small portable workstands provided by General Dynamics where necessary. Interfacing the Centaur/CISS assembly with the facility pneumatic system will be accomplished with hoses provided by General Dynamics. Transport between the KSC facilities will be in the multi-use mission support equipment (MMSE) canister provided by KSC. Following a normal mission, the CISS will be removed from the Orbiter in the Orbiter Processing Facility using the MMSE strongback and placed in the test and transport fixture and the CISS transport pallet (CSTP) provided by General Dynamics for return to Complex 36A.

Centaur propellants will be loaded and the airborne helium bottles charged during launch countdown at Complex 39. All fluids will come from Shuttle supply sources and will be controlled by the General Dynamics-provided LO_2, LH_2 and helium control skids. Piping required to interface the skids with the Orbiter and supply sources will be provided by KSC. Hydrazine will be loaded at Complex 36A before CCA arrival at KSC.

For Centaur G, some new and modified GSE-type workstands will be required to provide access to the vehicle in the Rotating Service Structure and Orbiter Processing Facility.

3.5.5 GROUND SUPPORT EQUIPMENT — Mechanical GSE required to integrate the Centaur with the Orbiter consists primarily of structural and fluid control items. The major structural items include the Centaur transport pallet, CRTP, test and transport fixture, Centaur/CISS transporter, and various slings required to handle major airborne and ground elements.

Centaur G will be transported from San Diego to the Cape Canaveral Air Force Station via the NASA Super Guppy.

Fluid control items required to support the Centaur G include the LO_2, LH_2, and helium control skids plus the standby pneumatic control unit. The control skids will be used for propellant transfer operations at Complex 36A. An additional set will be installed at Complex 39 to support launch operations. The standby pneumatic control unit maintains Centaur tank pressures after installation of the Centaur into the CISS whenever the airborne pressurization system is not in control.

3.6 ELECTRICAL GROUND SYSTEMS AND EQUIPMENT

Concepts for the electrical ground systems associated with Centaur have been proven in many years of Atlas/Centaur support.

The computer-controlled launch set (CCLS), launch control, telemetry ground station, and landline instrumentation systems at Complex 36A are an update of the current system used to support Atlas/Centaur. CCLS, working in conjunction with other ground support equipment, will control the vehicle avionics, the CISS avionics, and the tanking and pressurization skids. The monitor and control interface with the vehicle will be via a mobile support equipment (MSE) trailer, which will contain the hardware extension remote (HER), PCM, landline instrumentation, and remote launch control equipment. The MSE will be transportable and capable of supporting operations at Complex 36A, the Vertical Processing Facility (VPF), Shuttle Payload Integration Facility (SPIF), or Complex 39. Communications between the Complex 36A equipment and the MSE will be via existing wide-band transmission networks located throughout the Eastern Launch Site (ELS). Figure 3-67 shows the Shuttle/Centaur electrical ground system.

The only DoD mission peculiar change identified for this area is to modify the communications link from the CCLS to the Centaur digital computer unit. This change is necessary to ensure compliance with communications security requirements. An additional CCLS output port will be provided and encrypted to handle communications of mission flight constants and all classified information. DCU telemetry will be transmitted via an output port of the onboard encryptor. This will allow verification as well as uplink loading of classified information in a secure environment.

3.6.1 GENERAL DYNAMICS FACILITIES — Electrical ground systems are duplicated in San Diego for software development, simulation, and interface verification.

3.6.1.1 Computer Controlled Launch Set (CCLS) — Two CCLS Launch set systems will be located at the Convair Division in San Diego and will be used in conjunction with an MSE and ground station to provide a duplicate of the planned system at the Eastern Launch Site. The San Diego CCLS will monitor and control Centaur and CISS vehicle operations and will be used to develop and test all Centaur computer software. The flight analogous software test (FAST) system will be used for software development and software acceptance testing for all Centaur computer software used after T–0 (launch). The preflight analogous software test (PFAST) will be used for software development and acceptance testing for all Centaur computer software used before T–0 (prelaunch) and after Orbiter landing (postflight).

3.6.1.2 System Integration Facility (SIF) — The Shuttle/Centaur Systems Integration Facility is used to verify adequacy of operational interfaces

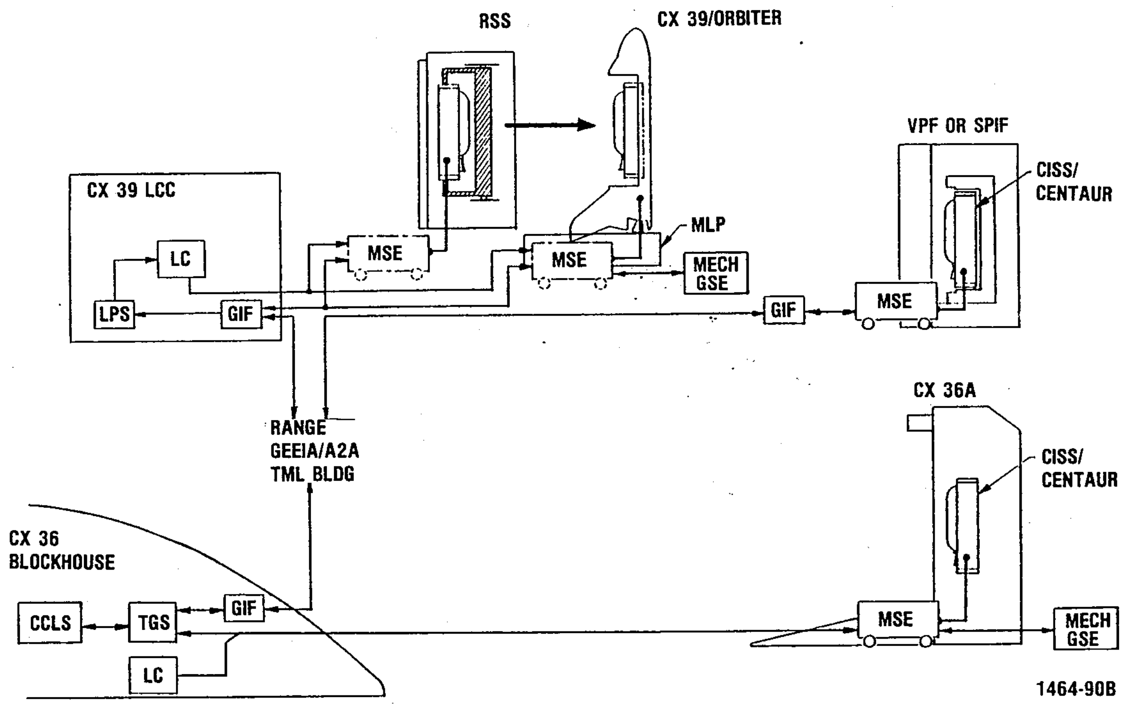

Figure 3-67. Electrical Ground Systems.

with the Orbiter aft flight deck and the spacecraft. It is also used to test the mobile support equipment (MSE), CISS, and Centaur avionics interface designs. In addition, the SIF will be used for CCLS, DCU, and CU software development and hardware/software integration testing. Actual flight hardware or emulated electrical equivalents will provide simulation of Centaur, CISS, spacecraft, orbiter, deployment, and tanking interfaces. The SIF is modular to enable use of the simulators at the Eastern Launch Site to verify interfaces during development of the Eastern Launch Site CCLS. The vehicle simulators will require modification to support DoD requirements. The STDN/TDRSS transmitter will be replaced with SGLS-compatible transponder and test set. COMSEC equipment and a telemetry interface unit are also added.

3.6.1.3 Real-Time Simulation Laboratory (RTSL) — The RTSL uses an Interdata 8/32 simulation to verify integrity of the CISS control system.

3.6.1.4 Software Engineering System (SES) — The SES is a Harris H800-based software engineering system. It will be used to develop the microprocessor software for the CISS control units.

3.6.1.5 Computer-Controlled Test Equipment (CCTE) — The CCTE is a computer-based automatic test set that will be employed for checkout and evaluation of Centaur avionic packages and associated circuit cards and modules. The CCTE system will be used for production testing, and to control and monitor initial and final acceptance tests, including temperature and vibration tests. All packages will be checked out by the CCTE in a consistent "hands-off" manner with appropriate history documentation that can be traced from component testing to launch.

3.6.2 EASTERN LAUNCH SITE FACILITIES — Electrical ground systems at ELS provide vehicle command, control, feedback and monitoring of Centaur airborne systems.

3.6.2.1 Computer-Controlled Launch Set — Two CCLS systems will be located at Complex 36 to check out and launch the Shuttle/Centaur. Each CCLS consists of a general-purpose computer with standard peripherals, a standard disc-based operating system, and General Dynamics-developed test programs. Each computer will interface to a local digital interface electronics (LDIE) and two operator consoles.

The avionics console will maintain control of Centaur, CISS, and skid electronic systems. Once total electronic control is established, the fluids console will control all fluids and tanking operations.

Commands to the vehicle will be sent via the LDIE, which contains long-distance serial bus protocol electronics (up to 25 miles), precision clock, time code translator, and high-speed parallel PCM DMA bus electronics. The long-distance receiver will be the hardware extension remote (HER) and will be located in the MSE. The HER will control the Centaur DCU and the five CISS control units via a redundant set of uplink lines to the Centaur and CISS.

Each MSE will contain two remote interface controllers (RIC) with independent manual control of remote functions. When placed in the remote mode, each RIC is tied to the CCLS system located at Complex 36. The dual RIC configuration operates under a status reporting configuration. If one RIC fails, the other may be commanded to take over and maintain failsafe operations.

The second CCLS system at Complex 36 will be in a standby-backup configuration where the operator can switch to the backup system within one minute of detected failure on the prime.

3.6.2.2 Launch Control Functions — The monitor and control interface with the vehicle will be via the mobile support equipment (MSE) trailer. The MSE will house the hardware required to provide external dc power to Centaur/CISS/tanking skids, installation of redundant HER (which provides the link between CCLS and the vehicle and tanking skids), landlines, and PCM system elements. The MSE supports operations at all locations from initial testing through launch. A manual detanking panel located in the Complex 39 LCC is hardwired into the MSE to permit draining of vehicle propellants in a safe and timely manner should circumstances so dictate.

3.6.2.3 Landline Instrumentation System — The landline instrumentation system as presently configured for Complex 36A will be used as much as possible with minimum modification by using existing recording systems, signal conditioning systems, patch panels, transducers, J-boxes, cabling, etc.

To support the Centaur G vehicle and CISS, the following additions to the Complex 36A landline system are required.

1. Addition of transducers, cabling, and J-boxes for the new LO_2, LH_2, and helium skids.
2. Addition of a MUX, signal conditioning system, transducers, J-boxes, and cabling in

the MSE to support vehicle hardware measurements, vehicle overboard measurements, and MSE-originated measurements. The MSE MUX feeds the data-bit stream into the MSE FM electronics equipment for transmittal to Complex 36A ground telemetry station for stripout and display.

These additions to the landline system would be used in support of Centaur G/CISS checkout at Complex 36A, tanking at Complex 36A, checkout at the VPF or SPIF and Complex 39, and launch at Complex 39.

3.6.2.4 Ground Telemetry Station — The ground telemetry station (GTS) provides input/output interfacing with wideband transmission lines, recording of PCM signals in a serial direct-encoded form, and conditioning, conversion, and decommutation of PCM data. The GTS located at Complex 36 will be upgraded to handle the Centaur G PCM requirements. PCM data decommutators, DACs, and discrete data latch/drivers will be provided to support data displays and CCLS requirements.

3.6.2.5 TV Systems — The TV system provides a means of visually monitoring the Centaur, LO_2, LH_2, and environmental ducting during tanking tests at Complex 36A. The TV system as presently configured will be used for Centaur G with minimal change by adding two cameras, monitors and associated lighting.

3.6.2.6 RF Systems — The RF system provides a capability of RF reradiation during checkout of Centaur G at Complex 36A. The coupled RF signal from the vehicle is routed via coax cable to the reradiating antenna located on the test stand.

3.7 OPERATIONS

General Dynamics experience in the ground and launch operation areas will be used in the Centaur G program. The operations functions have been performed economically and on schedule in a variety of programs (Atlas/Agena, Atlas/Centaur, and Titan/Centaur).

General Dynamics has coordinated with KSC ground operations personnel and with JSC flight operations personnel in developing a preliminary operations plan for Centaur G. This plan is compatible with planned Shuttle ground and flight operations. Safety is a prime consideration in all operations.

A Preliminary Flight Operations Plan, Payload Integration Plan, and Launch Site Support Plan have been presented to JSC and KSC.

General Dynamics has prepared preliminary System Interface Requirements (SIR), and will analyze all requirements thoroughly to provide detail interfaces at the Vertical Processing Facility (VPF), Shuttle Payload Integration Facility (SPIF), Orbiter Processing Facility (OPF), Launch Complex 39, and the multi-use mission support equipment canister. General Dynamics personnel at the Eastern Test Range (ETR) will provide continuing liaison with KSC to ensure suitable and timely documentation for the ground interfaces and procedures.

Preliminary flight operations events, timelines, and crew functions have been defined. This data is compatible with Orbiter operations. General Dynamics Convair Division will perform the necessary analyses to develop the required documentation and procedures.

3.7.1 GROUND OPERATIONS — General Dynamics has extensive experience in working with NASA in ground operations involving Centaur vehicles at Complex 36A and 36B (Atlas/Centaur) and Complex 41 (Titan/Centaur).

3.7.1.1 Normal Operations — Before receiving flight hardware at the Eastern Launch Site, General Dynamics will perform activation, validation, and checkout of Complex 36A. A Centaur/CISS simulator will be used to ensure compatibility with CCLS, mobile support equipment trailer, and Complex 36A. Following propellant skid validations at Complex 36A, the skids will be installed at Complex 39 and a cryogenic cold flow test performed to validate propellant loading interfaces at Complex 39. Operations at the VPF and Complex 39 can then be accomplished as dictated by the schedule.

Figures 3-68 through 3-70 show the flow of Centaur and its support equipment from receipt at Cape Canaveral Air Force Station through launch at KSC. One CISS, one mobile support equipment trailer, two LO_2 control skids, two LH_2 control skids, and two helium control skids will be used to support these operations.

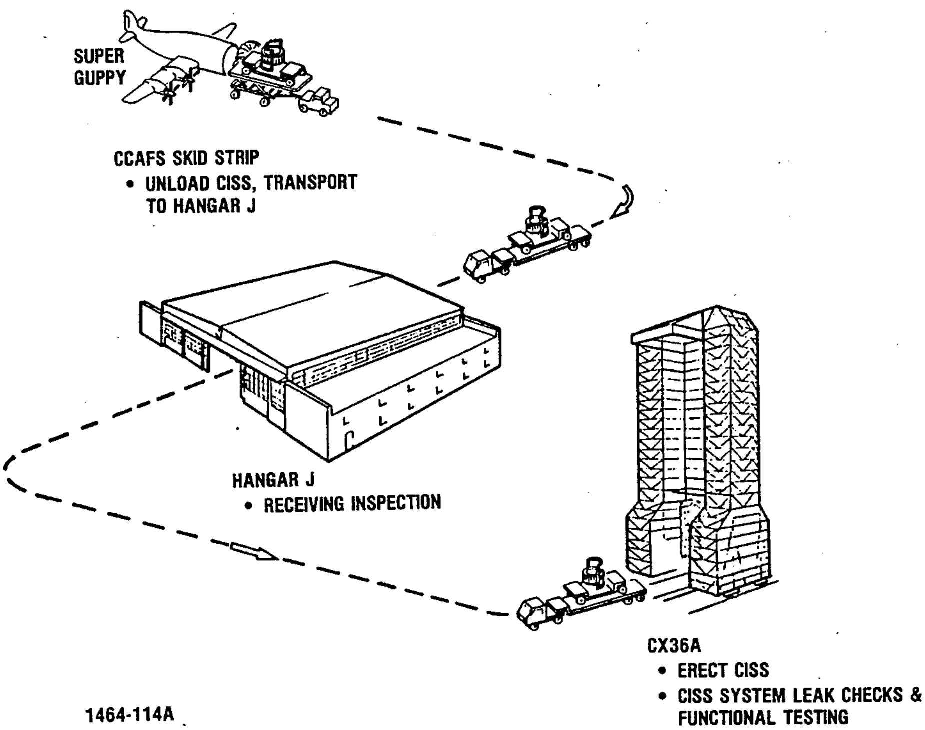

Figure 3-68. CISS Prelaunch Processing.

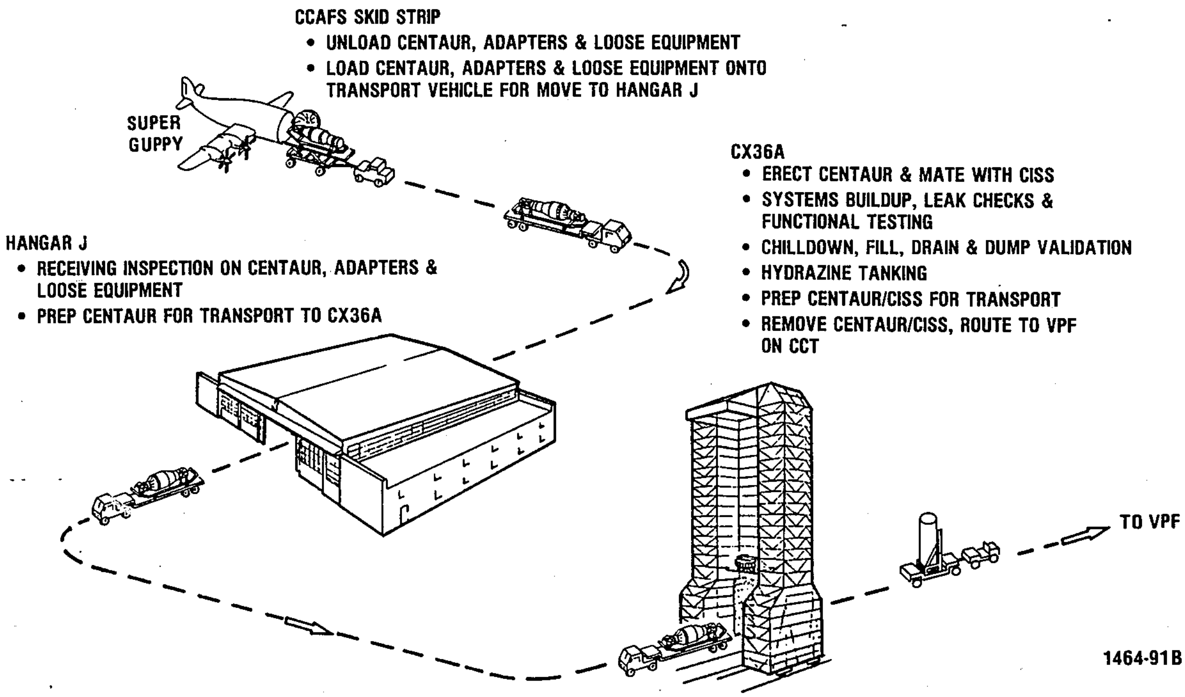

Figure 3-69. Centaur G Processing Flow at CCAFS Facilities.

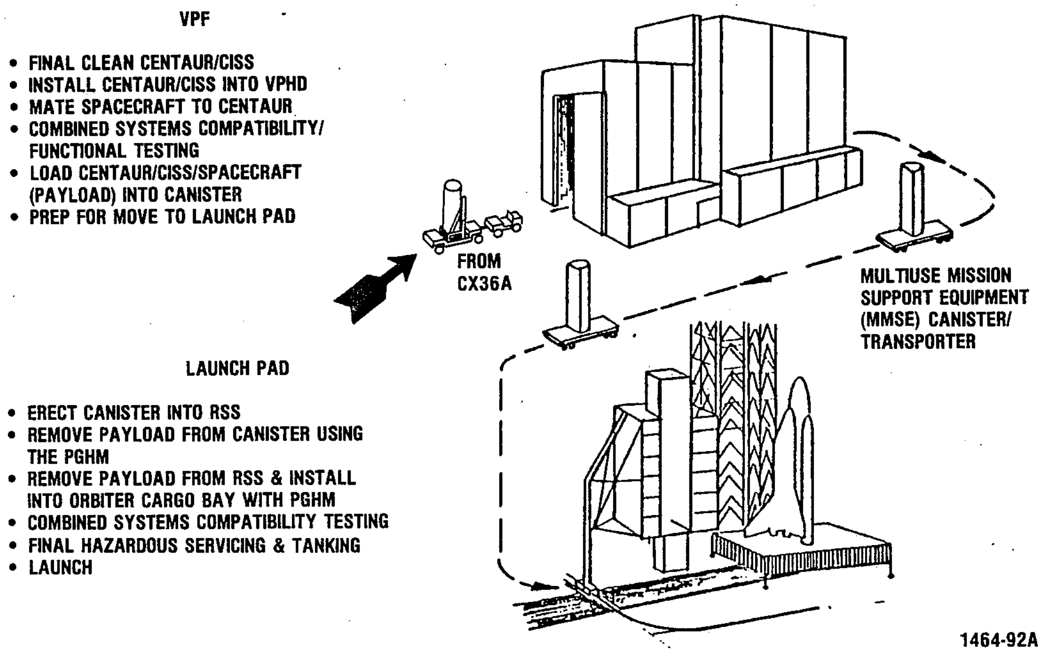

Figure 3-70. Centaur G Flow Path at KSC.

Following Complex 36A testing, the Centaur/CISS is transported to the VPF and mated with the spacecraft. Interface validation using the cargo integration test equipment is performed. When these tests are completed, the spacecraft/Centaur/CISS (cargo) is installed in the multi-use mission support equipment canister and transported to the Complex 39 Rotating Service Structure (RSS). The cargo is subsequently installed into the Orbiter bay using the RSS payload ground handling mechanism. Final integration testing and prelaunch operations are performed, and the Shuttle is launched.

For the first Centaur G launch only, the Centaur/CISS/spacecraft assembly will undergo a fit check with the Orbiter at Complex 39. A Countdown Demonstration Test will be performed to validate the Centaur/CISS/Shuttle/Complex 39 combination. This validation will be accomplished approximately two months before launch.

After Orbiter landing, the CISS will be removed from the Orbiter and returned to Hangar J in preparation for return to Complex 36A, as shown in Figure 3-71.

The DoD operations are similar to those for NASA except that all activities performed in the VPF for NASA will be performed in the Shuttle Payload Integration Facility (SPIF). The expected flow path is shown in Figure 3-72.

3.7.1.2 Abort Operations — The Centaur vehicle is an integral part of the Orbiter safing and securing procedure following the return from an abort (Figure 3-73). At the SPIF, the Centaur/CISS system requires telemetry data to monitor safety status. Safety is maintained automatically via the CISS control system for all abort ground opera-

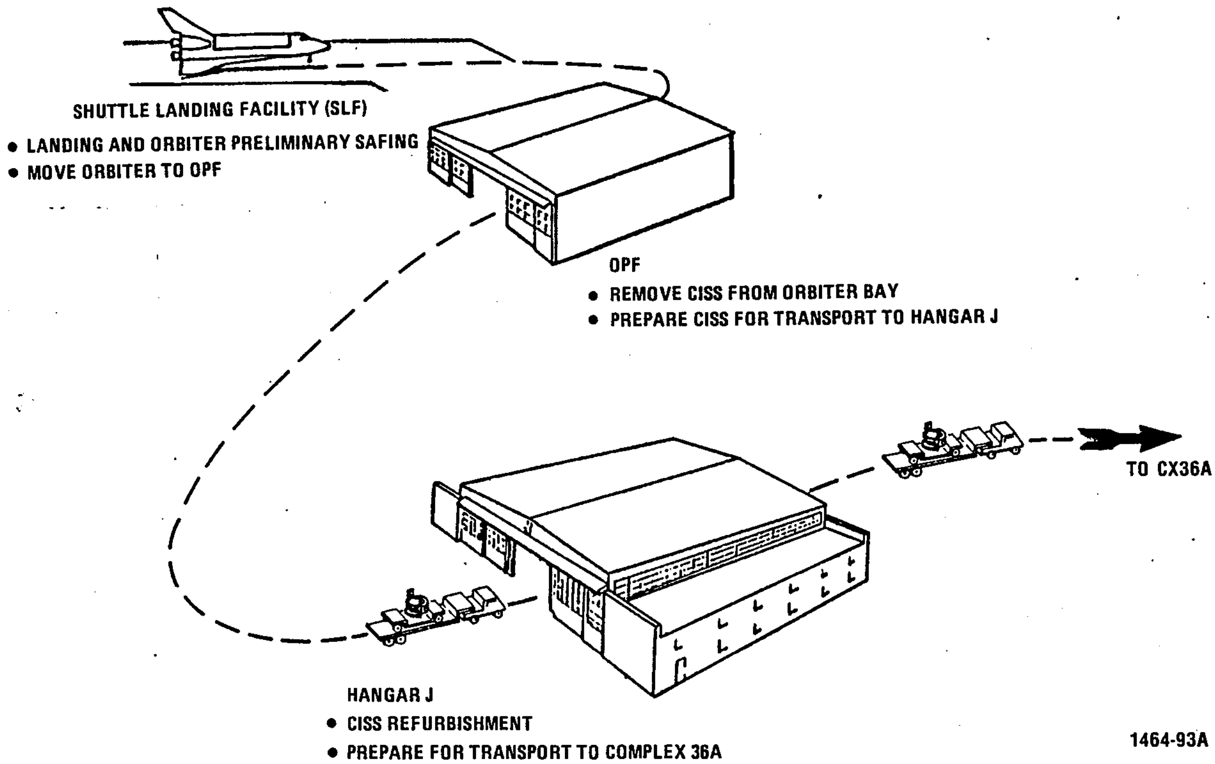

Figure 3-71. Postflight CISS Flow Path.

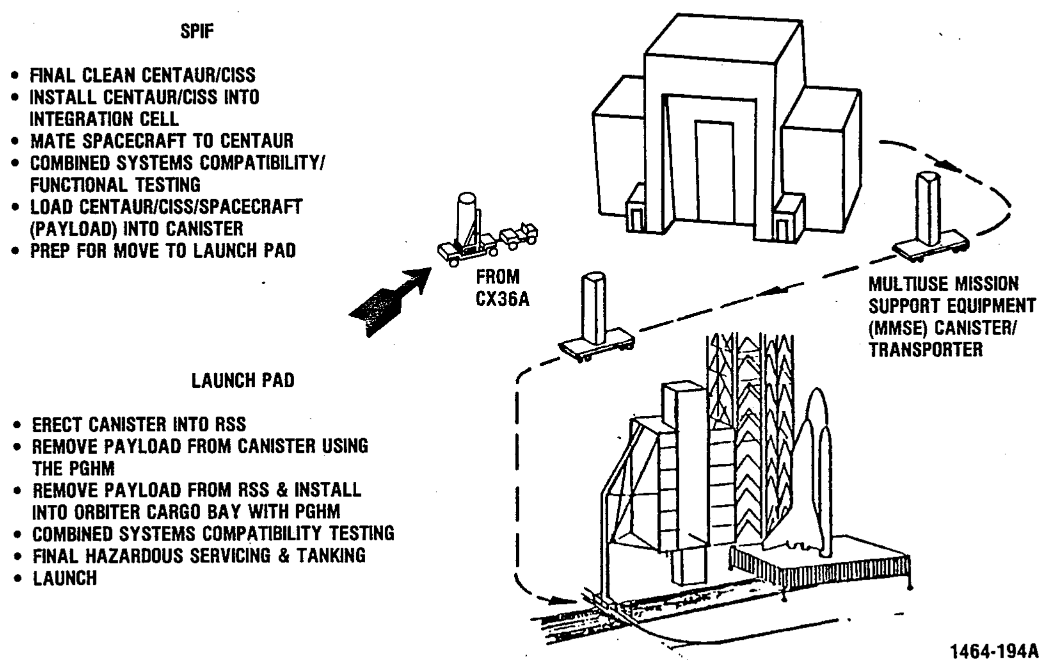

Figure 3-72. Centaur G DoD Flow Path.

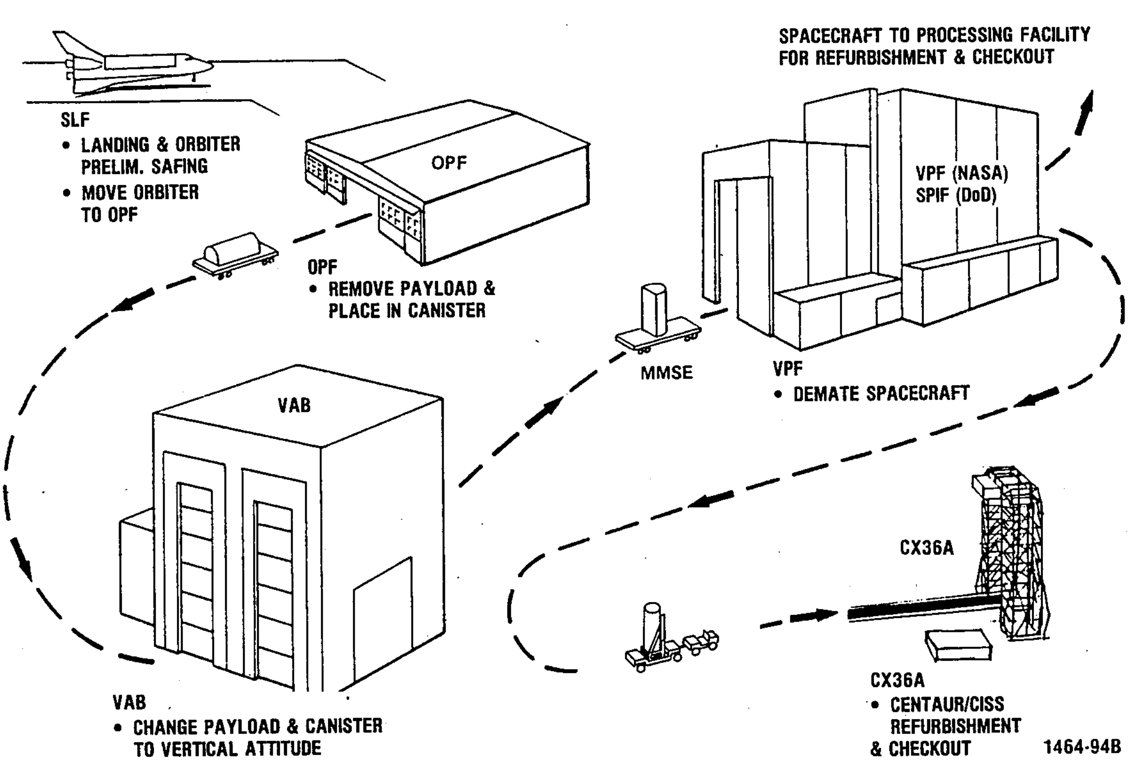

Figure 3-73. Centaur G Abort Flow Path.

tions. Verification of the payload bay hydrogen concentration level is required before the GSE payload bay purge can be activated. Within about 15 minutes of Orbiter landing, access will be required to the Orbiter aft fuel T – 0 panel to connect a gaseous helium charge line to replenish the CISS helium supply. Orbiter air conditioning and ground power are also required. Following confirmation that all safety requirements are met, the Orbiter is towed to the Orbiter Processing Facility.

In the Orbiter Processing Facility, the Orbiter is prepared for Centaur/CISS/spacecraft assembly removal. The assembly is removed and placed horizontally in the multi-mission support equipment canister, then moved to the Vehicle Assembly Building, where the canister is rotated to the vertical position. In this configuration, the assembly can be returned to the VPF or SPIF for spacecraft removal and subsequent refurbishment and checkout as required.

3.7.2 FLIGHT OPERATIONS — Centaur G can perform the baseline Galileo mission using flight operations plans and procedures that mesh smoothly into those for Mission Control and the Orbiter crew.

Centaur G can fly the reference Galileo mission within the NASA and JPL flight operations requirements. Flight operations planning and support for Solar Polar and DoD missions are similar to this reference Galileo mission. These operations will be developed as required to support their individual program requirements.

The generic and mission-peculiar flight operations requirements for the Galileo mission include:

- Centaur G will accomplish the reference trajectory with a figure of merit (FOM) equal to or better than 16 m/sec, for the Galileo spacecraft over a 10-day launch window. This will be done while operating within the constraints of the flight operations requirements.
- Preflight planning will coordinate training, operations control, operations support, and flight plans for nominal, contingency, and abort missions.
- Flight operations - nominal, contingency, and abort - ensure coordinated activities of the CCE, Orbiter, and crew with one another and with operations support on the ground.
- Flight operations during flight support the command and control for Shuttle/Centaur. This includes ground-based activities ranging from data monitoring and operations advice to the MCC, to operational control during Centaur free flight.
- Shuttle abort-to-orbit (ATO) may include near-nominal CCE operations, since the Centaur G can deploy and perform a successful Galileo mission from the 105-nmi ATO altitude.

- Postflight evaluation verifies data and operations related to the CCE, and recommends corrective action as necessary in coordination with NASA.

3.7.2.1 Preflight Planning — Centaur cargo element (CCE) flight operations plans will be developed for each mission. (The CCE comprises the Centaur integrated support system, Centaur G vehicle, and the spacecraft.) The overall objectives of the Centaur G flight operations are to:

1. Make the Centaur cargo flight operation-peculiar items as independent of the Orbiter operations are possible.
2. Give the Orbiter crew overall operational control of such critical functions as deployment, arm/safe, and abort operations.
3. Coordinate and integrate Centaur G operations with the spacecraft, Orbiter flight crew, and Mission Control Center operations.

The Centaur Flight Operations Plan will be integrated into the total Shuttle Flight Operations Plan.

The basic purpose of the Centaur Flight Operations Plan is to integrate operations of the various CCE subsystems to meet the mission requirements and to be compatible with Shuttle operational requirements. Elements of the plan include operational requirements, ground rules and assumptions, functional flow diagrams, sequence of events, mission timeline, procedures, flight rule input, and command control communication links. The plan also includes a detailed abort section with operational backout procedures.

This flight operations plan is a single document that, early in the development cycle, integrates inputs of all operational interfaces. It is most useful in identifying potential conflicts and inconsistencies.

The Flight Operations Plan will be used to develop input data for the basic STS Payload Integration Plan (PIP), and several PIP Annexes: Flight Planning Annex, Training Annex, Payload Operations Control Center (POCC) Annex, and - principally - the Flight Operations Support Annex. The latter requires development of flight rule input, decision points, and alternative plans and guidelines for off-nominal flight operations.

3.7.2.2 Flight Operations Support — During ascent and Orbiter-attached operations, the Galileo mission and flight operations will be controlled from the MCC. During this period, the Multi-Purpose Support Room (MPSR) will support CCE operations for the MCC at JSC, as shown in Figure 3-74. The Centaur Payload Operations Control Center (CPOCC) will be in close communication with the MPSR.

Within the MCC, the Flight Control Room (FCR) will control mission operations. Centaur flight controllers in the MPSR will include General Dynamics Centaur specialists to support the activities of the FCR during Orbiter-attached operations. After separation, when the Orbiter has maneuvered out of the zone of safety around the Centaur, responsibility of the Centaur will be handed over to the CPOCC. The CPOCC will then have responsibility for Centaur flight operations through Centaur burn, spacecraft separation, and Centaur postseparation maneuvers.

During the ascent phase of flight, flight operations support consists primarily of monitoring CCE health status until the Orbiter payload bay doors are opened. On-orbit operations then begin with initiation of Centaur/CISS and spacecraft checkouts.

Flight operations support continues on-orbit with ground analysis of checkout data, continuous real-time analysis of CCE health status, and providing advice regarding Centaur as necessary to the FCR. The latter includes go/no-go decisions for Centaur rotation and separation from the Orbiter.

Flight operations support of the Centaur vehicle after handover to the CPOCC consists primarily of monitoring Centaur automatic sequences, data recording, evaluating anomalies, and providing tracking acquisition data to the JPL MCCC.

For DoD missions, the Centaur Payload Operations Control Center (CPOCC) should be tied to the STC and SCC to provide Centaur analysis and support; see Figure 3-75. The CPOCC will continue to support STC and SCC operations through transfer coast, spacecraft separation, and Centaur post-separation maneuvers.

3.7.2.3 Nominal Flight — Nominal CCE flight operations are continuous from launch through orbit injection and postseparation maneuvers. The CCE is limited to such safe, automatic activities as passive navigation, vent control, and presssurization control until the crew assumes an active role in CCE on-orbit predeployment operations. Based on Shuttle flight requirements for ascent phase and on-orbit reconfiguration, the earliest time that CCE on-orbit predeployment operations can begin is 1 hour 17 minutes (all times referenced to liftoff). Nominal flight operations from this point on are illustrated in Figures 3-76 through 3-79 for the Galileo mission. The nominal operations for a

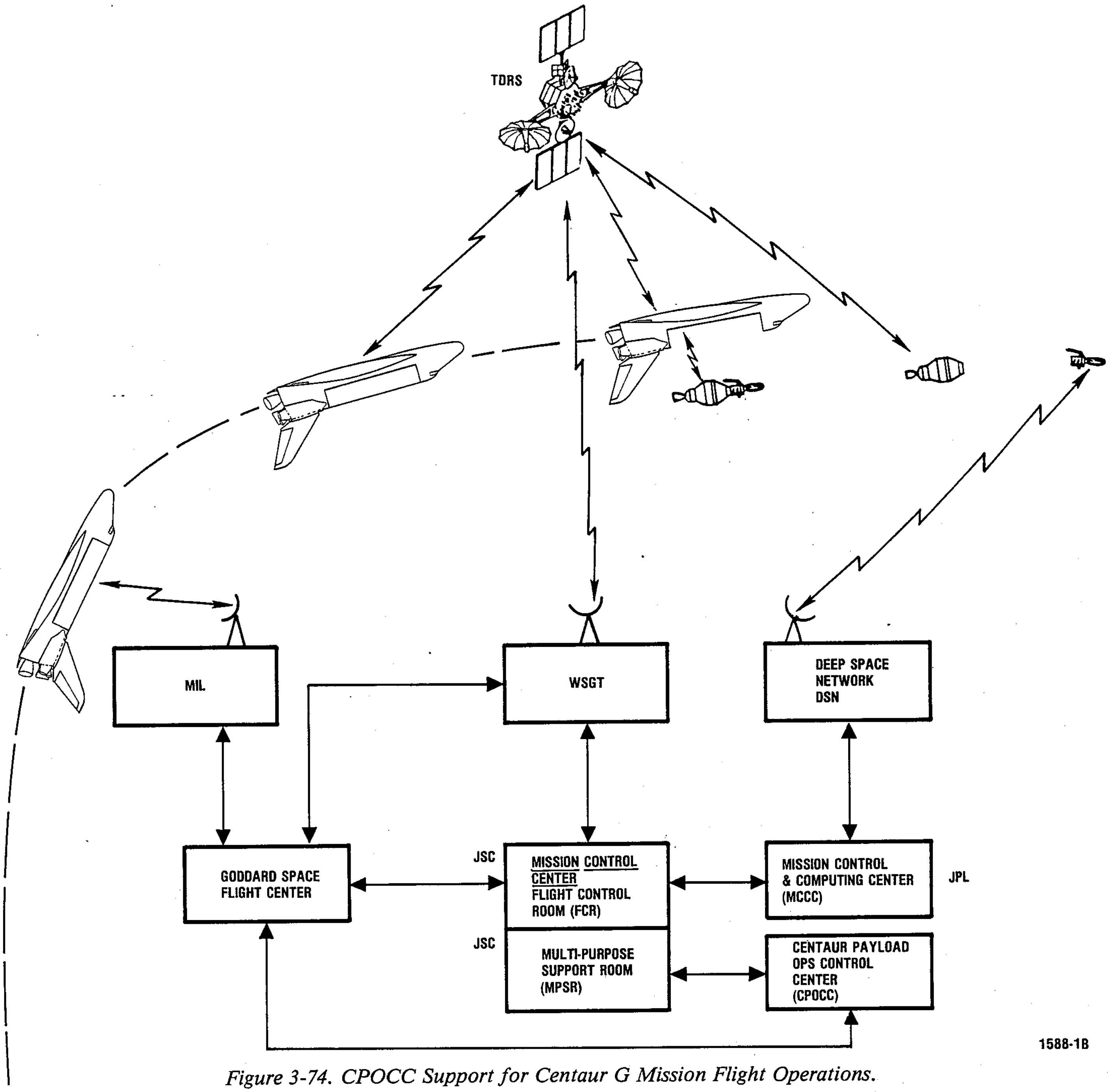

Figure 3-74. CPOCC Support for Centaur G Mission Flight Operations.

DoD geosynchronous orbit mission are presented in Figures 3-80 through 3-82.

From liftoff through Centaur postdeployment operations, the MCC and CPOCC will monitor the health and safety of the CCE via the telemetry link. The crew also has independent access to status information via a CRT display and can act as a backup source during attached operations.

Galileo Mission — Figure 3-76 illustrates the Orbiter crew control/interface for the flight operations by means of the standard switch panel or through the Orbiter keyboard. Switch-initiated actions are identified by asterisks in Figures 3-77 and 3-78, along with an outline of the computer-controlled automatic sequences. Two CCE predeployment operations require crew activity during the Orbiter's on-orbit reconfiguration sequence: (1) switch on Centaur/CISS and spacecraft checkouts, and (2) switch additional Orbiter power to the CCE (Figure 3-77). Figure 3-76 illustrates the Centaur G deployment operations required to deploy a Centaur with the Galileo spacecraft. Also shown are the Orbiter support operations required (e.g., reorientation maneuver, Orbiter RCS inhibit times, etc.), Orbiter crew control functions (denoted by asterisks), and two go/no-go key decision points:

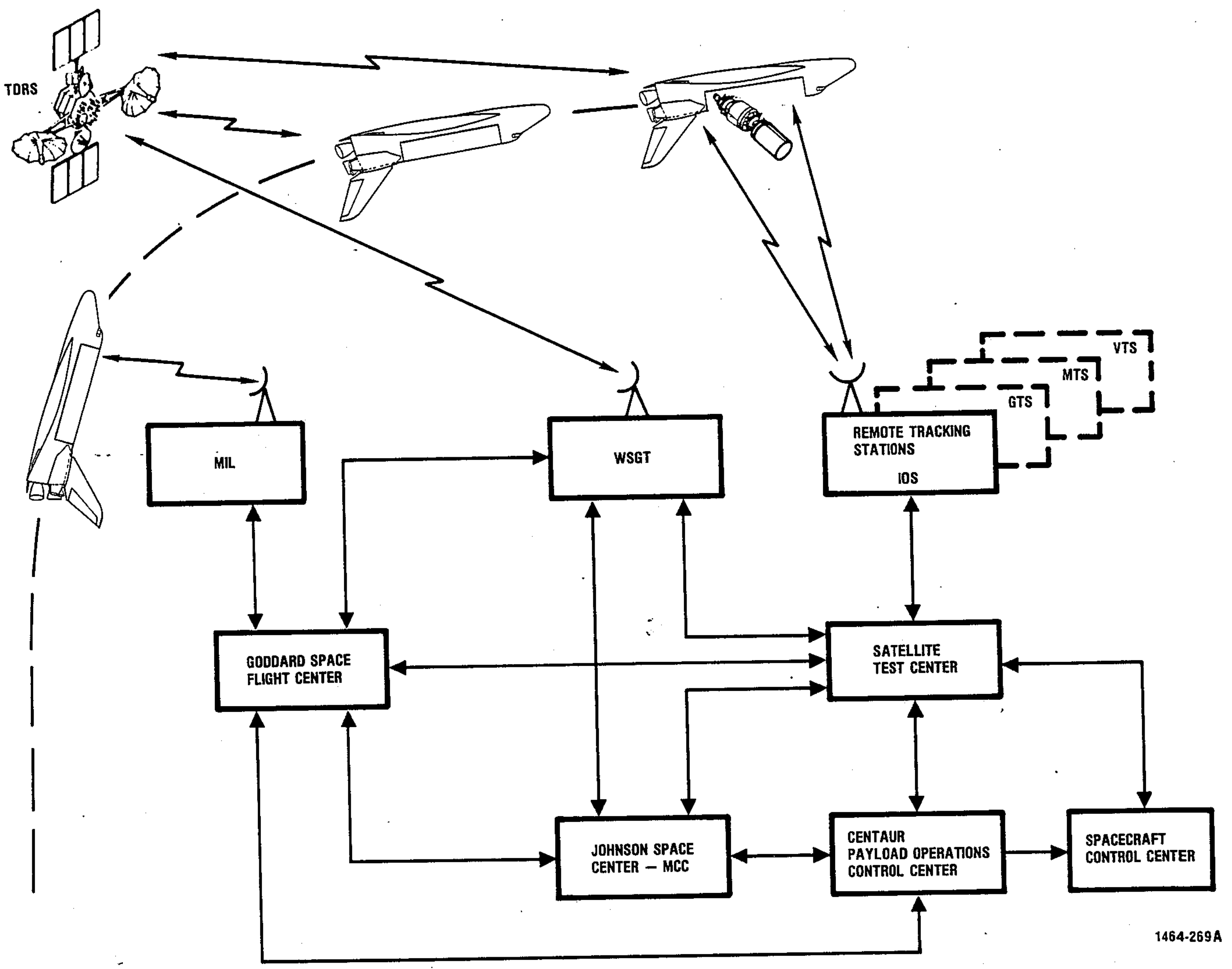

Figure 3-75. CPOCC Support for DoD Mission Flight Operations.

(1) to initiate the rotation operation at about 50 minutes before Centaur separation, and (2) at about four minutes before separation.

The deployment timeline is based on the reference Galileo mission, with the Centaur main engine start (MES) consistent with mission requirements.

All flight operations requirements, both generic and mission-peculiar, as listed in Table 3-10, are met by this sequence. This includes requirements for crew initiation of events, Centaur platform alignment (star scan in the earth's shadow) to meet the mission FOM, deployment attitude thermal control for the spacecraft, and Centaur separation in daylight.

Figure 3-79 illustrates operations from Orbiter/Centaur separation to Galileo spacecraft separation. Centaur coast attitude and sequence times are appropriate to meet spacecraft thermal contraints. Centaur separation coast and inhibit/arm sequence times are sufficient to ensure Orbiter safety constraints before MES. After MECO, Centaur RCS is inhibited to meet the mission-peculiar requirement for spacecraft boom deployment.

Two Orbiter postdeployment operations are required after Centaur separation: (1) Orbiter maneuvers away from the Centaur without contaminating the spacecraft, and (2) the CISS will be safed for atmospheric reentry and landing (e.g., venting the pressurant bottles and pressurizing lines to atmospheric levels).

3.7.2.4 DoD Flight — During ascent phase of flight for the Geosynchronous Orbit and Galileo mission, the Centaur G flight nominal operations are identical for a DoD flight. This phase consists primarily of monitoring CCE health status until after the Orbiter payload bay doors are opened and the radiators deployed. On-orbit operations are then initiated with the increase of Orbiter-supplied power to the Centaur/CISS.

The deployment activities illustrated in Figure 3-78 of the Galileo mission are identical to those of

Table 3-10. Centaur G Flight Operations Requirements.

Flight Operations - Generic

1. Orbiter (099 or 104) will be the Shuttle Orbiter.
2. Centaur/spacecraft shall be a dedicated payload and, as such, need not consider other payload requirements during the same STS mission.
3. The crew shall consist of only the Commander and Pilot.
4. Centaur flight operations shall provide for crew initiation of critical events. The events include on-orbit platform alignment, checkout, Centaur unlatch, rotation (up and down), final checks, and separation.
5. The crew will switch the CCE power to the Orbiter power supply after ascent when additional Orbiter power is available.
6. Centaur will perform a platform alignment while attached to the Orbiter, and will occur a minimum of time before Centaur separation from the Orbiter.
7. Attitude star scan will take place in the earth's shadow.
8. Orbiter primary and vernier RCS is to be inhibited during Centaur separation. Orbiter primary RCS low-aft mode shall be used from initiation of rotation to separation.
9. Centaur separation shall occur in daylight.
10. Centaur separation system shall impart a minimum of 1 fps relative velocity between the Centaur and Orbiter. (The RMS will not be used.)
11. Centaur RCS shall not be armed until an elapsed time of 5 minutes has been achieved after separation from Orbiter.
12. Centaur propellant tank pressurization and vent systems shall be inhibited before separation until after Centaur RCS is enabled.
13. Centaur main engine system shall not be armed until an elapsed time of 45 minutes has been achieved after separation from the Orbiter.
14. The Centaur shall not contaminate nor contact the spacecraft after spacecraft separation.

Flight Operations - Mission Peculiar

15. Galileo mission shall be launched in Sept 1985.
16. Galileo spacecraft attitude-thermal constraints are: (1) no direct sunlight in Orbiter payload bay, and (2) no more than 10 minutes of direct sunlight until RTG booms are deployed.
17. During postseparation, pre-MES coast, up to 16 spacecraft discretes can be issued by Centaur SCU.
18. Centaur RCS shall be inhibited for spacecraft boom deployment and spacecraft separation.

Contingency Operations - Generic

19. In event of an abort, Centaur main propellants (LO_2 and LH_2) shall be dumped before return.
20. Orbiter RCS propellant settling thrust shall be provided to initiate and terminate Centaur propellant dump for AFO abort. The Orbiter OMS thrust shall be used for Centaur propellant dump for AOA aborts.
21. Centaur systems shall permit simultaneous dump of LO_2 and LH_2 propellants within 250 sec during RTLS abort and 230 sec for TAL abort with no Centaur valve failures. RTLS abort dumping shall occur within 300 sec with a valve failure.
22. Centaur propellant abort dump shall be automatic during RTLS, TAL, and AOA aborts with a manually initiated backup option. TALA & AFO dumps shall be initiated manually.
23. Centaur is to continue mission in case of an ATO abort that does not affect capability to complete mission successfully.
24. Abort preferences are: ATO over AOA, and TALA over TAL.
25. Centaur systems shall accommodate a worst-case, closed-door abort thermal environment. Such an abort consists of the Orbiter payload bay doors remaining closed continuously with the duration from liftoff to landing of 6.5 hours.
26. Mission will be aborted, if cargo bay doors are not opened within three hours MET.
27. The Centaur shall be capable of being deployed and separated from the Orbiter at anytime during the mission after cargo bay doors open.

Contingency Operations - Mission Peculiar

28. Transmit signal from Centaur to Galileo spacecraft upon abort.

Flight Support Operations - Generic

29. Transmit signal from Centaur to Galileo spacecraft upon abort.

Flight Support Operations - Generic

29. A CPOCC provided by NASA and staffed by General Dynamics and NASA-LeRC shall be used to monitor Centaur operations and provide inputs to the mission director on Centaur health status throughout attached and detatched phases of flight.
30. TDRSS will be available and used for S-band uplink and downlink and Ku-band downlink.
31. GSTDN MIL station will be used for S-band downlink..
32. Centaur/CISS data rate of (TBD) kbps must be downlinked in real time to MCC/CPOCC. Quantity of data downlinked to be maximized within communications limitations and operational requirements of Orbiter and communications system.
33. Ascent recorded data will be downlinked as soon as communications constraints allow.
34. A period of (TBD) minutes will be allowed after checkout of the Centaur and CISS before a go/no-go decision for rotation is transmitted from the CPOCC to the MCC for relay to the crew.
35. A maximum period of (TBD) minutes will be allowed after rotation and final checkout before go/no go decision for separation is transmitted from the CPOCC to the MCC for relay to the crew.
36. Centaur data link will be transferred from the Orbiter to the TDRSS at (TBD) minutes after separation.
37. Centaur flight control operations will be transferred to the CPOCC at (TBD) minutes after separation.

Flight Support Operations - Mission Peculiar

38. Orbiter Ku-band shall not expose the Centaur/spacecraft to radiation greater than 68 v/m.
39. Spacecraft on-orbit checkout of (TBD) minutes will be required, and may be halted and restarted in segments by command.
40. Spacecraft real-time telemetry will be required during Centaur deployment (30 minutes), burn, spinup through separation, and separation through sun acquisition.

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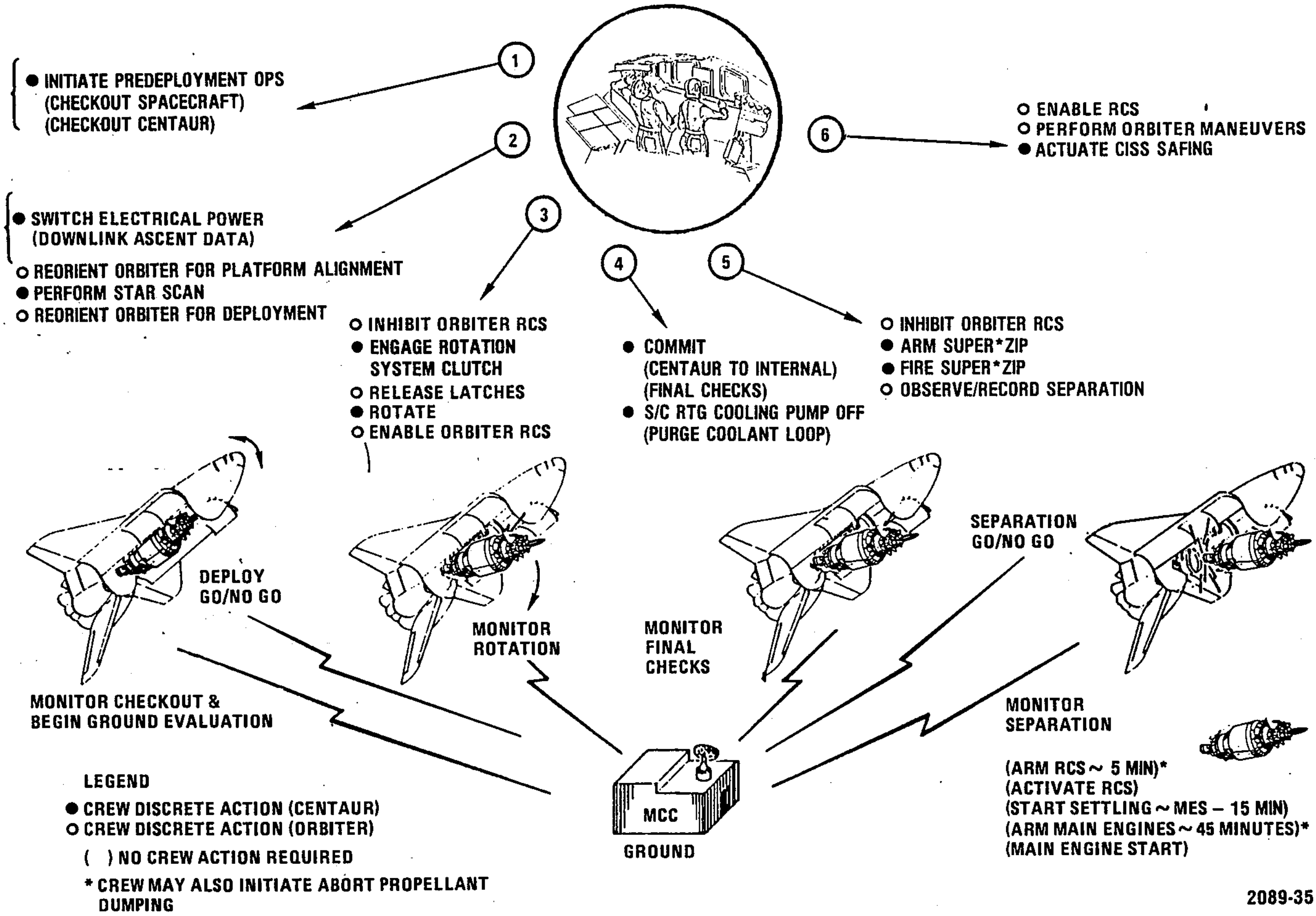

Figure 3-76. Orbiter Crew Control of Critical Functions.

the Geosynchronous mission except for spacecraft-peculiar operations. The deployment timeline is based on the reference geosynchronous mission, with the first Centaur main engine start (MES1) consistent with potential reference mission requirements of Table 3-11. The time interval from start of Centaur/spacecraft rotation to separation is within the 40-minute maximum requirement of the reference DoD spacecraft. A 10-minute hold in the deployed condition has been included to account for delays. Post-deployment switch operations for rotating down and safing the CISS are identical to the NASA configuration.

Three Orbiter post-deployment operations are required following Centaur/spacecraft separation: (1) The Orbiter maneuvers away from the Centaur without contaminating the spacecraft, (2) the CISS adapter will be rotated down, and (3) the CISS will be secured for atmospheric reentry and landing; (e.g., venting the pressurant bottles and pressurizing lines to atmospheric levels).

Figure 3-80 illustrates the Centaur separation coast phase. The times used in this illustration are based on Centaur MES1 at a reference nodal opportunity for the geosynchronous orbit mission. Centaur coast attitude and sequence times are appropriate to meet spacecraft thermal constraints. Centaur separation time is sufficient to ensure Orbiter safety constraints before MES1, and can allow additional revolutions in the parking orbit. If the deployment opportunity is lost, additional deployment opportunities with Centaur may be realized.

The Centaur first burn and transfer coast sequence is illustrated in Figure 3-81. An optimal two-degree plane change is made at perigee to reduce transfer orbit inclination. During the coast period, Centaur provides passive thermal control (PTC) with a 32 deg/min roll rate and telemetry orientation dipout maneuvers, both as required by the spacecraft. At about MES1 + 5 hours, Centaur is rotated to initiate its second burn at the geosynchronous altitude, will perform a star scan for attitude update to meet spacecraft burn-out accuracy constraints, and will perform propellant settling prior to MES2. These operations are performed within the 10-minute thermal constraint of the spacecraft.

Table 3-11. Flight Operations Requirements for DoD Option.

ITEM NO.	DESCRIPTION
1	**Performance Requirements** CENTAUR SHALL BE CAPABLE OF PLACING THE SPACECRAFT INTO ALL PORTIONS OF THE PERFORMANCE MISSION BOX DEFINED IN SECTION 3.2.4.
2	**Launch Requirements** THE CENTAUR SHALL SUPPORT LAUNCHES ON ANY SUCCESSIVE DAY FOR 30 DAYS COMMENSURATE WITH ORBITER CAPABILITY. THE CENTAUR SHALL BE CAPABLE OF TARGET LOADING AND VERIFICATION WITHIN 45 MINUTES DURING LAUNCH PREPS, USING PREVIOUSLY-VALIDATED CENTAUR TAPES.
3	**Trajectory Requirements** STS/CENTAUR SHALL SATISFY MISSION ORBIT INJECTION ACCURACIES. • $P_T \pm 66$ NM • $P_N \pm 40$ NM • $P_R \pm 50$ NM ± 92 NM RSS 3σ • $V_T \pm 16$ FT/SEC • $V_N \pm 12$ FT/SEC • $V_R \pm 75$ FT/SEC ± 78 FT/SEC RSS 3σ (1) COMPONENTS OF VELOCITY OR POSITION ERROR REQUIREMENTS MAY BE EXCEEDED BY 20% PROVIDED THE RSS VALUE IS MAINTAINED (3σ). (2) NORMAL POSITION AND/OR VELOCITY ERROR REQUIREMENTS MAY BE EXCEEDED PROVIDED THAT FINAL MISSION INCLINATION ACCURACY IS WITHIN 0.12° (3σ). THE S/C SEPARATION MECHANISM SHALL INDUCE A RELATIVE VELOCITY TO THE CENTAUR OF NO LESS THAN 1.0 FT/SEC IN THE S/C −Z DIRECTION. MISSION ORBIT INJECTION ACCURACIES ARE CONTINGENT UPON A PREDEPLOYMENT STATE VECTOR INITIALIZATION ACCURACY AS SPECIFIED IN SS-STS-100 NOMINAL AND DISPERSED TRAJECTORY STATE VECTOR AND ATTITUDE TIME HISTORIES FROM OMS-2 C/O THRU S/C SEPARATION SHALL BE PROVIDED 30 DAYS PRIOR TO LAUNCH
4	**TT&C Requirements** CONTINUOUS REAL TIME S/C TELEMETRY SHALL BE PROVIDED TO THE SCC THROUGHOUT ALL FLIGHT OPERATIONAL PHASES (EXCEPT FOR THE TDRSS GAP) THE CAPABILITY TO TRANSMIT DISCRETE COMMANDS FROM THE CENTAUR TO THE S/C IS REQUIRED FROM DEPLOYMENT THROUGH S/C SEPARATION (INCLUDING S/C ORDNANCE ENABLE, ARM, AND SEPARATION). PREDICTED STATE VECTOR DATA SHALL BE PROVIDED TO THE SCC PRIOR TO MES-1 IGNITION. THIS DATA SHALL INCLUDE PREDICTED MECO-1 AND MECO-2 STATE VECTORS. DURING THE TRANSFER ORBIT, THE CURRENT STATE VECTOR AND PREDICTED MECO-2 STATE VECTOR SHALL BE PROVIDED TO THE SCC. THE CURRENT STATE VECTOR SHALL BE AVAILABLE 15 MINUTES AFTER FIRST RTS RISE AND THE PREDICTED STATE VECTOR SHALL BE AVAILABLE 2 HOURS AFTER FIRST RTS RISE. WHILE IN THE BAY AND WHILE IN RF RANGE OF THE ORBITER, ALL S/C TELEMETRY TRANSMITTED THROUGH THE CENTAUR SHALL BE RECORDED VIA THE ORBITER'S PAYLOAD RECORDER. WHILE IN VIEW OF AN RTS, ALL S/C TELEMETRY TRANSMITTED THROUGH THE ORBITER OR THE CENTAUR SHALL BE RECORDED VIA GROUND BASED RECORDERS. THE CENTAUR SHALL TRANSMIT THE MISSION ORBIT INJECTION STATE VECTOR AND ATTITUDE DATA AFTER MECO-2.
5	**Attitude Requirements** THE PREFERRED ORIENTATION DURING PARK ORBIT SHALL BE WITH THE +Z AXIS OF THE ORBITER TOWARD NADIR (ZLV) WITHIN ±2°. THE SIMULTANEOUS EFFECTS OF DIRECT AND REFLECTED SUNLIGHT ON THE PAYLOAD SHALL BE AVOIDED WHILE THE PAYLOAD IS ATTACHED TO THE ORBITER. WHEN WITHIN SIGHT OF AN RTS, THE ORBITER ORIENTATION SHALL BE SUCH AS TO ALLOW THE CENTAUR ANTENNA TO VIEW THE RTS. TEMPORARY DEVIATIONS FROM ZLV SHALL BE ACCEPTABLE FOR ORBITER AND CENTAUR OPERATIONS PROVIDED THAT THE PAYLOAD THERMAL CONSTRAINTS ARE NOT VIOLATED.

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Table 3-11. Flight Operations Requirements for DoD Option (continued).

ITEM NO.	DESCRIPTION
5 CONT.	**Attitude Requirements Cont.** FROM CENTAUR RCS ACTIVATION UNTIL 10 MINUTES PRIOR TO MES 1, THE CENTAUR SHALL ORIENT TO THE PASSIVE THERMAL CONTROL (PTC) ATTITUDE (S/C Z AXIS NORMAL TO THE ECLIPTIC PLANE) AND INITIATE A ROLL RATE OF 32 ± 2°/MIN. FOLLOWING MECO 1, THE CENTAUR SHALL ORIENT TO A SPECIFIC PTC ATTITUDE (S/C +Z AXIS NORMAL TO THE ECLIPTIC PLANE AND ALIGNED WITH THE ECLIPTIC SOUTH POLE) AND INITIATE A ROLL RATE OF 32 ± 2°/MIN. THE PTC ROLL DURING THE TRANSFER ORBIT SHALL BE INTERRUPTED FOR 6 TEN-MINUTE TELEMETRY DIPOUTS. FROM TERMINATION OF PTC PRIOR TO MES 2 UP TO S/C SEPARATION, THE S/C ATTITUDE SHALL BE CONSTRAINED SUCH THAT NADIR REMAINS WITHIN A SPECIFIED RECTANGULAR AREA RELATIVE TO THE S/C COORDINATE FRAME. AT SEPARATION, THE S/C X-Z PLANE SHALL BE IN THE FINAL ORBIT PLANE WITH THE SPECIFIED ATTITUDE. EACH AXIS SHALL BE WITHIN +1.4 (3 SIGMA) DEGREES OF THE NOMINAL SEPARATION ATTITUDE. AT THE TIME OF SEPARATION, THE CENTAUR INERTIAL RATES SHALL BE NO GREATER THAN 0.1 DEG/SEC in CENTAUR PITCH AND YAW, AND 0.3 DEG/SEC IN CENTAUR ROLL. TIPOFF RATES IMPOSED ON THE CENTAUR BY THE S/C SHALL NOT CAUSE THE CENTAUR TO ROTATE MORE THAN 24° OFF CENTERLINE PRIOR TO RCS ENABLE (10 SECONDS) CENTAUR MISSION DESIGN SHALL PROVIDE AN ATTITUDE HOLD PERIOD FOLLOWING PROPELLANT VENTING TO MINIMIZE OUTGASSING CONTAMINATION. AFTER SPACECRAFT SEPARATION.
6	**Operational Requirements** THE CISS SHALL BE CAPABLE OF CENTAUR ERECTION TO THE 45° ELEVATED POSITION AND RESTOW/RELATCH FOR EACH DEPLOYMENT OPPORTUNITY AND/OR RETURN. THE PAYLOAD DEPLOYMENT SEQUENCE SHALL BE SUCH THAT THE S/C ASE IS UNLATCHED AND VERIFIED PRIOR TO CENTAUR UNLATCH AND VERIFICATION. THE ORBITER RCS THRUSTER OPERATIONS SHALL SATISFY THE S/C CONTAMINATION AVOIDANCE REQUIREMENTS. THE CENTAUR SHALL PROVIDE A SEPARATE TIME INDICATION TO THE SCC 3 MINUTES PRIOR TO SEPARATION, WITH AN ACCURACY OF ±1 SECOND. THE CENTAUR RCS SHALL BE INHIBITED PRIOR TO SEPARATION AND FOR 10 SECONDS FOLLOWING S/C SEPARATION. AFTER S/C SEPARATION, THE CENTAUR SHALL AVOID S/C RECONTACT AND CONTAMINATION OF THE S/C. ALL CENTAUR POST-SEPARATION FLIGHT ACTIVITIES SHALL BE SUSPENDED IN THE EVENT SEPARATION DOES NOT OCCUR. THESE ACTIVITIES SHALL BE TIED TO ACTUAL SENSED SEPARATION.
7	**Contingency Requirements** THE CENTAUR SHALL PROVIDE FOR THE CONTINGENCY SITUATION OF ONE ADDITIONAL PARK ORBIT REVOLUTION AFTER PAYLOAD DEPLOYMENT FROM THE ORBITER. IN THE EVENT OF A MISSION CRITICAL FAILURE DETECTED PRIOR TO DEPLOYMENT, THE PAYLOAD SHALL BE SAFELY RESTOWED AND RETURNED FROM ORBIT. TO RESTOW THE PAYLOAD FOR RETURN TO EARTH, THE S/C ASE SHALL BE RELATCHED AND VERIFIED AFTER THE CENTAUR HAS BEEN RELATCHED AND VERIFIED. ENVIRONMENTAL DATA SHALL BE RECORDED FOR RETURN TO EARTH OPERATION TO SUPPORT POST FLIGHT ANALYSIS.

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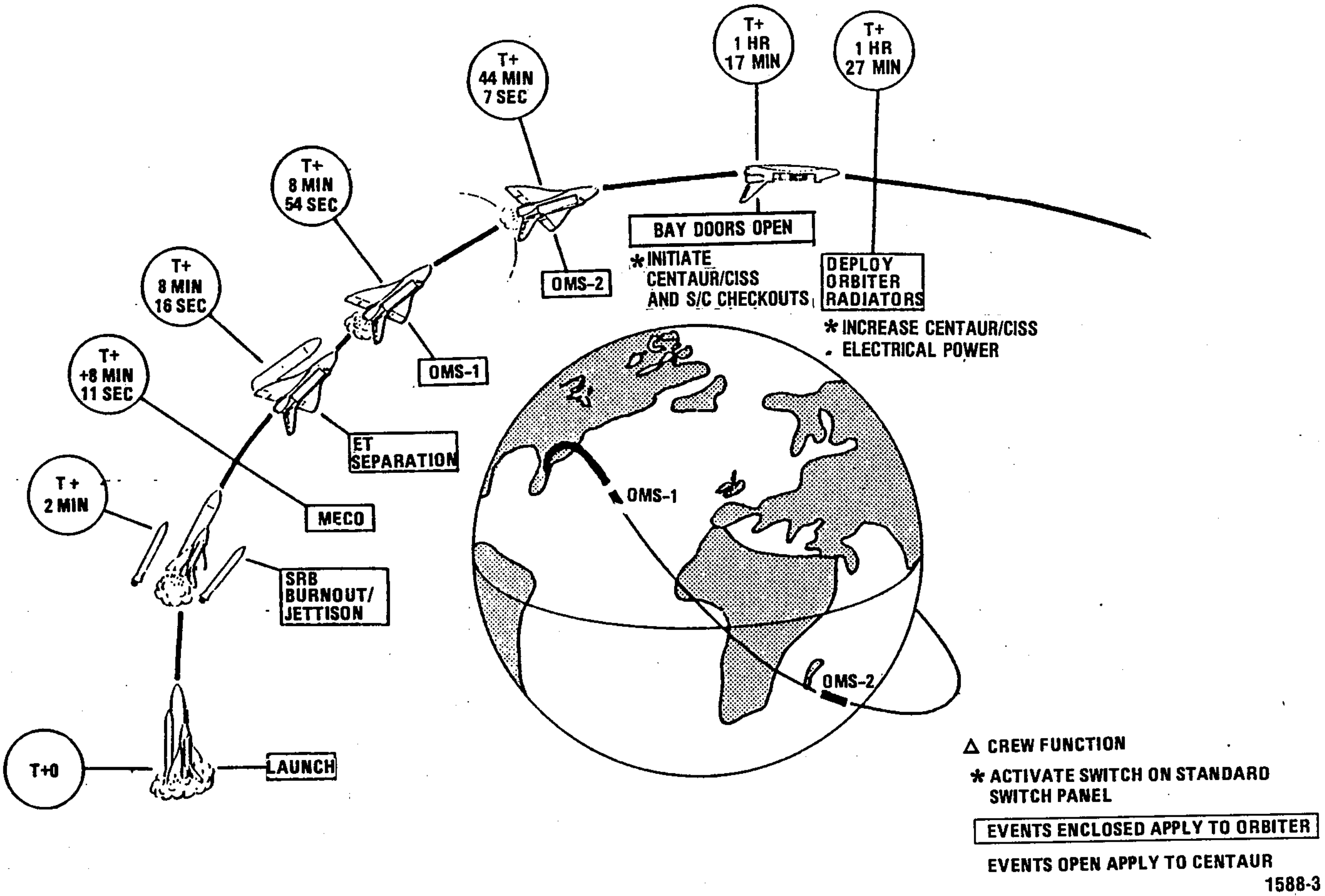

Figure 3-77. Nominal CCE Ascent Operations.

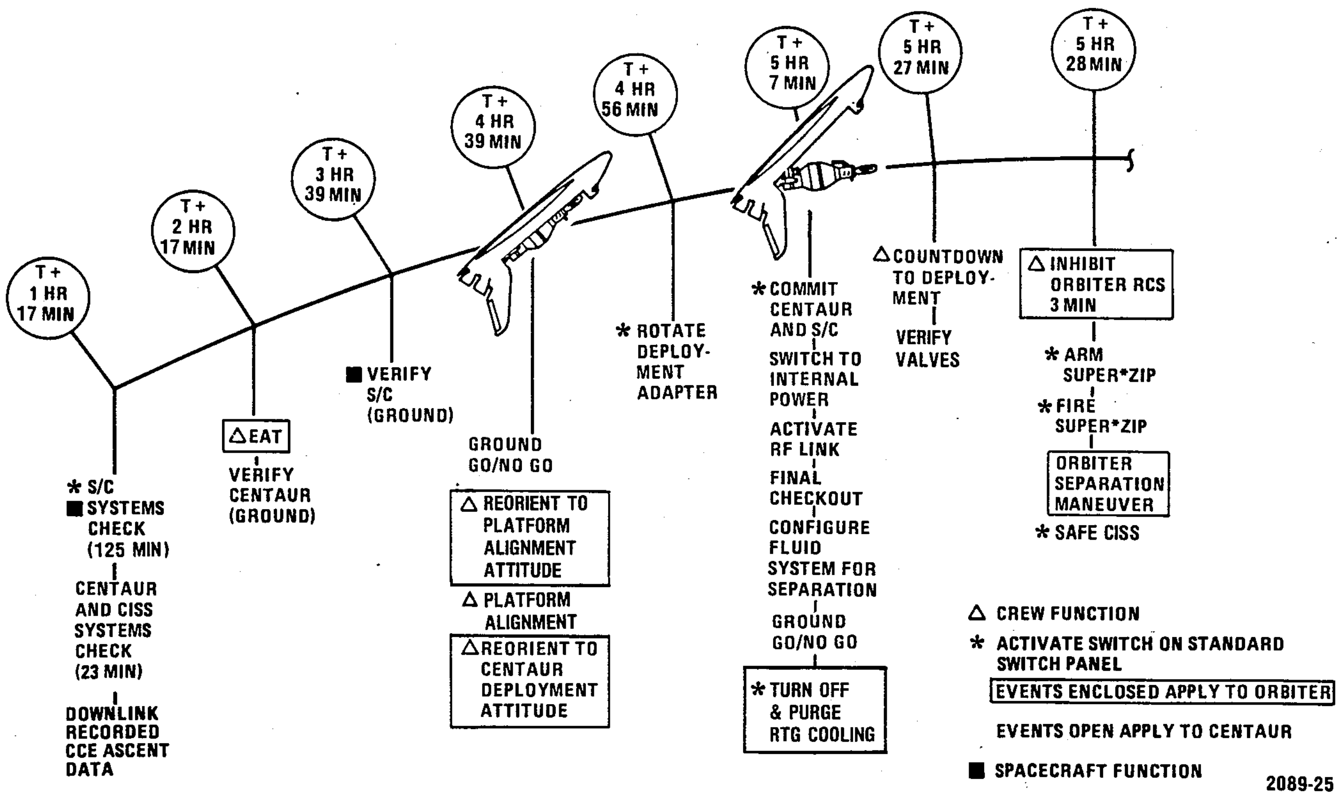

Figure 3-78. Centaur/Galileo for Deployment.

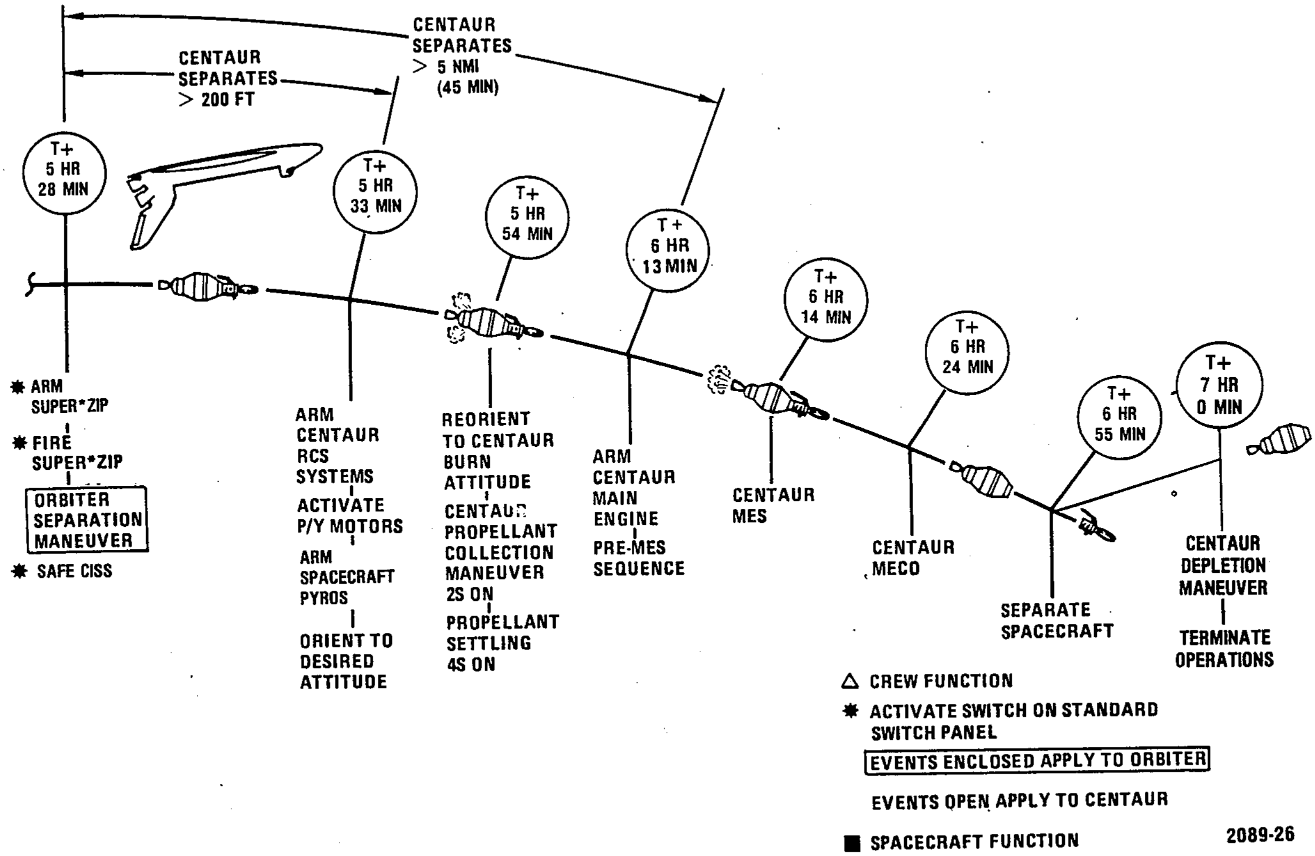

Figure 3-79. Nominal Centaur Postdeployment Operations.

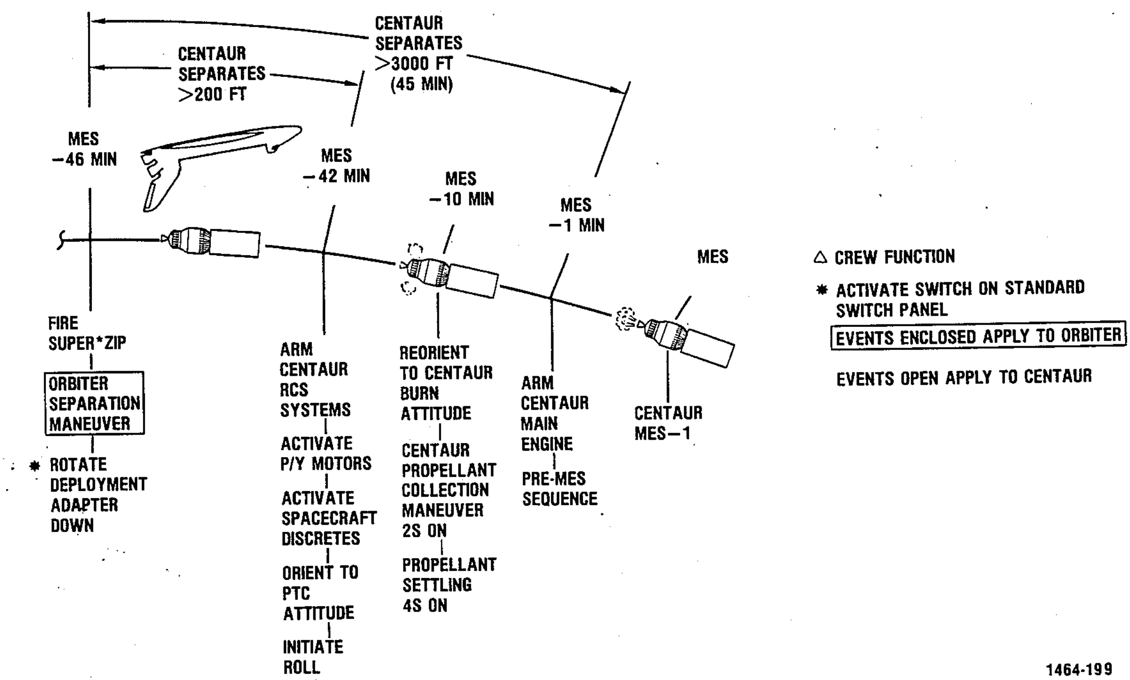

Figure 3-80. Separation Coast Phase for DoD Operations.

Figure 3-82 illustrates Centaur operations during the second main engine firing and through spacecraft separation maneuvers. A 26-degree plane change and geostationary orbit insertion occur in about two minutes. The Centaur establishes the spacecraft separation attitude and spacecraft separation, then performs orbit deflection maneuvers to ensure no contamination of or recontact

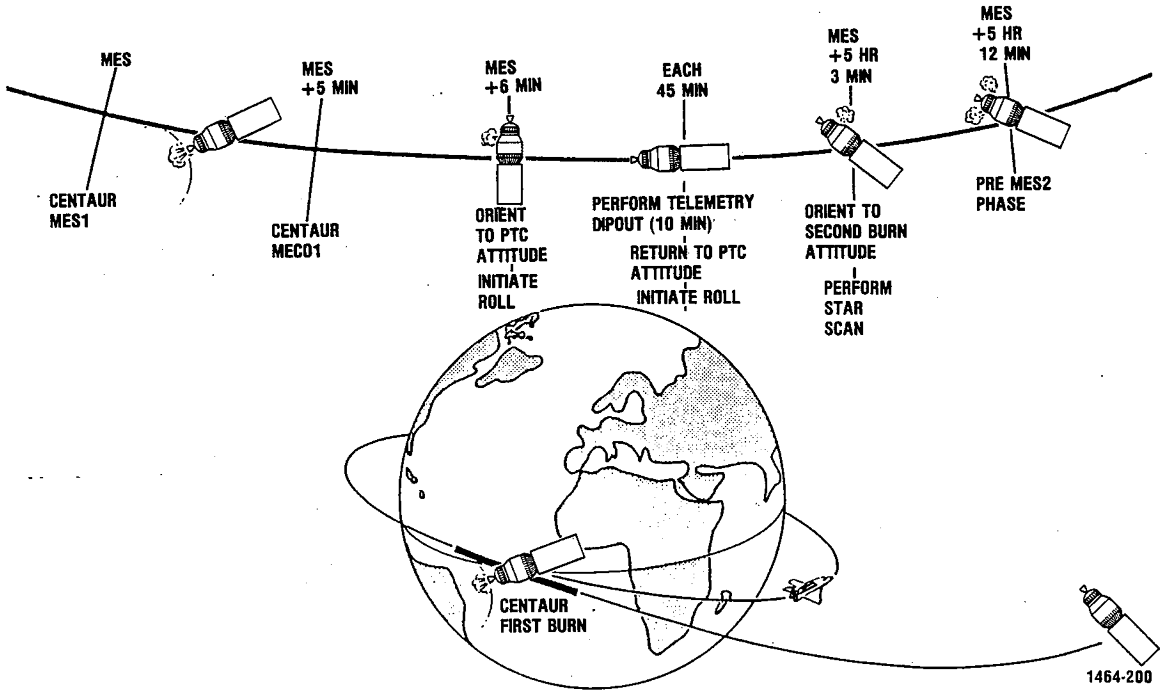

Figure 3-81. Spacecraft PTC Orientation and Telemetry Dipout Maneuver Requirements.

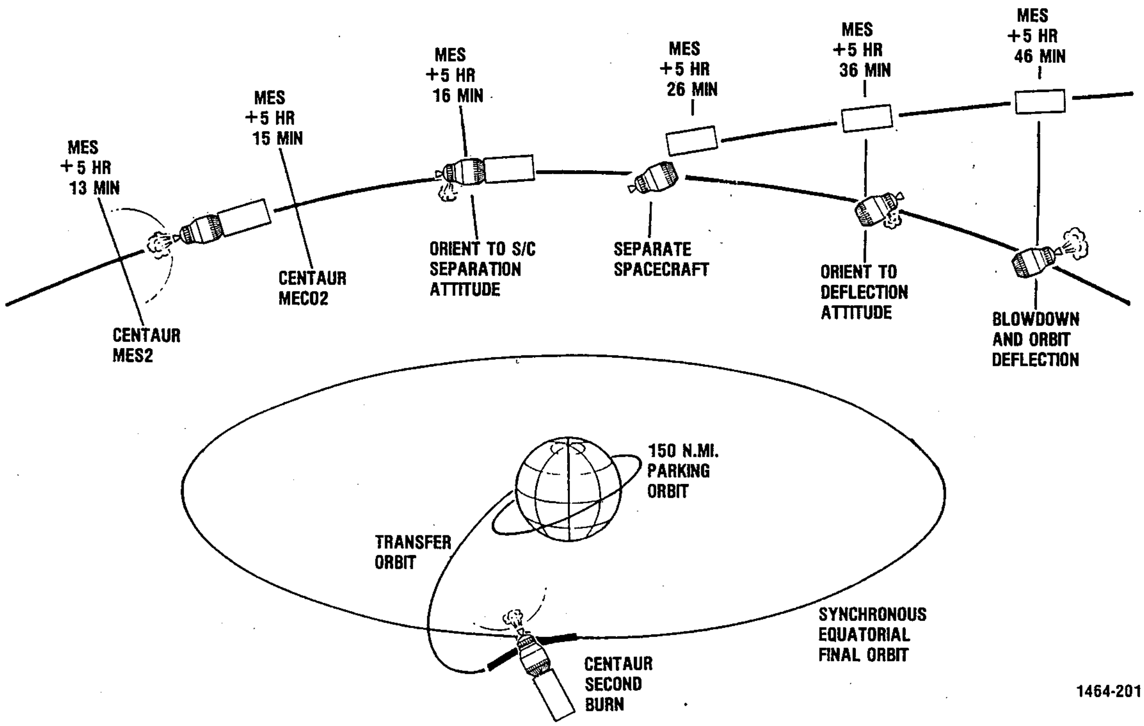

Figure 3-82. Centaur Spacecraft Separation.

with the spacecraft. The times presented in Figure 3-82 after MECO2 (second main engine cutoff) are typical.

3.7.2.5 Abort — The primary abort objective is to land safely with the spacecraft, Centaur, and CISS intact and reusable (after refurbishment) for a later flight. The Centaur/spacecraft can be restowed in the Orbiter payload bay up to the time of physical separation of the Super*Zip separation ring. The Centaur/spacecraft cannot be retrieved after separation.

CCE flight operations will be developed for six preplanned Shuttle abort modes:

1. Return to Launch Site (RTLS).
2. Trans-Atlantic Abort Landing (TAL).

3. TAL Avoidance (TALA).
4. Abort Once Around (AOA).
5. Abort to Orbit (ATO).
6. Abort From Orbit (AFO).

A deployment backout sequence will be developed that can be performed at any time from a normal deployment sequence. This backout sequence will be computer controlled, leaving the Orbiter crew free to attend to Orbiter operations; however, a certain degree of CCE support may be required to supplement abort operations; e.g., initiate Centaur propellant dump.

To return with the CCE intact, a Centaur propellant dump is planned before reentry for AOA and AFO aborts, or before Orbiter main engine cutoff for RTLS, TAL, and TALA aborts. Analyses of this propellant dump capability have been made for all preplanned Shuttle abort modes, as illustrated in Figure 3-83.

Centaur nominal dump times of 250 seconds during RTLS and 230 seconds for TAL aborts, are completed before MECO. The TAL mode may be avoided (TALA) dumping Centaur propellants and continuing into an ATO or AOA mode. The dump system can operate in a zero-g environment (on-orbit, Figure 3-84), but requires a settling acceleration at the start and end of the dump to minimize residual propellants. These settling burns may be provided by either the Orbiter RCS (AFO mode) or by the orbital maneuvering system (OMS) during normal OMS burns (AOA mode).

An abort to orbit may still result in a successful mission. When an ATO is caused by non-mission-critical functions, the Orbiter can remain in its 105-nmi ATO orbit from five orbital revolutions up to one day; consequently, Centaur can proceed with deployment and perform the Galileo mission.

All planned abort operations are in accordance with the contingency requirements of Tables 3-10 and 3-11.

The STS uses a caution and warning (C&W) system that will require CCE inputs. The criteria for issuing a C&W signal will be programmed into the safety and health status software. This data will be issued to the Orbiter crew and to the ground MCC/CPOCC; specific systems will be identified and their tolerance condition indicated. The crew and ground support can then review the status data on any CRT display to highlight critical items. Alternative flight plans will be developed for such possible contingency conditions and will be included in the Flight Operations Support Annex. No differences in abort operations exist between the NASA and DoD requirements except an abort

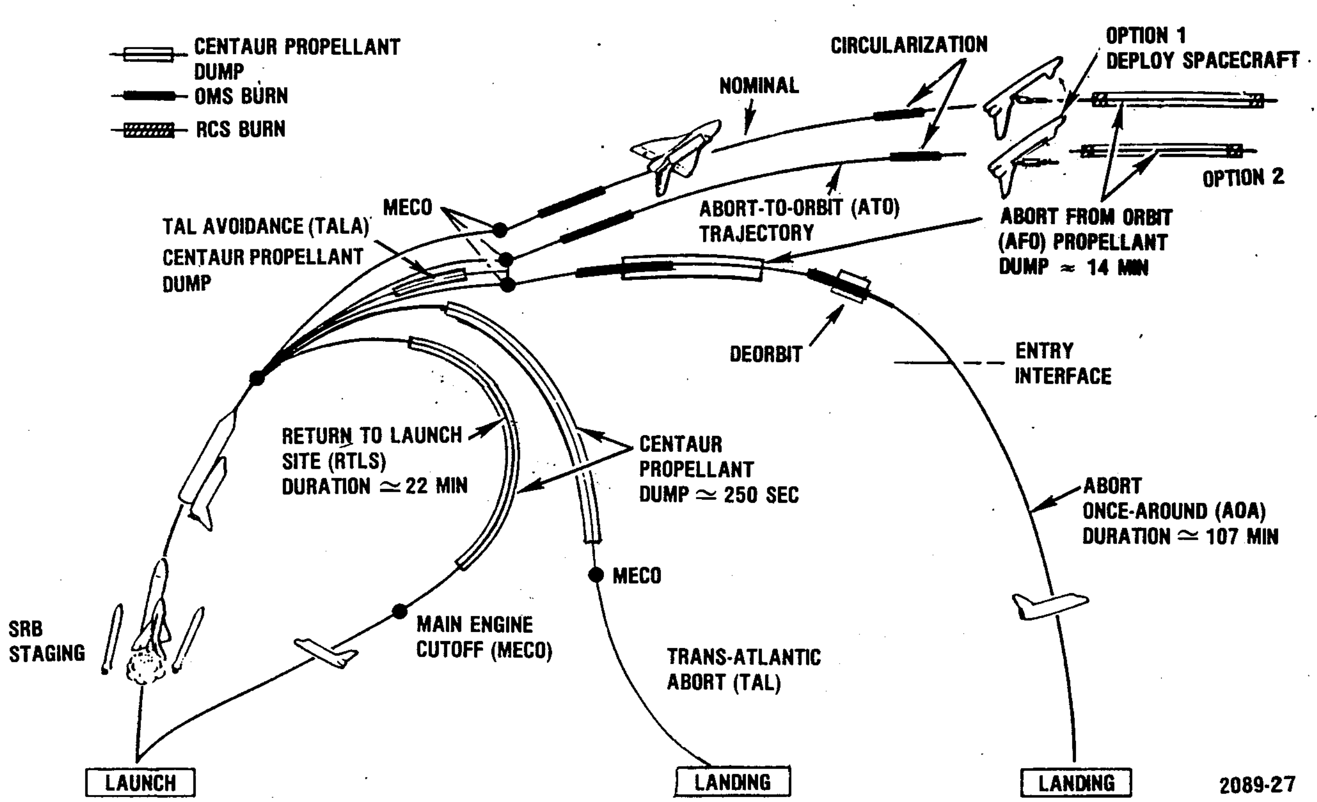

Figure 3-83. Centaur Abort Modes.

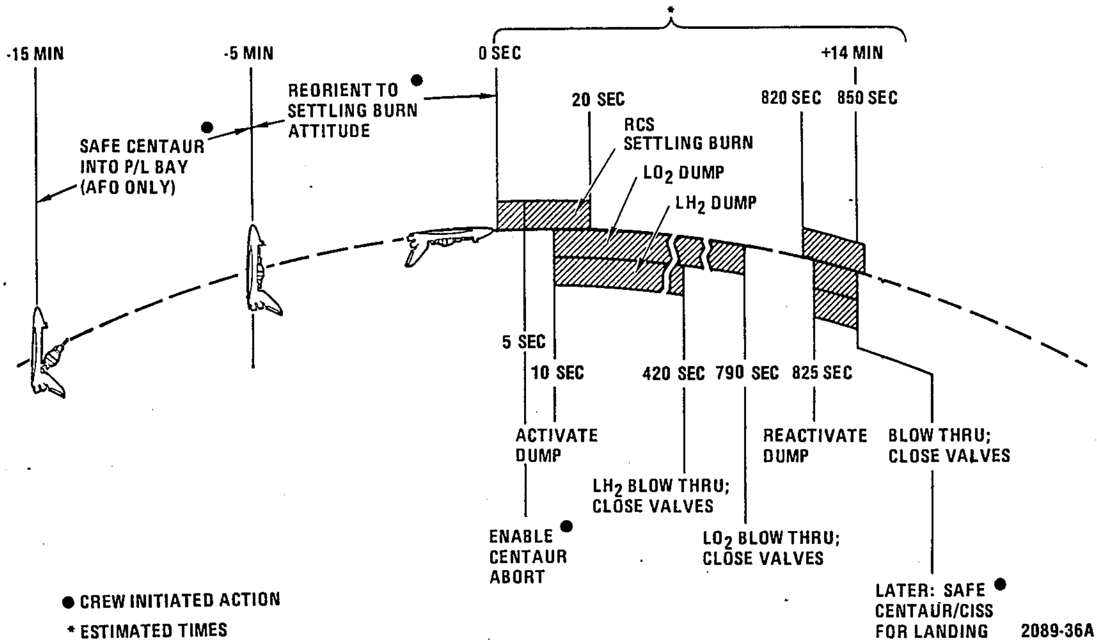

Figure 3-84. Zero-g Propellant Dump.

signal will be provided to the NASA Galileo spacecraft, and spacecraft environmental data will be recorded for the DoD spacecraft.

3.7.2.6 Postflight Evaluation — Each flight will have a detailed evaluation to verify correct operation of all Centaur/CISS systems. Any anomaly will be evaluated and corrective action taken before the next flight. This type of evaluation has been performed in the past and has supported short turnarounds between flights; e.g., Viking missions had 20 days between flights.

3.8 DEVELOPMENT REQUIREMENTS

General Dynamics has been successful in developing and launching space vehicles with Centaur since 1962 and with Atlas since 1958.

All dynamic analyses to date have shown vehicle and spacecraft response accelerations and Orbiter interface loads to be less than those obtained using the preliminary design accelerations in JSC-07700 Vol. XIV. The interface loads, in particular, show very significant reductions, and result in positive margins of safety for the Orbiter structure in all cases. Load alleviation devices have proven to be unnecessary.

The above sizing and analysis procedure is presently in work for the Centaur G configuration. Optimization techniques are being employed to obtain maximum spacecraft performance capability for a given vehicle length by trading propellant capacity and vehicle weight. The bulkhead shape has been optimized to provide maximum benefit of increased propellants balanced by the structural weight inherent in flatter bulkheads.

All structural requirements, such as factors of safety, fracture control, materials selection, etc., of JSC-07700 Vol. X and XIV, will be adhered to in the Centaur G designs.

3.8.1 MAJOR ANALYSIS REQUIREMENTS — Accuracy of our analyses is demonstrated by our 38 consecutive operational successes in Centaur flights since 1971.

3.8.1.1 Structural — Centaur G structural sizes and interface loads have been determined and verified to be acceptable through the use of detailed finite-element models and dynamic transient analyses based on STS models and forcing functions.

Orbiter interface locations chosen were those with the highest strength in each Orbiter bay, based on JSC-07700 Vol. XIV. Interface loads and point accelerations were initially calculated using the preliminary design accelerations of Vol. XIV. These interface loads and accelerations were then used, along with detailed finite element models (Figure 3-85), discontinuity analyses, or standard frame solutions of each major piece of structure, to determine optimized section sizes of the tank, adapters and CISS.

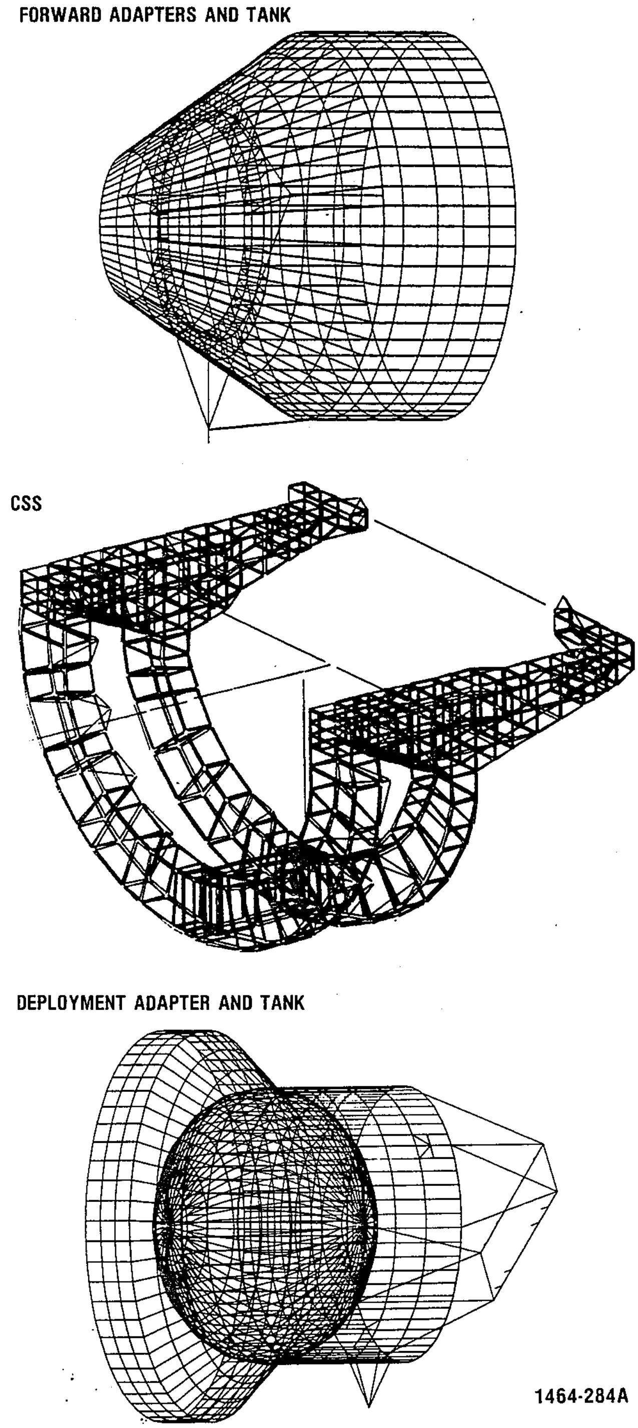

Figure 3-85. Structural Sizing Models.

Structural flexibilities were then obtained from these detailed models and incorporated into a dynamics model of the entire Centaur G. This dynamics model was then coupled, using modal synthesis, with STS dynamics models supplied by Rockwell International, and subjected to STS lift-off and landing forcing functions in dynamic transient response analyses. Cargo internal loads, accelerations, deflections, net load factors, and STS interface loads were calculated, as were spacecraft responses for the spacecraft contractors.

Quasi-static analyses were also performed in which the Centaur vehicle was coupled into the Orbiter flexibility matrix and subjected to quasi-static loads and Orbiter thermal deflections for ascent, on-orbit, and descent conditions. On-orbit thermal deflections are sufficiently small to avoid problems during a restow and relatch abort from erected attitude.

The above end-to-end procedure has been performed on three major vehicle configurations using five different spacecraft during the current Shuttle/Centaur effort. The standard D-1A Centaur (as used on Atlas/Centaur) was analyzed in the Shuttle using a 5,500-pound Galileo and 7,000-pound dual International Solar Polar Mission (ISPM) STAR-48 spacecraft.

3.8.1.2 Thermodynamics — General Dynamics will employ the same heat transfer and thermodynamic design analysis methods developed for Centaur, and refined by 20 years of application to Centaur missions. We will conduct Centaur cargo element thermal analyses to support design of Centaur G vehicle and CISS structures, avionics, and fluid systems. Prelaunch and post-abort gas conditioning system analyses will define payload bay thermal environments. Thermal analyses of structures and structural assemblies will provide thermal response data to support structural analysis and design, and will also yield main propellant tank heating rate partials to support fluid system analysis and design. Thermal analysis of components will support definition of component-level thermal control design requirements and qualification levels. A vehicle-level thermal math model will be formulated as input to a thermal integration analysis of the entire Centaur G cargo element, and will provide refined definition of STS payload bay environment temperature levels.

Thermal design analyses of Centaur G and CISS structures will include analysis of the entire forward structural assembly, including the forward adapter, equipment module, and stub adapter. An analysis of the aft structural assembly will address the aft skirt, deployment adapter, disconnect panels, and engine support structures. Detailed analysis of the CISS will include latching and support assemblies. Insulation blanket design analyses will support structural design goals, and will also yield tank heating histories and purge requirements.

Thermal control design analyses of all avionics components and subsystems will be conducted or updated, including new or existing components mounted on the forward equipment module, deployment adapter, and CISS.

Fluids thermodynamic analyses will be conducted to support design of the Centaur and CISS structures, along with the fluid systems. Thermal analysis support for fluid systems design will include a continuing update of main propellant tank heating rates for all operational conditions, including chilldown, tanking, inflight, and post-abort. Additional thermal analysis in support of fluids system designs includes tank pressurization, fill and drain, reaction control, abort/dump, and main propulsion subsystems and components. An analysis will support selection of pressurization and vent systems, abort helium requirements and CISS helium storage bottle selection, and mission propellant tank pressure profiles required to satisfy main engine NPSH requirements. Two areas of major emphasis for Centaur G development will be the thermodynamic vent systems and the abort dump system.

Thermodynamic vent system capability will be required to maintain Centaur G hydrogen tank pressure control while in the payload bay in low earth orbit and following deployment from the Orbiter. General Dynamics Convair Division designed and tested prototype thermodynamic vent systems in the 1960s and 1970s for liquid hydrogen and liquid oxygen application. These systems demonstrated the feasibility of zero-g propellant tank pressure control, which is achieved by throttling tank fluid through a heat exchanger, where it extracts energy from the bulk propellants. A propellant mixing device, operating in the LO_2 tank, will ensure low pressure rise rates to eliminate the need for venting before Centaur G deployment.

The Centaur G abort dump system is designed for compatibility with all Shuttle abort modes that can occur before vehicle deployment. For these aborts, we will devise methods for operating Centaur safely and for disposing of propellants before landing. JSC has required that a dumping duration of 250 seconds be imposed during a return to launch site abort. Experimentation described in Section 3.8.2 will provide empirical data on the extent to which frozen equilibrium conditions exist during propellant dump. Analysis of the abort dump procedure will allow us to establish design requirements for the propellant dump lines, pressurization technique, and tank inerting. The abort dump flow rate histories will serve as an input to the Rockwell International study for abort safety considerations.

3.8.1.3 Performance — General Dynamics will conduct trajectory design analyses for the reference mission to determine and define trajectory shaping and sequencing. Variations of performance and trajectory geometry will be developed for the mission box, and nominal and dispersed closed-loop trajectories will be simulated and provided to the various design and analysis disciplines. Centaur flight performance reserve requirement will be determined using the Monte Carlo technique. Trade studies will be performed to maximize the performance margin for nominal and backup deployment times. Factors affecting selection of the nominal and contingency windows include performance capabilities of the Orbiter and Centaur, Orbiter crew schedule constraints, tracking and telemetry requirements of the Orbiter, Centaur, and spacecraft, and possible launch delays.

3.8.1.4 Guidance — A preliminary guidance system accuracy analysis for two Centaur G planetary missions has been performed. The results show that the expected requirements can be satisfied by the Centaur inertial guidance system and baseline avionics. General Dynamics' analysis assumed a navigation update from the Orbiter and an attitude update using a star scanner. A navigation and attitude update was assumed 45 minutes (45 minutes used for analysis only) before main engine start (MES). Table 3-12 summarizes the FOMs computed at injection plus ten days for the Galileo and ISPM missions.

Table 3-12. FOMs for Galileo and ISPM Missions.

Deployment	Analysis Mode	FOM (m/sec) Galileo 85	FOM (m/sec) ISPM 85
OMS burnout plus 3 orbits	No updates	23.9	44.0
	Nav update	23.6	44.6
	Attitude update	11.8	28.8
	Nav/attitude update	9.3	28.5
OMS burnout plus 5 orbits	No update	36.0	59.3
	Nav update	34.1	59.2
	Attitude update	16.3	30.3
	Nav/attitude update	9.4	28.6
OMS burnout plus 7 orbits	No update	48.9	76.5
	Nav update	44.8	74.7
	Attitude update	22.7	33.8
	Nav/attitude update	9.4	28.6
	Preliminary requirements	16.0	38.0

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A preliminary guidance system accuracy analysis for a mission peculiar two-burn Shuttle/Centaur geosynchronous mission has been performed. The results show that the expected requirements are satisfied by the Centaur inertial guidance system and baseline avionics. The General Dynamics Convair Division analysis assumed a navigation update using the Tracking and Data Relay Satellite System and attitude updates using a star scannner. A navigation and attitude update was assumed 45 minutes (45 minutes used for analysis only) before the first main engine start (MES1), and a second attitude update 45 minutes before MES2. The trajectory simulated for this analysis performed the first Centaur burn and injection into the transfer orbit at the fourth descending node. Table 3-13 summarizes the state errors at injection into the geosynchronous orbit in terms of the tangential, normal, and radial position and velocity errors. Since navigation and attitude updates are assumed, this data is valid for transfer orbit injection at any ascending or descending node opportunity.

Table 3-13. Three-Sigma T, N, R State Errors.

Error State	3σ Error	Requirement*
T (nmi)	43	66
N (nmi)	23	40
R (nmi)	46	50
RSS (nmi)	67	92
$\dot{T}$ (fps)	10.3	16
$\dot{N}$ (fps)	14.3	12
$\dot{R}$ (fps)	34.1	75
RSS (fps)	38.4	78

* Components may be exceeded by 20% if RSS is not exceeded.

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3.8.1.5 Stability and Control — A dynamic model of Centaur, including elastic and slosh properties, will be furnished to evaluate the STS control stability by coupling the Centaur and STS models.

Centaur erection, separation, and coast will be evaluated to verify full compliance with STS requirements if component failures affect stability and control. This analysis will include six-degree-of-freedom (6 DOF) simulation of both Centaur and STS to define the failure clearance envelope. Centaur powered and coast phases will be analyzed to verify stability and control of the Centaur vehicle during all phases of flight. This will include the effects of the modified propellant tanks and revised stiffness on control. These analyses will include time-domain 6 DOF simulations with all nonlinearities and time-varying properties modeled. Modern control techniques will be employed to evaluate the noise and multi-loop/multi-disturbance effects. Frequency-domain analyses, such as root locus for basic stability and modified Z transform to evaluate the effect of sampling and digital computations, will be included and the effect of engine startup and shutdown on control will be delineated. A coast phase sequence will be generated and hydrazine usage estimated. This sequence development includes support for separation and blowdown.

3.8.1.6 CISS Control System Safety — Verification of the integrity of the failure-tolerant CISS control system design will be accomplished by three analytical approaches:

1. An Interdata 8/32 realtime simulation will be performed on the control system and the vehicle system being controlled (e.g., vehicle tank pressure). All control commands and responses will be simulated to demonstrate the effects of multiple failures (e.g., open relays, failed valves) under worst-case variations of time in the five asynchronously operating control units.
2. General Dynamics will conduct a sneak circuit analysis using NASA-developed pathfinding programs for analog circuitry and computer-aided digital analysis techniques for complex digital circuitry. This analysis will identify latent electrical circuit paths and conditions that can result in an undesirable event occurring without component failure.
3. A qualitative fault tree analysis will be performed to examine the interactions between CISS and Centaur subsystems and to verify that overall system fault tolerance levels have been achieved. The fault trees will also aid in identifying common cause and common mode failures that could defeat the intended level of failure tolerance.

3.8.2 TEST PROGRAM — The development, qualification, and integration tests performed for Centaur G, and our experience with cryogenic Atlas and Centaur vehicles will provide us with a low-risk program.

3.8.2.1 Development Tests — Early testing will add confidence to a mature design.

Development testing for Centaur G is planned to provide early solutions to design problems and to identify key characteristics of hardware and software. Component and/or subsystems will be tested in progressive stages to ensure earliest recognition of possible problem areas.

Development tests include all tests that are not qualification, acceptance, or prelaunch validation tests. The test program summary (Table 3-14) depicts test items and associated conditions and the test program flow diagram (Figure 3-86) shows the integrated test program flow, which describes an orderly progression to meet the program test objectives and test requirements. The test program is built on developmental testing experience of Atlas/Centaur and the cruise missile. The operational test program summary (Table 3-15) depicts test items related to supporting a DoD program. (Figure 3-87) shows the DoD test program option flow diagram.

3.8.2.1.1 Structures — A limited amount of structural development testing will be necessary for Centaur G. These development tests will consist initially of material elements and welding tests, then separation tests, tank insulation tests, Centaur support structure load tests, and tests due to the new launch and landing environment. The tests due to new environment(s) are acoustic vibration tests, Centaur load tests, and modal survey test.

3.8.2.1.2 Fluids and Mechanisms — Fluids and mechanisms systems for Centaur G are based on Atlas/Centaur technology except where Shuttle imposes additional requirements. The development test will cover mechanisms to deploy the Centaur from the Orbiter, propellant dump capabilities, and fluid interfaces with CISS.

3.8.2.1.3 Avionics and Software — Avionics and software on the Centaur G are derived from Atlas/Centaur systems with all changes required because of the additional Shuttle requirements. These added requirements include safety, operations sequence, and different-shaped vehicle.

Additional tests will be accomplished for optional DoD missions. This will consist of 14 tests. Three avionics boxes will be developed and tested. The remaining tests are system-level development tests. One significant test is the EMI/TEMPEST evaluation.

TEMPEST testing will be conducted in our Electromagnetics Laboratory in a controlled electromagnetic environment. Centaur G avionics will be mounted on a common ground plane and interconnected with vehicle harnesses. This test fixture will be placed within a shielded enclosure constructed of welded sheet iron. The room (12 by 24 by 10 feet) complies with the most stringent DoD and NASA requirements to preclude radiation leakage that might interfere with TEMPEST testing.

The CCLS will be used to command and control the avionics systems and to act as a system monitor for proper operation; see Figure 3-88. All system data rates will be excited by the CCLS so that a complete survey of electromagnetic leakage at all operational speeds can be assessed by the TEMPEST test environment.

Table 3-14. Centaur G Test Program Summary.

Test Item	Planning Test	Test Location	Hardware Configuration	Support Requirements
STRUCTURES				
1. Insulation System Material	Determine Electrostatic, Solar Emittance, Mechanical, & Outgassing Properties	GDC Material Research	Test Hardware — Various Samples of Insulation Material	Existing Test Facility & Support Test Equipment
2. Structural Test-Stub Adapter Stringer	Establish Strength of Typical Stub Adapter Stringer. Verify Calculated Values	GDC Material Research	Test Hardware — Stub Adapter Stringer/Plate Constructed with End Fittings	Existing Test Facility & Support Test Equipment
3. Structural Test-Aft Adapter Ring Joints	Establish Strength of Typical Aft Adapter Ring Joint. Verify Calculated Value	GDC Material Research	Test Hardware — Aft Adapter Ring Joints Constructed with End Fitting	Existing Test Facility & Support Test Equipment
4. Structural Test-Equipment Module Support Struts	Demonstrate the Structural Strength & Stability of the Forward Support Struts. Verify Calculated Strength	GDC Material Research	Test Hardware — Forward Support Struts with End Fittings	Existing Test Facility & Support Test Equipment
5. Structural Test-CSS Structural Members	Demonstrate the Structural Strength & Stability of the Panel Aft Support Bar & Pin	GDC Material Research	Test Hardware — Machined Panel, Aft Support Bar Segment with End Fitting & Machined Interface Pin	Existing Test Facility & Support Test Equipment
6. Structural Test-Deployment Adapter Stringer	Perform Structural Test of Plate/Stringer Combination Simulating Deployment Adapter Construction	GDC Material Research	Test Hardware — Plate/Stringer Construction with End Fittings for Applying Load	Existing Test Facility & Support Test Equipment
7. Structural Test-Spotweld/Seamweld Tank Joints	Perform Structural Test on Various Type of Joint Coupons of Tank Skins & Rings	GDC Material Research	Test Hardware — Specimens are Coupons made of Buildup on Skin/ Doubler/Ring Thicknesses joined by Weld Like Production Article	Existing Test Facility & Support Test Equipment
8. Structural Test-Equipment Module Stringers	Demonstrate Structural Strength & Stability of the Stringer/Skin Combination	GDC Material Research	Test Hardware — Stringer Riveted to Skin with End Flanges for Applying Load	Existing Test Facility & Support Test Equipment
9. Structural Test-CSS Gas Duct Bellows	Perform Load Deflection Test & Permanent Deflection Test on Gas Conditioning Bellows	GDC Material Research	Test Hardware — Bellows with End Fittings for Holding During Test	Existing Test Facility & Support Test Equipment
10. Structural Test-Engine Support System Strut	Demonstrate Structural Strength & Stability of the Engine Support Struts	GDC Material Research	Test Hardware — Engine Support Struts with End Fittings	Existing Test Facility & Support Test Equipment
11. Structural Test Equipment Module Longeron	Demonstrate Structural Strength & Stability of Longeron	GD/C Material Research	Test Hardware — Equipment Module Longeron with End Fittings	Existing Test Facility & Support Test Equipment
12. CISS Helium Bottle Support	Demonstrate Helium Bottle Support to withstand Flight Structural Loads	GDC Mechanical Lab	Test Hardware — Typical Helium Bottle Support Structures	Existing Test Facility & Support Test Equipment
13. Centaur Functional-Equipment Module Vent Door	Functional Tests to Demonstrate the Equipment Module Vent Door Operations	GDC Environmental Lab	Test Hardware — Equipment Module Vent Door	Existing Test Facility & Support Test Equipment
14. Centaur Functional-Deployable Antenna	Functional Test to Demonstrate Deployment of Antenna Support Structure	GDC Environmental Lab	Test Hardware — Spring Loaded Support Structure Released by Redundant Pyrotechnic Pin Pullers	Existing Test Facility & Support Test Equipment

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Table 3-14. Centaur G Test Program Summary (continued).

Test Item	Planning Test	Test Location	Hardware Configuration	Support Requirements
15. CISS Functional-Centaur Severance System	Demonstrate the SUPER*ZIP Functions in Flight Environment (Primarily Low Temperature)	Vender LMSC Environmental Lab	Test Samples — SUPER*ZIP	Existing Test Facility & Support Test Equipment
16. CISS Functional Spring Thrust System	Demonstrate that Spring Thrust System will provide Energy to Thrust Centaur Vehicle from Deployment Adapter with Required Acceleration/Velocity	GDC KM Test Tower	Test Hardware — Spring Thrust System, Engine Support Cone, Electrical Flyaway Umbilicals, Fluid System, Disconnects, Deployment Adapter & SUPER*ZIP Ring	Existing Test Facility & Support Test Equipment
17. CSS Static Load Test	Demonstrate that CSS Exhibits Satisfactory Structural Properties when Subjected to Ultimate Design Loads	GDC Structural Lab	Test Hardware — Centaur Support Structural	Existing Test Facility & Support Test Equipment
18. Centaur Fwd Structure Static Load	Demonstrate Structural Integrity of Centaur Tank & Forward Adapter to Ultimate Loads	GDC Sycamore Canyon Test Site	Test Hardware — Stub Adapter, Aft Adapter, Centaur Test Vehicle, & Deployment Adapter. Tank must be complete enough for Cryo Tanking	Existing Test Facility — New Support Structure Required
19. Centaur Aft Structure Static Load	Demonstrate Structural Integrity of Centaur Tank & Aft Adapter Components to Ultimate	GDC Sycamore Canyon Test Site	Test Hardware — Stub, Adapter, Aft Adapter, Centaur Vehicle, & Deployment Adapter, Including Engine Support Structure	Existing Test Facility — New Support Structure Required
20. Centaur LO_2 Tank Aft Bulkhead Hydrodynamics Loads & Deflection	Validate LO_2 Aft Bulkhead for Application of Longitudinal & Lateral Dynamic Hydrodynamics Pressure Loads at STS Liftoff	GDC CEVAT Centrifuge	Test Hardware — Existing Stub Tank	Existing Test Facility & Support Test Equipment
21. LH_2 Tank Sidewall Blanket	Demonstrate Purge System Performance in Maintaining Blanket Delta P during Pretanking, Chilldown, & Tanking to Evaluate Tank Thermal Properties	GDC Sycamore Canyon Test Site	Test Hardware — Test Centaur Tank with PLIS Probes, All Forward Adapters, Blanket System, Purge System, Vent System, Aft Adapter, & CSS	Existing Test Facility — New Support Structure Required
22. Centaur Tank, Adapters & CISS Dynamic Modal Survey	Determine Principal Mode Shapes & Natural Frequency of the Centaur/CISS.	GDC KM Vibration Tower	Test Hardware — Complete Test Centaur Tank, Adapters, Test CISS & Simulated Payload	Existing Test Facility & Support Test Equipment
23. Deployment Adapter Acoustic Test	Measure Environmental Vibration on Simulated Components Attached to Deployment Adapter with Shuttle Acoustic Levels	Johnson Space Center Acoustic Lab	Test Hardware — Aft Deployment Adapter & Set of Simulated Components	Existing Test Facility & Support Test Equipment
24. Equipment Module Acoustic Test	Measure Environmental Vibration on Simulated Components Attached to Equipment Module with Shuttle Acoustic Levels	Johnson Space Center Acoustic Lab	Test Hardware — Production Equipment Module, Stub Adapter & Set of Simulated Avionics	Existing Test Facility & Support Test Equipment
25. Equipment Module Swivel Mount Assembly	Demonstrate the Swivel Mount to Withstand Flight Vibration & Structural Loads	GDC Environmental Lab	Test Hardware — Four Mount Supporting a 70 lb Box	Existing Test Facility & Support Test Equipment

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Table 3-14. Centaur G Test Program Summary (continued).

Test Item	Planning Test	Test Location	Hardware Configuration	Support Requirements
FLUIDS				
26. Cryo Flange	GHe & Cryogenic Leakage of Various Flange /Joint Sealing Methods Used on Centaur — CISS	GDC KM Fluids Lab	Test Hardware — Flanges/ Joints Configured per Centaur — CISS Application	Existing Test Facility & Support Test Equipment
27. Slip-Type Disconnect Low Pressure	Verify Connect/Disconnect Force, Leakage, & Environmental Compatibility for Low Pressure Slip-type Disconnect	GDC KM Fluids Lab	Test Hardware — Low Pressure Slip-type Disconnect, Engine Duct Elbow & Deployment Adapter Mounting Interface	Existing Test Facility & Support Test Equipment
28. Elemental Mechanisms	Early Demonstration of Critical Elements of the Mechanical Systems	GDC KM Test Tower	Test Hardware — Disconnects, Seals & Materials	Existing Test Facility & Support Test Equipment
29. Ascent Vent Valve-LO_2	Verify Purge Will Prevent Liquid Lockup & Will Not Adversely Affect Valve Operation System	GDC KM Fluids Lab	Test Hardware — Flight Configuration Valve with Purge	Existing Test Facility & Support Test Equipment
30. Hydraulic Recirculating Motor Purge	Verify Explosion Proofing of 28 Vdc Electric Motor.	GDC KM Fluids Lab	Test Hardware — D-1A DPT Unit Refurbished & Modified by Vender	Existing Test Facility & Support Test Equipment
31. Pilot Operated Solenoid Valve	Verify Feasibility of New Modular Design & Solenoid Valve Operating at Maximum Inlet Pressure of 4000 psig	GDC KM Fluids Lab	Test Hardware — Pilot Operated Solenoid Valve	Existing Test Facility & Support Test Equipment
32. 2.5 in. Three Gimbal Duct	Perform Rotation Tests Under Varying Installation Misalignment & Operating Conditions & Flow to Verify Functional & Structural Integrity of the Centaur-to-CISS Gimbal Duct Line & Rotation Loads	GDC Sycamore Canyon Test Site	Test Hardware — Gimbal Duct	Existing Test Facility — New Support Structure Required
33. 5.5 in. Three Gimbal Duct	Perform Rotation Tests Under Varying Installation Misalignment & Operating Conditions & Flow Tests to Verify Functional & Structural Integrity of the Centaur-to-CISS Gimbal Duct Line & Rotation Loads	GDC Sycamore Canyon Test Site	Test Hardware — Gimbal Duct	Existing Test Facility — New Support Structure Required
34. Insulation Blanket Purge System	Demonstrate Purge System Capability to Maintain Insulation Blanket Delta-P under Various Conditions	GDC Sycamore Canyon Test Site	Test Hardware — Flight-type Solenoid Valves, Delta-P Transducers, Avionics, Test Box, Orifices, Insulation Vent/ Check Valves & Regulator	Existing Test Facility — New Support Structure Required
35. LO_2 Jet Mixer	Verify Jet Mixer Provides Proper Propellant Mixing in the LO_2 Tank & Components Perform Properly as a System	GDC KM Fluids Lab	Test Hardware — 0.2 Scale System Hardware	Existing Test Facility — Support Test Equipment
36. Tank Two-Phase Outflow Test	Perform Outflow Test with Scaled Down LH_2 & LO_2 Tanks to Determine Quantity of Liquid Being Expelled as a Function of Tank Residuals	GDC Sycamore Canyon Test Site	Test Hardware — 1/5 Scale & 1/20 Scale Tanks with Simulated LO_2 & LH_2 Tank Outlets	Existing Test Facility — New Support Structure Required

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Table 3-14. Centaur G Test Program Summary (continued).

Test Item	Planning Test	Test Location	Hardware Configuration	Support Requirements
37. Dump System Flow Test	Conduct Individual LN_2 & LH_2 Flow Tests through a Representative Flight Propellant Dump System to Verify Computer Model	GDC Sycamore Canyon Test Site	Test Hardware — Representative Foam-Insulated Propellant Dump System Consisting of Typical Flight Weight Bellows, Gimbal Joints, Valving & Ducting	Existing Test Facility — New Support Structure Required
38. Centaur Rotation System Operation	Functional Systems Tests include Rotation Followed by Deployment Adapter Retraction, Also Demonstrate the Backup Rotation System	GDC KM Test Tower	Test Hardware — Oxidizer Gimbal Ducts, Flex Hoses, D/A Rotation Systems, (CISS D/A, Aft Skirt & Centaur Mass Simulation), Orbiter Latches, Fuel Umbilical Loads Simulator & Centaur "Whalebone."	Existing Test Facility & Support Test Equipment
39. Fill/Drain Residual Purge	Verify the Feasibility of Reducing Pre-liftoff Residuals to an Acceptable Level by Purging the LO_2 & LH_2 Fill/Drain Lines	GDC KM Fluids. Lab	Test Hardware — Tygon Tubing Simulation of the Fill/Drain Lines	Existing Test Facility & Support Test Equipment
40. Rise Off Disconnect Panel	Perform Separation Test of Fluid System Disconnects Mounted in Centaur & Deployment Adapter Panel	GDC KM Fluids Lab	Test Hardware — Set of Flight Disconnect Pairs	Existing Test Facility & Support Test Equipment
41. LH_2 Propellant Mixing	Verify Zero-g Vent Mixer Will Provide Proper Propellant Mixing	GDC KM Fluids Lab	Test Hardware — 0.2 Scale System Hardware	Existing Test Facility & Support Test Equipment
42. Engine Actuator Stiffness	Determine Stiffness & Damping Characteristics of Actuator in 5 to 50 Hz Range	GDC KM Vibration Lab	Test Hardware — Engine Actuator & Servo Valve	Existing Test Facility & Support Test Equipment
43. LH_2 Sump Design	Perform LH_2 Outflow Test with Simulated Scale Model Tank to Determine Sump Design	GDC Sycamore Test Site	Simplified Scale Model of LH_2 Tank with LH_2 Tank Outlets	Existing Test Facility & Support Test Equipment
AVIONICS				
44. Vacuum Transducer Evaluation	Evaluate Off-the-shelf Vacuum Transducers	GDC KM Environmental Lab	Test Hardware — Off-the-shelf Vacuum Transducers	Existing Test Facility & Support Test Equipment
45. Differential Pressure Transducer Evaluation	Evaluate Off-the-shelf Differential Pressure Transucers	GDC KM Environmental Lab	Test Hardware — Off-the-shelf Differential Pressure Transducers	Existing Test Facility & Support Test Equipment
46. LH_2 PLIS Probe	Evaluate LH_2 PLIS Probe	GDC KM Vibration Lab	Test Hardware — LH_2 PLIS Probe	Existing Test Facility & Support Test Equipment
47. LO_2 PLIS Probe	Evaluate LO_2 PLIS Probe	GDC KM Vibration Lab	Test Hardware — LO_2 PLIS Probe	Existing Test Facility & Support Test Equipment
48. LH_2 PU Probe	Evaluate LH_2 PU Probe & Harness	GDC KM Vibration Lab	Test Hardware — LH_2 PU Probe	Existing Test Facility & Support Test Equipment
49. LO_2 PU Probe	Evaluate LO_2 PU Probe & Harness	GDC KM Vibration Lab	Test Hardware — LO_2 PU Probe	Existing Test Facility & Support Test Equipment

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Table 3-14. Centaur G Test Program Summary (continued).

Test Item	Planning Test	Test Location	Hardware Configuration	Support Requirements
50. CCVAPS Pressure Transducer	Evaluate CCVAPS Pressure Transducer	GDC KM Environmental Lab	Test Hardware — Off-the-shelf Pressure Transducers	Existing Test Facility & Support Test Equipment
51. CISS-Angular Displacement Transducer	Evaluate Angular Position Transducer	GDC KM Environmental Lab	Test Hardware — Off-the-shelf Displacement Transducers	Existing Test Facility & Support Test Equipment
52. CISS-Absolute Pressure Transducer	Evaluate Pressure Transducer	GDC KM Environmental Lab	Test Hardware — Off-the-shelf Pressure Transducer	Existing Test Facility & Support Test Equipment
53. CISS Battery Performance	Demonstrate Current & Voltage Performance both Parallel & Single Battery. Demonstrate Single Battery Capacity under worst Case Loads	GDC KM Battery Lab	Test Hardware — Eagle Picher P/N Map 4240 Battery	Existing Test Facility & Support Test Equipment
54. TT&C Coax Cable Assemblies	Evaluate TT&C Coax Cable Assemblies in Conjunction with Telemetry Subsystem Compatibility Test	GDC KM RF Lab	Test Hardware — Coax Cable Assemblies	Existing Test Facility & Support Test Equipment
55. R.F. Antenna Patterns	Perform RF Radiation Pattern Testing with Antennas Mounted on 1/4 Scale Centaur Mockup	GDE KM Antenna Range	Test Hardware — Centaur Mockup (1/4 Scale), Two Antennas (1/4 Scale), Antenna (Full Size) & Spacecraft Mockup (1/4 Scale)	Existing Test Facility & Support Test Equipment
56. CISS DC/DC Converter	Demonstrate Standard Performance Parameters during Ambient & Elevated Temperature Exposure & Vibration	GDC KM Environmental Lab	Test Hardware — CEA Div. of Berkleonics, Inc., ac/dc Converter	Existing Test Facility & Support Test Equipment
57. Centaur Signal Conditioner	Perform Evaluation Tests or Signal Conditioner for the Centaur	GDC KM Environmental Lab	Test Hardware — Prototype Signal Conditioner	Existing Test Facility & Support Test Equipment
58. Dual Failure Tolerant Arming Sequencer	Perform Breadboard & Hot Bench Testing on Prototype Dual-Fault-Tolerant Arm Safe Sequencer Units	GDC KM SIF & Environmental Lab	Test Hardware — Prototype DUFTAS & Replica Unit	Existing Test Facility & Support Test Equipment
59. Control Unit Performance	"Hot Bench" Testing on Prototype Control Units to Demonstrate Functionally Compatible. Temperature & Vibration Testing of Replica	GDC KM SIF & Environmental Lab	Test Hardware — Prototype CUs & Replica Unit	Existing Test Facility & Support Test Equipment
60. Control Distribution Unit	"Hot Bench" Testing to Ensure Electrical Compatibility with Total Control Subsystem. Temperature & Vibration Testing of Replica	GDC KM SIF & Environmental Lab	Test Hardware — Replica Unit	Existing Test Facility & Support Test Equipment
61. PLIU Performance	"Hot Bench" Testing on Prototype PLIU to Demonstrate Functionally Compatible Instrumentation Subsystem. Temperature & Vibration Testing of Replica	GDC KM S/F & Environmental Lab	Test Hardware — Replica Unit	Existing Test Facility & Support Test Equipment
62. Pyro/Initiator Controller	Demonstrate Pyro/Initiator Controller Capability in Centaur/Shuttle Environments	GDC KM Environmental Lab	Test Hardware — Replica Pyro/Initiator Controller	Existing Test Facility & Support Test Equipment

Table 3-14. Centaur G Test Program Summary (continued).

Test Item	Planning Test	Test Location	Hardware Configuration	Support Requirements
63. Electrical Distribution Unit	"Hot Bench" Testing on Prototype Units to Demonstrate Functionally Compatible. Temperature & Vibration Testing of Replica	GDC KM Mechanical Lab	Test Hardware — Prototype	Existing Test Facility & Support Test Equipment
64. Erector Harness Assembly	Demonstrate CISS/Centaur Umbilical Riseoff Harness Accommodate 45 Degree Change of Erector Orientation	GDC KM SIF & Environmental Lab	Test Hardware — Partial Harness Containing Proper Wire Gauge, Number of Wires & Protection	Existing Test Facility & Support Test Equipment
65. CISS Signal Conditioner	Evaluate Signal Conditioner for the CISS	GDC KM Environmental Lab	Test Hardware — Prototype Signal Conditioner	Existing Test Facility & Support Test Equipment
66. Vehicle DCU Software-Pre-Flt Prog. Module Level & Integrated Level	Test All Preflight (Pre-Liftoff) Modules Separately & then together as an Integrated Program	GDC KM TICS & SIF Labs	Test Hardware — N/A	Existing Test Facility & Support Test Equipment
67. Vehicle DCU Software-Flt. Prog. Module Level & Integrated Level	Test All Flight Modules Separately & then Together as an Integrated Program	GDC KM "TICS/TRATEX" on GPC & "FAST" on Harris	Test Hardware — N/A	Existing Test Facility & Support Test Equipment
68. CISS DCU & CU Software-Prog. Module Level & Integrated Level	Test All Software Modules Separately & then Together as an Integrated Program	GDC KM SIF Lab	Test Hardware — N/A	Existing Test Facility & Support Test Equipment
69. CCLS Software	CCLS Software Development, Integration & Validation Testing	GDC KM SIF Lab	Test Hardware — N/A	Existing Test Facility & Support Test Equipment
70. Guidance & Navigation System	Verify Guidance/Navigation, Gyro Compassing & Star Scanner Hardware/Software Interfaces for New Modes of Operation	GDC KM SIF Lab	Test Hardware — Prototype DCU, IMG, & Star Scanner	Existing Test Facility & Support Test Equipment
71. Avionics System Integration	System Level Hardware & Software Interface Compatibility, Software, & Procedure Development & System Level Safety Demonstration	GDC KM SIF Lab	Test Hardware — Prototype CISS & Centaur Packages Simulators	Existing Test Facility & Support Test Equipment
72. EMI Evaluation	EMI Evaluation Testing on Centaur & CISS Avionics Boxes & System	GDC KM SIF Lab	Test Hardware — Prototype Centaur & CISS Units	Existing Test Facility & Support Test Equipment
73. EMC System Level	System Level EMC Testing on Centaur Vehicle & CISS	GDC Vehicle Final Assembly	Test Hardware Production Centaur & CISS	Existing Test Facility & Support Test Equipment
74. TT&C Subsystem Integration	Perform Evaluation Tests for TT&C Subsystem	GDC KM RF Lab & SIF	Test Hardware Prototype TT&C Subsystem	Existing Test Facility & Support Test Equipment
GRD. AVIONICS				
75. Antenna Test Couplers	Evaluate Antenna Test Couplers	GDC KM RF Lab	Test Hardware — Prototype Antenna Test Coupler, Prototype Antenna	Existing Test Facility & Support Test Equipment

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Table 3-14. Centaur G Test Program Summary (continued).

Test Item	Planning Test	Test Location	Hardware Configuration	Support Requirements
76. GSE	Development Tests for: CCLS, Hardware Extension Remote, Missile Checkout Computer System, Software Development Computer System & Mobile Support Equip	GDC KM SIF Lab	Test Hardware — CCLS, HER, MCCS, SDCS, & MSE	Existing Test Facility & Support Test Equipment
INTEGRATION TESTS				
77. Centaur/CISS/-Orbiter Mate Test	Demonstrate Compatibility of Centaur CISS Attach Fittings & Hardware Interfaces	KSC CX-39	Test Hardware — Orbiter Centaur & CISS	Existing Test Facility & Support Test Equipment
78. Fill, Drain & Dump Validation	Chilldown, Fill to Flight Level, Drain, & Dump System Validation	GDC ETR CX-36	Test Hardware — Centaur, CISS, & Simulated Orbiter	Existing Test Facility. New Support Test Equipment
79. Fluid System Dry Mode Integration Test	Perform Fluid System Dry Mode Integration Test before Flowing Cryogenics or Helium for Three Configurations	GDC ETR CX-36	Test Hardware — LO_2/LH_2/ GHe Ground Systems, MSE Simulator, CCLS, CISS, MSE, Centaur	Existing Test Facility. New Support Test Equipment
80. LO_2/LH_2 Cold Flow Validation Tests	Perform Cold Flow Validation Tests for LO_2 & LH_2 Systems both before & after CISS Erection	GDC ETR CX-36	Test Hardware — LO_2/LH_2 Ground Systems, MSE Simulator, CCLS, CISS, MSE, & LO_2 Heat Exchanger	Existing Test Facility, Modified Support Test Equipment
81. LO_2/LH_2 Cold Flow Validation Tests	Perform One Time LO_2 & LH_2 Cold Flow Validation Tests prior to Launch Countdown Demonstration	KSC CX-39	Test Hardware — LO_2/LH_2 Control Skids & MSE Simulator Installed at CX-39	Existing KSC Facility, Modified Support Test Equipment
82. Launch Count-down Demonstration	Prior to Launch Tanking Perform One-Time Tanking Test of Shuttle/Centaur	KSC CX-39	Test Hardware — Centaur & CISS, LH_2, LO_2 & GHe Control Skids Supporting Avionics & Orbiter	Existing KSC Facility, Modified Support Test Equipment
83. Centaur/Spacecraft Interface Test	Demonstrate Interface Compatibility of Centaur to Spacecraft	KSC — Vertical Processing Facility (VPF)	Test Hardware — Flight Hardware or Simulator	Existing KSC Facility & Support Test Equipment
84. Centaur/Space-craft/TDRSS/MCCC End to End Test	Verify Uplink/Downlink Data Thru Spacecraft, Centaur, Orbiter & JPL-MCCC	KSC-VPF	Test Hardware — Flight Hardware or Simulator	Existing KSC Facility & Support Test Equipment
85. Spacecraft/Cen-taur/Orbiter Functional Interface Test	Demonstrate Interface Compatibility Between Space-craft/Centaur to Orbiter Avionics	KSC-VPF	Test Hardware — Flight Hardware or Simulator	Existing KSC Facility & Support Test Equipment
86. Mission Simulator Test	Perform Mission Simulation Sequence from Pre-Liftoff Thru Spacecraft Separation	KSC Cargo Inte-gration Test Equipment Facility	Test Hardware — Flight Hard-ware & Software	Existing KSC Facility & Support Test Equipment
87. ECS Validation Test	Perform Validation Tests on CX-36 Environmental Control System both Before & After Centaur Installation	GDC ETR CX-36	Test Hardware — CX-36 Air Conditioning Units, Simulated Orbiter Bay Enclosure & Interconnecting Ducting Plus Centaur	Existing Test Facility. Modified Support Test Equipment
88. Helium System Validation	Perform Validation Tests on Helium Skid & Piping both Before & After CISS Erection	GDC ETR CX-36	Test Hardware — GHe Ground System, MSE, CISS & CCLS	Existing Test Facility. Modified Support Test Equipment

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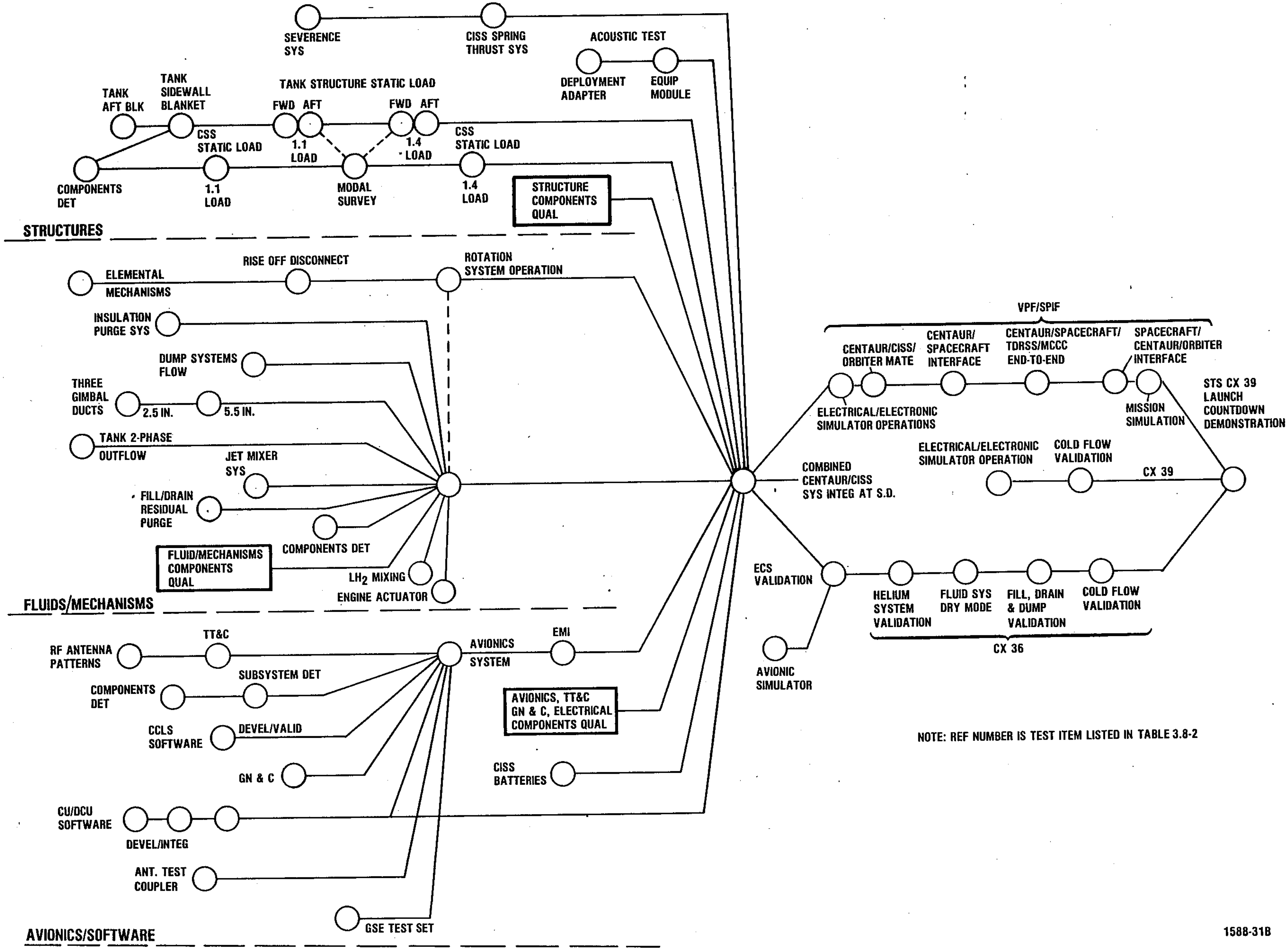

Figure 3-86. Centaur G Test Program Flow Diagram.

Table 3-15. Centaur G Test Program Summary for DoD Option.

Test Item	Planning Test	Test Location	Hardware Configuration	Support Requirements
AVIONICS				
1. Spacecraft ASE/ CISS Power Control Unit	"Hot Bench" Testing on Prototype Power Control Units to Demonstrate Functionally Compatible. Temperature & Vibration Testing of Prototype.	GDC KM SIF & Environmental Lab	Test Hardware — Prototype Spacecraft ASE/CISS Power Control Unit.	Existing Test Facility & Support Test Equipment
2. Signal Interface Unit	Perform "Hot Bench" Test to demonstrate component compability and temperature/ vibration tolerance	GDC — KM S/F & Environmental Lab	Test Hardware — Prototype Payload Power Transfer Unit	Existing Test Facility & Support Test Equipment
3. Spacecraft Power Transfer Unit	Perform "Hot Bench" test to demonstrate component compability and temperature/ vibration tolerance	GDC — KM S/F & Environmental Lab	Test Hardware — Prototype Payload Power Transfer Unit	Existing Test Facility & Support Test Equipment
4. Vehicle DCU Software-Flt. Prog. Module Level and Integrated Level	Test All Flight Modules Separately and then Together as an Integrated Program.	GDC KM "TICS/TRATEX" on GPC & "FAST" on Harris	Test Hardware — N/A.	Existing Test Facility & Support Test Equipment
5. CCLS Software	CCLS Software Development, Integration and Validation Testing.	GDC KM SIF Lab	Test Hardware — N/A.	Existing Test Facility & Support Test Equipment
6. Avionics System Integration	System Level Hardware and Software Interface Compatibility, Software, and Procedure Development and System Level Safety Demonstration.	GDC KM SIF Lab	Test Hardware — Prototype CISS and Centaur Packages Simulators.	Existing Test Facility & Support Test Equipment
7. EMI/Tempest Evaluation	EMI/Tempest Evaluation Testing on Centaur & CISS Avionics Boxes & System.	GDC KM SIF Lab	Test Hardware — Prototype Centaur and CISS Units.	Existing Test Facility & Support Test Equipment
8. TT&C Coax Cable Assemblies	Evaluate TT&C Coax Cable Assemblies in Conjunction with TT&C Subsystem Compatibility Test.	GDC KM RF Lab	Test Hardware — Coax Cable Assemblies.	Existing Test Facility & Support Test Equipment
9. R.F. Antenna Patterns.	Perform RF Radiation Pattern Testing with Antennas Mounted on 1/4 Scale Centaur Mockup.	GDE KM Antenna Range	Test Hardware — Centaur Mockup (1/4 Scale), Two Antennas (1/4 Scale), Antenna (Full Size) and Spacecraft Mockup (1/4 Scale).	Existing Test Facility & Support Test Equipment
10. TT&C Subsystem Integration	Perform Evaluation Tests for TT&C Subsystem.	GDC KM RF Lab & SIF	Test Hardware — Prototype TT&C Subsystem.	Existing Test Facility & Support Test Equipment
GROUND AVIONICS				
11. SGLS R.F. Test Set	Assess Performance of R.F. Test Set.	GDC KM RF Lab	Test Hardware — R.F. Test Set.	Existing Test Facility & Support Test Equipment
12. Antenna Test Couplers	Evaluate Antenna Test Couplers.	GDC KM RF Lab	Test Hardware — Prototype Antenna Test Coupler, Prototype Antenna.	Existing Test Facility & Support Test Equipment
13. Coax Test Cable-STE	Evaluation Tests on STE Coax Test Cable in Conjunction with RF Test Set.	GDC KM RF Lab	Test Hardware — Coax Test Cable.	Existing Test Facility & Support Test Equipment
14. Telemetry Interface Unit Test Set	Demonstrate that the TIU Test Set can accurately test the S/U.	GDC RF Test Lab	Test Hardware — S/U Test Set	Existing Test Facility & Support Test Equipment

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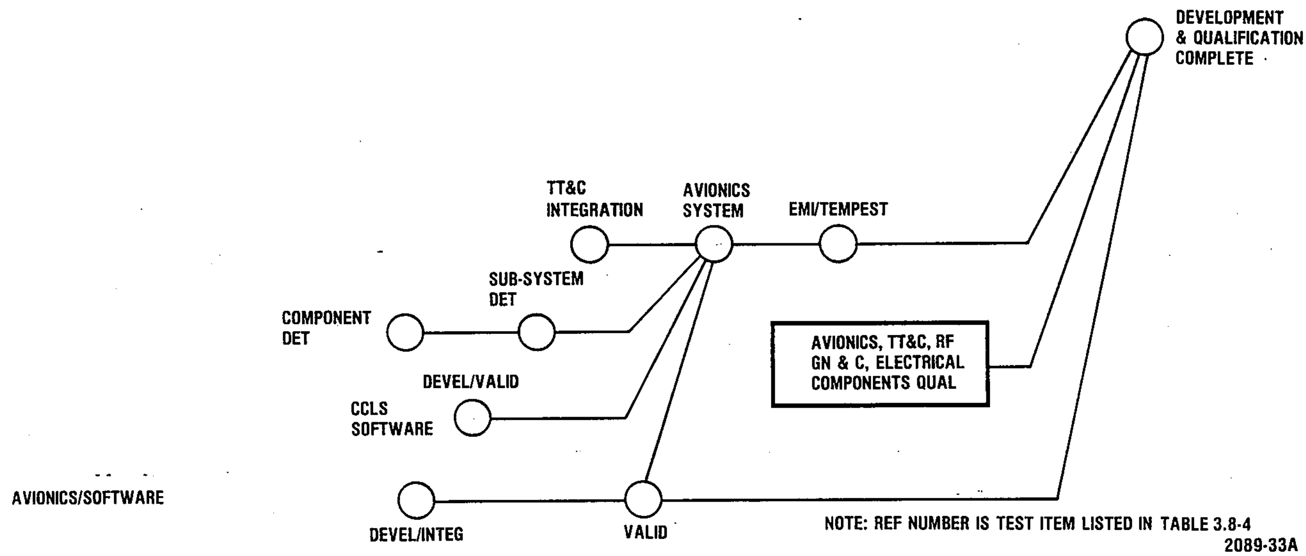

Figure 3-87. Additional Centaur G DoD Test Program Option Flow.

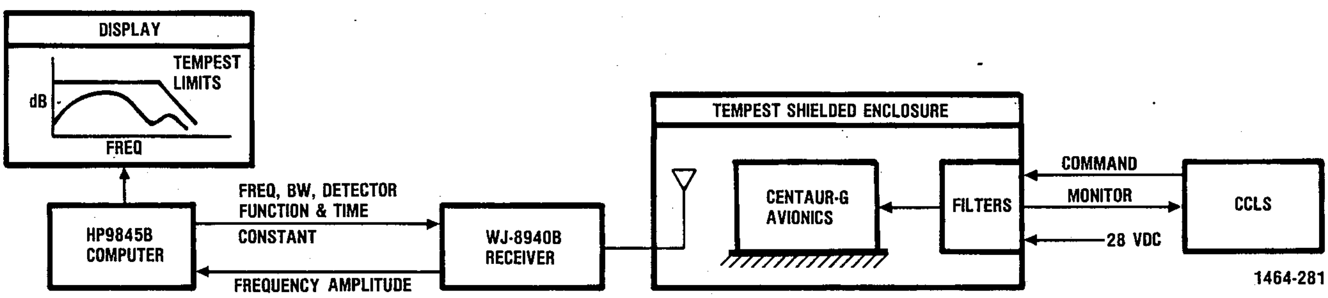

Figure 3-88. TEMPEST Testing.

Test equipment consists of a computer-controlled receiver with variable frequency, bandwidth, detector function, and detector time constant. The computer also collects the amplitude and frequency data, adds correction factors, and plots the results on graphs relative to the appropriate TEMPEST test levels.

3.8.2.1.4 Ground Avionics — Although most ground avionics will be the same as that used on Atlas/ Centaur, a few additional items of test equipment or test sets will be required to test the Centaur G avionics and software.

3.8.2.1.5 CISS/Centaur Integrated Tests — The functional integration tests verify that the Centaur vehicle with CISS will meet vehicle-level performance requirements. The initial phase of functional integration consists of tests on each functional subsystem using the other systems as necessary to support the tests. These individual subsystem tests will concentrate on detailed performance and margins of each individual subsystem. The test flow is shown in Figure 3-89.

Factory testing of the Centaur first article will be similar to current practice. New tasks include checkout of redundant systems, Centaur-to-CISS interfaces, and combined Centaur/ CISS system tests. Since CISS is a new item, the test philosophy will be similar to that of Centaur testing using the CISS simulator.

3.8.2.2 Qualification Tests — Early qualification testing will reduce cost and increase reliability.

3.8.2.2.1 Component Qualification Test — Our component qualification testing for Centaur G will discover any problems before system and subsystem-level testing.

All components will have successfully completed a functional checkout and acceptance testing including burn-in (if required) before qualification testing. Environmental qualification test requirements will comply with JSC-07700, Volume XIV (Revision G, September 26, 1980), *Space Shuttle System Payload Accommodations,* which includes as an attachment ICD 2-19001 and the *Shuttle Orbiter/Cargo Standard Interface (Revi-*

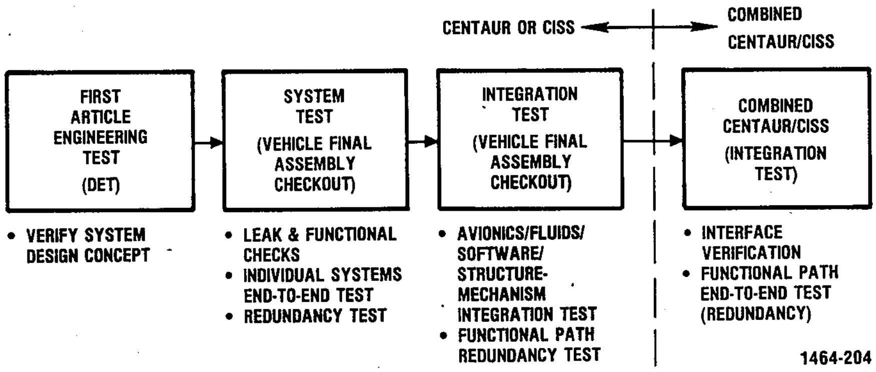

Figure 3-89. CISS/Centaur Test Flow.

sion G), September 26, 1980). All newly designed components will be qualified to ensure full compliance with Shuttle requirements. Existing Centaur avionics will meet the expected levels of acoustics environment as stated in Volume XIV. New components that require qualification testing include 5 structures, 37 fluids and mechanisms, and 26 avionics.

Structures

1. Vendor Tests
   - Super*Zip separation system
   - Equipment module vent door solenoid
2. General Dynamics Tests
   - Spring thrust system
   - Equipment module vent door
   - LO_2 vent standpipe

Fluids

1. Vendor Tests
   - ½- and ¼-inch check valve
   - Fluid disconnects
   - Flex-hose
   - Pyrotechnic valve – cryogenic (NC)
   - 5.0, 3.5 and 2.0-inch Pneumatically actuated ball valve
   - 3/8 and ¼-inch two-way solenoid valve
   - LH_2 1.0-inch pneumatically actuated three-way
   - ½-inch high-pressure two-way solenoid valve
   - ¼-inch three-way solenoid valve
   - Helium storage bottle
   - Pneumatic filter
   - Sintered orifice
   - Deployment adapter rotation system
   - 5.5 and 2.5-inch three-gimbal ducts
   - High-pressure regulator – high flow
   - Pressure regulator – low flow
   - Vacuum check valve
   - 2, 2.5, and 4 inch bellows
   - 3/4 inch pyro valve-cryo
   - Cryogenic check valve
   - Manual shutoff valve
   - Quick-disconnect (SPCU-connector)
   - LH_2 zero-g vent system
2. General Dynamics Tests
   - Pilot-operated solenoid valve
   - LH_2/LO_2 propellant feed system
   - Ascent vent valve (LH_2/LO_2)
   - LO_2 propellant JET mixer pulse
   - Low pressure slip-type disconnect
   - LH_2 propellant feed duct

Avionics

1. Vendor Tests
   - CISS battery
   - RF switch
   - RF antenna
   - RF amplifier
   - Differential pressure transducer
   - Vacuum transducer
   - Angular position transducer (CISS)
   - Absolute pressure transducer (CISS)
   - Shuttle/Centaur transponder

- Pressure transducer (CCVAPS)
- Dc/dc converter (CISS)
- CISS/Centaur rise-off disconnect
- Signals transponder (DoD)

2. General Dynamics Tests
   - Control unit
   - Control distribution unit
   - Pyrotechnic initiator controller unit
   - Electrical distribution unit
   - LH_2/LO_2 propellant utilization probes
   - LH_2/LO_2 propellant loading instrumentation system
   - Propellant level indicating unit
   - Dual-failure-tolerant arm/safe sequencer
   - Spacecraft power transfer unit (DoD)
   - Telemetry interface unit (DoD)

3.8.2.3 Interface and Validation Tests — Interface and validation tests on Centaur G will increase reliability.

Interface and validation tests to be performed on Centaur G are:

1. Centaur/CISS/Orbiter Mate Test — Verify compatibility of the CISS attach fittings and hardware interfaces.
2. Fill, Drain, and Dump Demonstration Test — Validate the integrated Centaur, CISS, and associated equipment before installation of the flight hardware at Complex 36.
3. LH_2/LO_2 Cold-Flow Validation Tests — Demonstrate the interface compatibility of CCLS, mobile support equipment (MSE) trailer, and Complex 36 facility by performing a coldflow test with the use of simulators.
4. LH_2/LO_2 Validation Tests — Perform a one-time cold-flow test at Complex 39 to validate Centaur-peculiar LH_2/LO_2 transfer systems, including LH_2/LO_2 control skid interfaces and to verify control compatibility of skids with the MSE simulator at Complex 39 and CCLS.
5. Launch Countdown Demonstration — Before initial launch tanking of Shuttle/Centaur, perform a one-time tanking test at Complex 39 to demon strate capability of Centaur tanking while installed in the Orbiter payload bay.
6. Centaur/Spacecraft Interface Test — Demonstrate interface compatibility between Centaur vehicle and spacecraft.
7. Centaur/Spacecraft/TDRSS/MCCC End to End Test — Verify spacecraft data uplinks and downlinks through Centaur, Orbiter, and RF line to the JPL-Mission Control and Command Center (MCCC) via the TDRSS.
8. Spacecraft/Centaur/Orbiter Functional Interface Test — Demonstrate interface compatibility between spacecraft/Centaur avionics with the Orbiter avionics.
9. Mission Simulation Test — Demonstrate the total functional end to end Integrated System Compatibility, including all ground command and monitor stations, during a simulated flight sequence.
10. Fluid System Dry Mode Integration Test — Verify control compatibility between the $LH_2/LO_2/GH_E$ ground system and the MSE simulator/CCLS before system flow tests for each configuration.
11. Environmental Control System Validation Test — Verify that the Complex 36 environmental control system adequately simulates the Orbiter bay purge provided by Shuttle GSE at Complex 39.
12. Helium System Validation — Validate the helium control skid and connecting piping and check control compatibility with the MSE and CCLS.
13. Avionic Simulator — Demonstrate CISS/Centaur Avionics operational compatibility with Complex 36 GSE before receiving flight hardware. The test will use CISS/Centaur simulators.
14. VPF Electrical/Electronic Simulator Operations — Demonstrate Centaur/Spacecraft/Orbiter Avionics Interface Compatibility with KSC Vertical Processing Facility (VPF) modifications before receiving flight hardware. The test will use CISS/Centaur Electrical/Electronic Simulators.
15. CX-39 Electrical/Electronic Simulator Operations — Demonstrate compatibility with CX-39 by conducting the following tests; data circuit verification to CX-36, Centaur prepower interface test, Centaur standard turn on profile, propellant skid validation and integrated propellant cold flow. The test will use CISS/Centaur Electrical/Electronic Simulators.

3.8.2.4 Interface and Validation Tests for DoD Option

1. Centaur/Spacecraft Interface Test — Demonstrate interface capability between Centaur

Vehicle and spacecraft at Shuttle Payload Integration Facility (SPIF).

2. Centaur/Spacecraft/SGLS/SCF End-to-End Test — Verify spacecraft data uplink and downlink through Centaur, Orbiter, and RF line to the Satellite Control Facility (SCF) ground stations via the Space Ground Link System (SGLS) in unsecured and secured modes. Test will be performed at SPIF.

3. SPIF Electrical/Electronic Simulator Operations — Demonstrate Centaur/Spacecraft/Orbiter avionics interface capability with Shuttle Payload Integration Facility (SPIF). General Dynamics' test will use CISS/Centaur electrical/electronic simulators.

4. Mission Simulation Test — Demonstrate the total functional end-to-end integrated system compatibility, including all ground command and monitor stations, during a simulated flight sequence at SPIF.

GENERAL DYNAMICS

Convair Division