AD-A021 401

GENTAUR INTERIM UPPER STAGE (IUS) SYSTEM STUDY. VOLUME I. EXECUTIVE SUMMARY

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General Dynamics/Convair

Prepared for:

Space and Missile Systems Organization

31 July 1975

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER SAMSO-TR-75-181	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Centaur Interim Upper Stage (IUS) System Study Volume I, Executive Summary		5. TYPE OF REPORT & PERIOD COVERED Final Report 1 Oct 1974 to 1 July 1975 6. PERFORMING ORG. REPORT NUMBER CASD/AFS-75-006
7. AUTHOR(s) D. A. Heald, A. W. Nelson, R. D. Harris, C. F. Peters, et al.		8. CONTRACT OR GRANT NUMBER(s) F04701-75-C-0035
9. PERFORMING ORGANIZATION NAME AND ADDRESS General Dynamics, Convair Division P. O. Box 80847 San Diego, California 92138		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Space and Missile Systems Organization (LVRE) Los Angeles Air Force Station, CA 90009		12. REPORT DATE 31 July 1975 13. NUMBER OF PAGES 60
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release: Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Interim Upper Stage (IUS)
Centaur
Interface
Shuttle

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The overall objective of this system study was to provide preliminary design(s), airborne and ground interface definition, substantiated life-cycle cost estimates and total program definitions for a Centaur Interim Upper Stage (IUS) System. The IUS system consists of a primary propulsive stage (a Centaur version), auxiliary propulsive stage(s) (when required), airborne support equipment, aerospace ground equipment, software, and unique facilities. Six alternative Centaur IUS programs were defined;

20. ABSTRACT (Continued)

each satisfying DOD and/or NASA requirements as specified in SAMSO document SR-IUS-100, "Interim Upper Stage (IUS) System Requirements," Change 3, dated 4 April 1975.

The IUS programs defined in the study incorporate a primary propulsive stage based on the existing D-1 Centaur vehicle used by NASA for Viking and by DOD for Fleet-SatComm. The study concludes that lowest development costs are incurred with an expendable Centaur IUS which is 89 percent existing hardware. The principal development tasks for this program would be modifications for compatibility with the Orbiter and SGLS/STDN communications. Lowest life-cycle costs can be achieved with a reusable Centaur IUS where added development is requird for a wide hydrogen tank and a fuel cell power supply. Trade studies and options including shorter length vehicles and compatibility with NASA planned Tracking and Data Relay Satellite (TDRSS) system are also defined. The inherent high performance of cryogenic propellants assures comfortable accommodation of current and future IUS program requirements.

FOREWORD

The final report on the Centaur IUS System Study was prepared by the General Dynamics Convair Division for the Air Force Space and Missile System Organization (AFSC/SAMSO) in accordance with Contract F04701-75-C-0035, CDRL data article A008.

The study results were developed during the period from October 1974 through June 1975. Detailed results were furnished during the study in the form of Technical Operating Reports (TOR) and other supporting documentation. This report summarizes the study and consists of two volumes:

Volume I - Executive Summary
Volume II - Technical
Volume II Addendum - Cost Summary (Proprietary)

The SAMSO Project Officer was Major Bob Probst from the IUS Office of Reusable Launch Vehicle Program Office. Technical support was provided Major Probst by Aerospace Corporation, with Len Schilb being the primary contact. Chet Whitehair, Director of the Upper Stage Office of the Space Transportation Directorate at Aerospace Corporation, lead the technical effort.

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SUMMARY

The Space Shuttle will deliver large payloads to low earth orbit. A large number of planned missions require an upper stage to reach higher orbits, such as synchronous, or to escape for planetary probes. Minimum development funds will be available for a new upper stage (Tug) until Shuttle development funding requirements begin to decline. Therefore, existing upper stages, modified for Shuttle compatibility, are being considered as an Interim Upper Stage (IUS) to be available at or near Shuttle IOC.

This report describes the use of Centaur as an IUS. The Centaur D-1T Configuration is the basis for evolving Centaur as a Shuttle upper stage. The Centaur high energy upper stage has flown 37 missions and currently has a future mission backlog through 1979.

Two basic operational modes were investigated: an expendable mode wherein the IUS is expended while delivering the payload, and a reusable mode wherein, subsequent to payload deployment, the IUS returns to rendezvous with the Orbiter for return to earth and reuse. Expendable IUS requires the least investment in early year dollars (i.e., development). The reusable IUS requires slightly greater early year development funding, but results in lower total life-cycle costs due to its recovery and reuse. The decision as to which concept is more desirable is then essentially a trade between a small saving in early year funding versus a substantial reduction in total life-cycle cost.

General Dynamics Convair has investigated two programs for each operational mode – a "basic" program, which represents minimum development spending, and a "short vehicle" program, which provides capability for longer payloads at some increase in development cost.

The approach in all programs has been to provide a basic capability to accommodate all DOD requirements at minimum cost. A small Δ cost will then provide the additional capability to accomplish all missions in the National Mission Model. The ability to accomplish the National Mission Model with small changes from the DOD program is a direct result of the high performance capability inherent in the Centaur vehicle. This high performance capability also provides the basis for Centaur reusability where high energy is required to return IUS from the mission orbit back to the Shuttle.

The Centaur IUS programs proposed in this final report offer low-cost, high-performance, low-risk solutions to the requirements for an Interim Upper Stage.

Each program has certain distinct advantages (i.e., high performance, low development cost, low life-cycle cost, long payload accommodation). The decision as to which program best fulfills the IUS role must be based on projected available funding and final program goals.

The expendable Centaur (EC) program provides very high capability with minimum program risk. The basic program consists of a 25-foot-long stage designed for geosynchronous and high-altitude missions and a 31-foot version (identical to the D-1T length), which is designed for planetary and escape missions. The 31-foot EC is identical in design to the 25-foot EC except for the addition of a cylindrical section to the LH_2 tank. These configurations use approximately 90 percent (by value) of existing Centaur equipment, thereby providing high program confidence. The 25-foot EC can deliver almost 5000 pounds to geosynchronous, and the 31-foot EC, although designed for earth escape missions, can deliver over 12,000 pounds to geosynchronous. The only auxiliary propulsion system required (for very high energy missions) is a small spin-stabilized kick stage modified from Helios missions. The high performance of these stages provide significant payload margin above anticipated single payload weights. This allows significant multiple payload deployment capability, which greatly reduces total transportation costs.

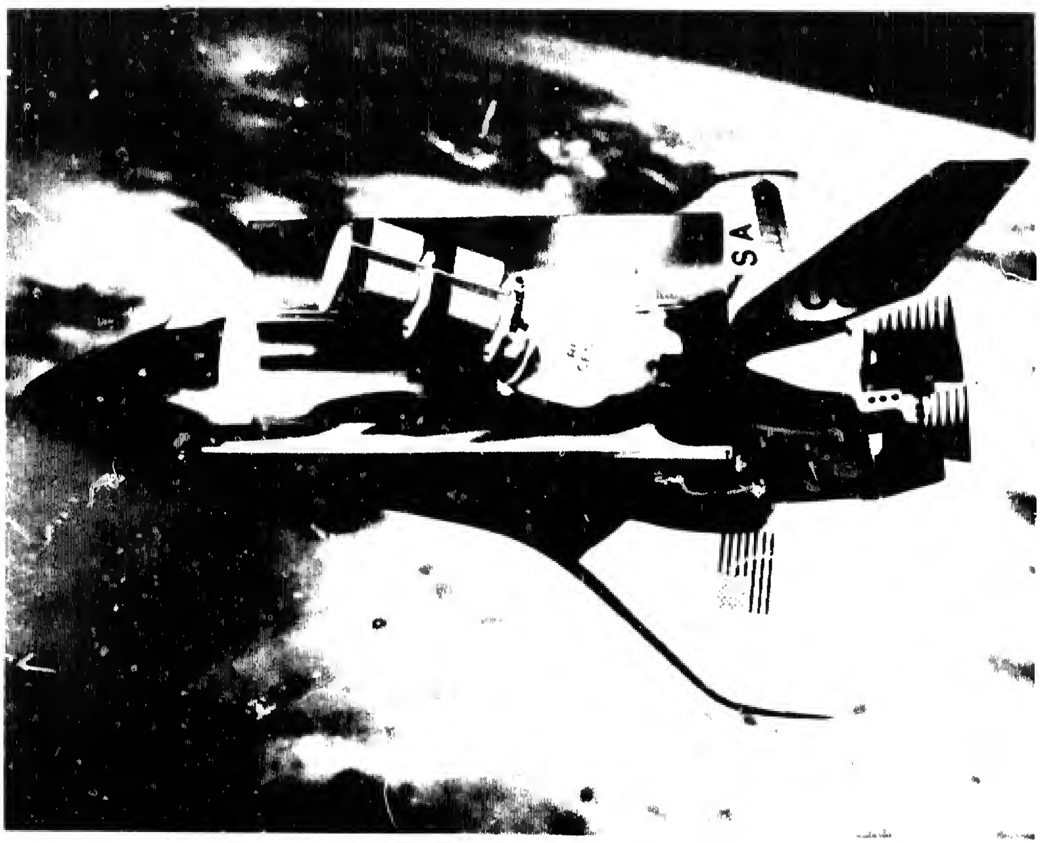
An extremely attractive option is the "short" expendable version. This stage, at slightly greater development cost, delivers nearly 12,000 pounds to geosynchronous and is less than 22 feet long. It combines the advantages of short length and high performance, so that a single configuration accommodates the entire National Mission Model. This stage, with the use of a simple, spin-stabilized kick stage for very high energy missions, has more than sufficient performance and payload length availability to satisfy all users. The short length/high performance combination makes it particularly attractive for multiple payload deployment.

The reusable Centaur (RC) program has low total program cost at somewhat higher initial development cost. The inherent high performance of the Centaur provides the basis for reusability with approximately 70 percent (by value) of existing Centaur equipment used on the reusable configurations. The basic reusable program consists of a 28-foot-long vehicle and a 22-foot-long vehicle, identical except for different cylindrical sections of the propellant tanks. The 28-foot RC can deliver over 5000 pounds to geosynchronous orbit in a fully reusable mode and can perform the most demanding high energy mission in an expendable mode. Both missions are accomplished without the use of any auxiliary propulsion stage. The 22-foot version is designed for long payloads. The high performance of these stages provides the users significant flexibility in either the reusable or expendable mode (16,000 pounds payload capability to geosynchronous orbit for 28-foot stage), and can be used for both single and multiple payload deployment.

The short RC program is similar to the basic program with a 28-foot stage for most missions and a second stage less than 20 feet to accommodate very long payloads.

The use of tandem expendable stages in the cargo bay was evaluated to determine if a life-cycle cost advantage could be obtained. The study indicated that reusability of the Centaur IUS stage, coupled with its multiple payload delivery capability, resulted in significantly lower life-cycle cost. This approach avoids the high expenditure inherent in expending two tandem stages as well as avoiding the increased Orbiter complexities associated with payload bay loading, center of gravity (c.g.) limits, cargo bay length and Orbiter abort.

The Centaur derivative IUS programs described in this report offer a wide range of capability and significant advantages as a complement to the Space Shuttle. Convair is looking forward to being a member of the DCD team to make the IUS program a success.



SECTION 1

INTRODUCTION

On 1 October 1974, the Air Force Space and Missile Systems Organization (AFSC/SAMSO) issued Contract F04701-75-C-0035 to General Dynamics Convair Division for a "Centaur Interim Upper Stage System Study."

This executive summary summarizes the program alternatives proposed by Convair to meet the specified requirements for an Interim Upper Stage and includes both expendable and reusable versions of Centaur modified for Shuttle use.

1.1 BACKGROUND

The Space Transportation System is designed to accommodate national space needs in the next two decades, including activities in low earth orbit, high-altitude orbit, and planetary missions. The basic transportation, or delivery system, consists of a Space Shuttle and an upper stage (Figure 1-1). The Shuttle is used to place payloads in low earth orbit, with the major elements of the Shuttle (i.e., the solid motor cases and the Orbiter) being reusable. About one-half of the planned missions require an upper stage to extend mission capability to higher orbits, plane changes, or escape velocity.

Minimum development funding will be available for a new upper stage until after 1978 when Shuttle expenditures begin to decline. It is desirable that an upper stage be available at the Shuttle initial operating capability (IOC) date to provide the maximum operational, performance, and cost benefits. Therefore, existing upper stages, modified for Shuttle and payload compatibility at minimum cost, are being considered as Interim Upper Stages (IUS). The operational Centaur stage, with some modifications, represents a cost-effective development solution in the face of present and projected funding constraints. Several versions suitable for a Shuttle interim upper stage are possible depending on mission performance needs and available funds.

Figure 1-1. Space Transportation System

Two operational modes were considered: expendable and reusable. The expendable mode, where the upper stage delivers a payload and is then expended in a manner similar to current stages, requires minimal modification and development funding. The reusable mode, where the upper stage delivers a payload and then returns to the

Orbiter, necessitates some additional changes with associated higher development costs, but results in significantly lower total program costs due to upper stage reuse.

The Centaur D-1T configuration, shown in Figure 1-2, is the basis for our Interim Upper Stage (IUS) concepts. The Centaur high-energy upper stage has flown 37 missions, and currently has a future mission backlog firm through 1977 and planned into 1982.

Centaur uses cryogenic propellants, 25,000 pounds of liquid oxygen and 5,000 pounds of liquid hydrogen, in a pressure-stabilized stainless steel tank. Oxygen is aft; separated from the hydrogen by a double-wall evacuated stainless steel intermediate bulkhead. Two Pratt & Whitney RL10A-3-3 engines provide the main impulse. A hydrogen peroxide system provides attitude control during coast as well as turbine drive for the tank-mounted boost pumps that feed the main turbopumps.

The Centaur configuration for Shuttle use represents a logical progression in its evolution as an upper stage vehicle providing high performance with low development cost to incorporate it into the Shuttle. It provides the capability of reuse if that operational mode is selected for the interim upper stage.

- LENGTH 31.5 FT., DIAMETER 10 FT

  STRUCTURAL WEIGHT 3974 LB.
- HYDROGEN/OXYGEN PROPELLANTS

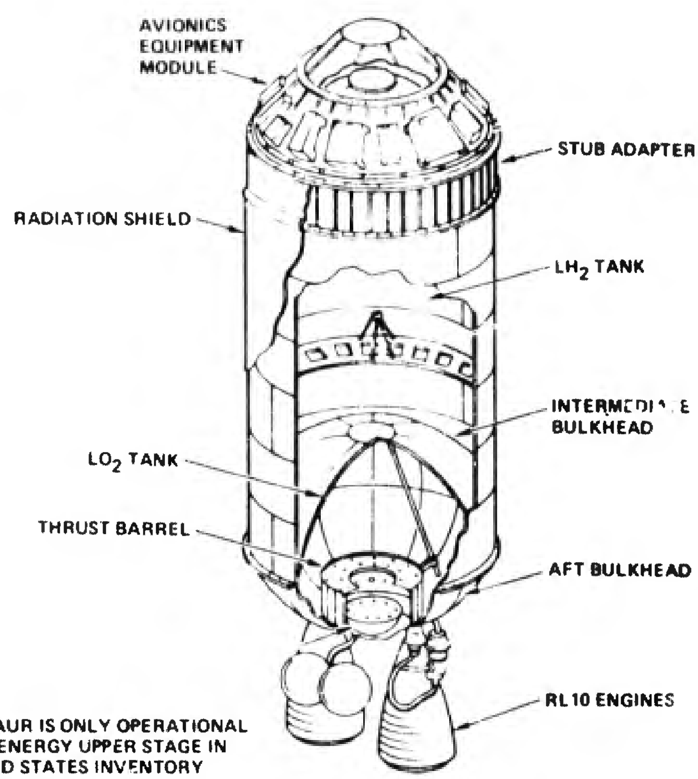
  LH_2 = 5,000 LB., LO_2 = 25,000 LB.
- TWO RL 10 ENGINES

  TOTAL THRUST = 30,000 LB

  Isp = 445 SEC.
- IMPROVED COMPUTER CONTROLLED

  AVIONICS SYSTEM
- 37 CENTAUR LAUNCHES
  - 9 RESEARCH & DEVELOPMENT
  - 7 SURVEYOR
  - 2 ATS
  - 3 OAO
  - 5 MARINER
  - 8 INTELSAT IV
  - 2 PIONEER
  - 1 HELIOS
- D-1 FUTURE MISSIONS

VIKING	INTELSAT IV	HEAO
MJS	INTELSAT IVA DOMSAT (CDCS)	
HELIOS	FLEETSATCOM	



CENTAUR IS ONLY OPERATIONAL HIGH-ENERGY UPPER STAGE IN UNITED STATES INVENTORY

Figure 1-2. D-1T Centaur

1.2 STUDY OBJECTIVE

The overall objective of this system study was to provide preliminary designs, interface definitions, operational concepts, life cycle costs, and total program plans for Centaur IUS versions. Four IUS system programs are included: Expendable, Short Expendable, Reusable, and Short Reusable.

1.3 STUDY SCOPE

This study was a nine-month effort directed primarily toward program definition and preliminary designs of an IUS system and all interfaces with the STS system. The study produced Shuttle Orbiter interface information and defined alternative IUS system designs for both expendable and reusable stages including derivatives allowing for increased spacecraft length.

1.4 STUDY GROUND RULES AND CONSTRAINTS

Study ground rules and constraints, summarized in Table 1-1, were derived primarily from SR-IUS-100 "Interim Upper Stage (IUS) System Requirements."

Table 1-1. Study Ground Rules and Constraints

1.	Base configurations on the operational D-1T Centaur.
*2.	Baseline mission is satellite deployment in synchronous equatorial orbit and return to the orbiter for recovery. Other missions include high energy planetary.
3.	IUS operates only out of ETR from June 1980 through 1984 or longer.
4.	0.97 probability of successful payload placement is a requirement.
*5.	Design must be fail-safe (not jeopardize Orbiter or its crew) both during ascent and return.
6.	Communications must be compatible with NASA and DOD.
7.	Centaur IUS detail requirements are defined in SAMSO Specification SR-IUS-100, Change No. 3, 4 April 1975. Interface and operations requirements specified in JSC 07700 will be met.

*Underlined passages applicable to reusable versions only.

SECTION 2

REQUIREMENTS

The primary requirement for an Interim Upper Stage is to deliver payloads to orbits and trajectories beyond the capability of the Space Shuttle. Mission performance requirements are the basic drivers for stage sizing and configuration. There are additional requirements which must be met which fall into the general categories of design requirements, interface requirements, reliability/safety requirements, and operational requirements.

2.1 MISSION REQUIREMENTS

IUS mission requirements are the prime drivers of Centaur IUS system designs and operational procedures. They establish a basis for reference mission definitions which, in turn, determine IUS performance requirements; hence, IUS system and subsystem dimensions, capacities, and capabilities. When NASA high-energy planetary missions are included, mission requirements dictate the need for auxiliary propulsive stages.

There are two basic mission concepts considered in the study (see Figure 2-1). The first is payload delivery with the IUS expended, and the second is payload delivery with the IUS returned to the Orbiter for reuse on subsequent missions. The first concept (expendable) imposes the least requirements, causes minimum stage modification, and results in the lowest development cost. The second concept (reusable) imposes more system requirements resulting in higher development costs, but achieves significantly lower life cycle costs.

2.1.1 EXPENDABLE STAGE REFERENCE MISSIONS. Reference missions were selected to envelop the range of requirements driving IUS design and operations. Three Expendable Centaur reference missions were selected as identified in Table 2-1.

Table 2-1. Expendable Centaur Reference Mission Requirements

Driving Requirement	Reference Mission		
	Geosynchronous	High Altitude	Planetary
Payload Weight (lb)	3,376	1,000	1,052
Payload Length (ft)	32	10	10.2
Ideal Delta Velocity (FPS) (Ref. 160 n.mi.)	13,887	13,937	27,694
Mission Duration (hr)	7.28	19.48	2.70
No. of Engine Burns	2	2	1
Launch Window (sec)	None	None	30

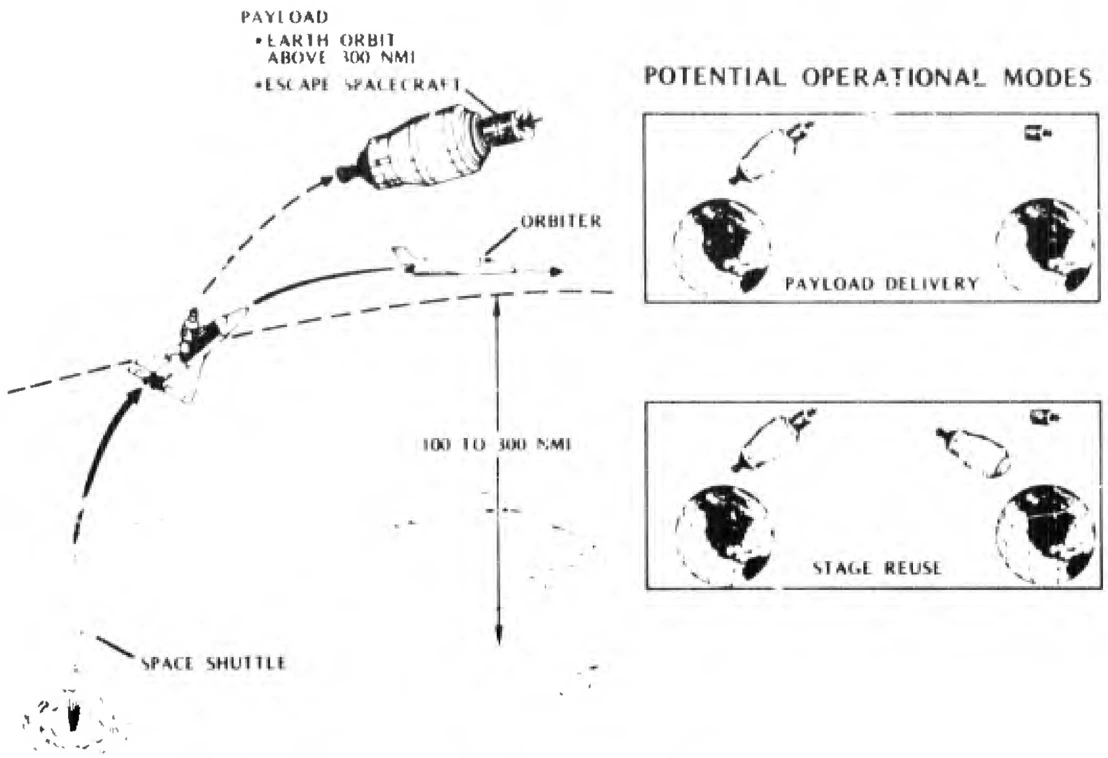


Figure 2-1. Shuttle Upper Stage Mission Concept

A geosynchronous mission was chosen since about one-half of the spacecraft are delivered to this orbit. The high altitude mission was selected since it defines the longest IUS mission duration. The Pioneer Saturn/Uranus flyby mission (PL-11) was selected because it has the maximum velocity requirements, and requires use of an auxiliary propulsive stage.

2.1.2 REUSABLE CENTAUR REFERENCE MISSIONS. Reference missions were selected to envelop the range of requirements driving IUS design and operations. Two reference missions were selected for the Reusable Centaur: geosynchronous and high altitude.

A geosynchronous mission was selected as a reference mission, because about one-half of the spacecraft are delivered to this orbit. The high altitude mission was selected because it defines the longest RC mission duration. The high energy planetary missions utilize the Reusable Centaur in an expendable mode; and therefore, have the same basic requirements as the Expendable Centaur.

Table 2-2 shows the Reusable Centaur reference mission requirements.

Table 2-2. Reusable Centaur Reference Mission Requirements

Driving Requirements	Geosynchronous	High Altitude
Payload Weight (lb)	3,376	1,000
Payload Length (ft)	32	10
Ideal ΔV, one way (FPS)	13,887	13,937
Mission Duration (hr)	47.04	93.65
No. of Engine Burns	5	5

2.1.3 MULTIPLE SPACECRAFT, POLAR/SUN-SYNCHRONOUS AND PLACEMENT MISSIONS. These missions are desirable goals for the IUS, but are not program requirements. Centaur IUS, because of its excellent performance capability, is able to accomplish these missions.

Three or more multiple spacecraft can be delivered to geosynchronous orbits, and up to eight Global Positioning Satellites can be delivered to low earth orbits by Centaur IUS in either the expendable or reusable mode. During early years of the program when WTR is not activated (and later years if WTR is not activated), Centaur IUS in the expendable mode can deliver all polar and sun-synchronous spacecraft with lengths up to 38-feet. It may be preferable to deliver some spacecraft to specific locations within an orbit (e.g., a specific longitude in a geosynchronous orbit) as a means of eliminating a spacecraft propulsion system. Centaur IUS stages have this capability, in both the expendable and reusable modes, with only minor impacts on payload capability.

2.2 DESIGN REQUIREMENTS

During the study the most demanding design requirements were found to be the guidance and navigation accuracies (too tight), the fine attitude control rates (too tight), and telemetry compatibility with the Orbiter (different bit error rate). In each case, these problems were addressed during the study and the appropriate subsystems modified to satisfy the requirements. In addition to those changes, other changes were recommended to clarify c.g. limits, and to permit thermal control maneuvers. Requirements having the more significant impact on design were those of guidance and navigation accuracies and telemetry compatibilities.

2.3 INTERFACE REQUIREMENTS

Interface requirements as imposed by the Orbiter, by the spacecraft, by the ground, and by environments do not have a significant impact on the Centaur IUS system. Analyses accomplished during the study resulted in requesting revisions in the area of fluid venting to allow venting small quantities of nonhazardous fluids in the payload bay, and in the area of fluid services to clarify that all such services required for the spacecraft would also be chargeable to the spacecraft.

2.4 RELIABILITY/SAFETY REQUIREMENTS

Centaur IUS performance margins readily allow implementation of IUS safety and reliability requirements without a reduction of the Centaur capabilities as an IUS.

Safety/reliability requirements having the greatest impact on Centaur design and operations when the Centaur is used as an IUS were:

1. No single failures of dynamic systems permitted.
2. Separation of incompatible materials.
3. No release of hazardous materials into Orbiter/payload bay.
4. Positive means of preventing tank overpressurizing.
5. Thermal protection systems for cryogenic tanks to minimize flammable fluid accumulation.
6. Interlocks to prevent firing or dumping propulsion fluids into payload bay.
7. Insure against tank implosion during return flight.
8. The probability of successful payload deployment, for both EC and RC, is at least 0.97.

2.5 OPERATIONAL REQUIREMENTS

Operational requirements had a major impact on the Centaur IUS system. Requirements such as payload weight and length, payload c.g. location, velocity budget, mission duration, number of main engine burns, ACS maneuvers, communication constraints, and guidance and navigation constraints were considered in the design and operational procedures of the IUS and are accommodated by the Centaur IUS system.

SECTION 3

SELECTED CONFIGURATION SUMMARY

Four programs are recommended for Centaur IUS as shown in Table 3-1. Each program is capable of accomplishing the entire National Mission Model. In the expendable mode, the 25-foot-long stage without any auxiliary propulsion stage can capture the entire DOD mission model. Programs with two stage lengths have been selected to minimize development costs as the simple addition of tank length is significantly less expensive than development of a new three-axis stabilized auxiliary stage.

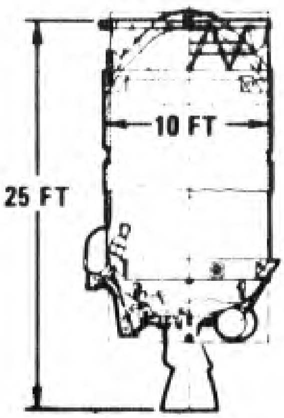
Table 3-1. Recommended IUS Programs

Operational Mode	Primary Stage Centaur Size	Auxiliary Stage
Expendable		
Basic	25 ft L by 10 ft D	Small spin stabilized solid
	31 ft L by 10 ft D	
Short	22 ft L by 14.5 ft D	Small spin stabilized solid
Reusable		
Basic	28 ft L by 14.5 ft D	None
	22 ft L by 14.5 ft D	
Short	28 ft L by 14.5 ft D	None
	19.5 ft L by 14.5 ft D	

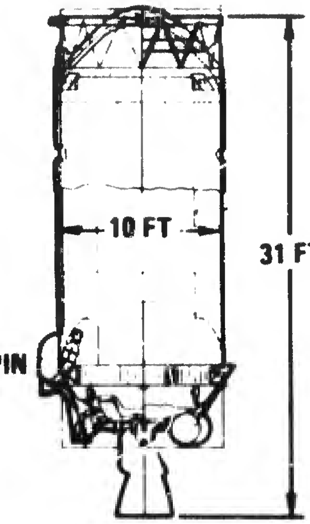
There are two expendable programs: a program with two vehicle lengths to capture the National Mission Model, and a program with one configuration (shorter and wider) which is able to capture the entire National Mission Model with a slight increase in development cost.

The basic Expendable Centaur IUS program consists of two lengths of vehicles essentially identical to the current D-1T Centaur (see Figure 3-1). The 25-foot-long configuration (EC-25) captures the DOD mission model and many of the NASA requirements. For the highest velocity or heaviest NASA payloads, the 31-foot version (EC-31) is required plus spin-stabilized auxiliary stages similar to those that have flown on Helios and Pioneer missions.

The General Dynamics design approach for IUS is to make maximum use of existing D-1T Centaur. The Expendable Centaur family utilizes 89% existing Centaur components and subsystems measured as percentage of the cost of producing a Centaur. Centaur IUS in the 25-foot EC configuration can deliver and inject over 4900 pounds to synchronous equatorial orbit; ~50 percent growth capability over the 3500 pounds requirement. This 25-foot configuration captures the entire DOD mission model.



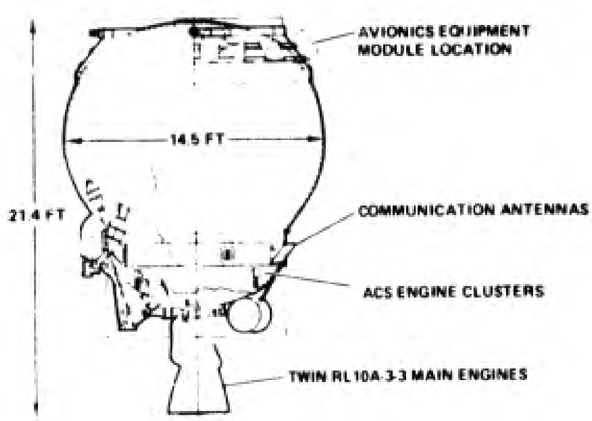
(25 FT D-1T)	DESIGNATION	31-FT EC
22,600 LB	STAGE GROSS WEIGHT	35,600 LB
4,900 LB	PL/TO SYNC	12,000 LB
NONE	AUXILIARY STAGE	TE-M-364-4, SPIN STABILIZED*
1,000 LB AT 18,500 FPS	PL/PLANETARY	1,300 LB AT 28,000 FPS



* USED ON ONLY TWO HIGH ENERGY PLANETARY FLIGHTS

Figure 3-1. Expendable Centaur IUS Program

For the higher energy NASA missions, this 25-foot EC is stretched to 31 feet by a simple LH_2 tank length extension. The 31-foot Centaur can inject 12,000 pounds into synchronous equatorial orbit; and when paired with the 25-foot EC, can capture the entire National Mission Model. This 31-foot EC is the same length as the existing Centaur.



STAGE GROSS WEIGHT	35,106 LB
PAYLOAD TO SYNCHRONOUS (MAX.)	11,698 LB
AUXILIARY STAGE	TE-M-364-4, SPIN STAB.*
P/L PLANETARY (PL 11)	1,140 LB @ 28,000 FPS

* USED ON ONLY TWO HIGH ENERGY PLANETARY FLIGHTS

Figure 3-2. Short Expendable Centaur IUS Program

In response to the DOD request for a short option, a 22-foot vehicle with a 14.5-foot-diameter hydrogen tank was configured (see Figure 3-2). This one stage has a 12,000-pound capability to synchronous equatorial orbit and maintains the same high degree of parts commonality mentioned above. This configuration particularly lends itself to multiple payload deployment with a minimum number of Shuttle launches. It also offers evolution potential from an expendable stage to a reusable stage. This is a very attractive option in that a single length Centaur captures the National Mission Model without any new kick stages. The 22-foot-long, wide-tank version has essentially the same propellant capacity as the current

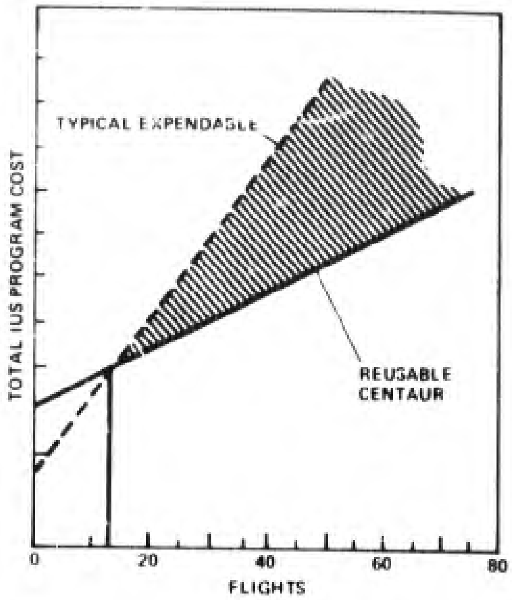


Figure 3-3. Low Cost Payload Delivery

31-foot-long, 10-foot-diameter Centaur D-1T. Only two high energy planetary shots in the current mission model require kick stages similar to the spin-stabilized TE-M-364-4 vehicles already used on Pioneer and Helios flights.

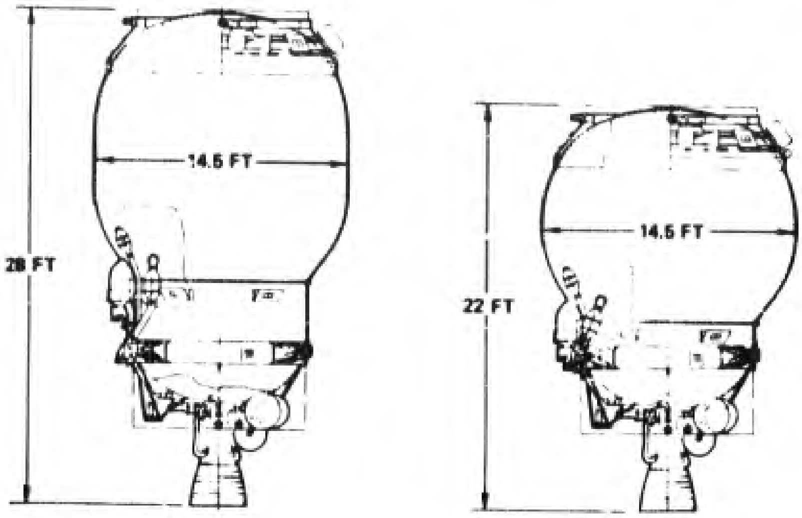
Use of an expendable IUS is characterized by a low development cost but a high operations cost due to expending a vehicle for each launch. RC IUS, with its slightly higher development cost, provides a considerable saving per flight due to stage reuse. This operations cost saving allows the higher development cost to become cost-effective at twelve flights. Further operation provides increasing savings to the user (see Figure 3-3).

There are also two programs to consider for the Reusable Centaur IUS. Both programs use two vehicle lengths to capture the National Mission Model without use of auxiliary propulsion stages. The difference between the two programs is that one is a minimum development cost and the other results in the ability to carry longer payloads while incurring slightly higher development costs.

The first case consists of 28-foot and 22-foot versions (Figure 3-4). The 22-foot RC, structurally similar to the 22-foot EC, is capable of performing the lower altitude DOD missions in a reusable mode. By adding cylindrical sections to the hydrogen and oxygen tanks this stage is stretched to 28 feet. This 28-foot RC has a capability of delivering 5000 pounds to synchronous equatorial orbit, circularizing the payload at that altitude, then returning to the cargo bay for reuse. No auxiliary propulsion stages are required, and this pair of stages (28-foot and 22-foot RCs) perform the entire DOD mission model in a completely reusable mode while a few are expended to pick up the most demanding planetary mission. These RC configurations utilize 70 percent existing Centaur parts and provide considerable performance/growth margin thereby assuring flexibility in future mission planning.

The RC can be shortened to less than 20 feet (see Figure 3-5) by changing the hydrogen tank bulkheads. This will allow longer spacecraft to be flown to medium altitude orbits, and when paired with the 28-foot RC, meets the National Mission Model.

The Centaur IUS offers significant advantages. The use of a high percentage of existing components reduces technical risk to an absolute minimum. Performance margin is extremely important at this point in a program offering flexibility in future spacecraft

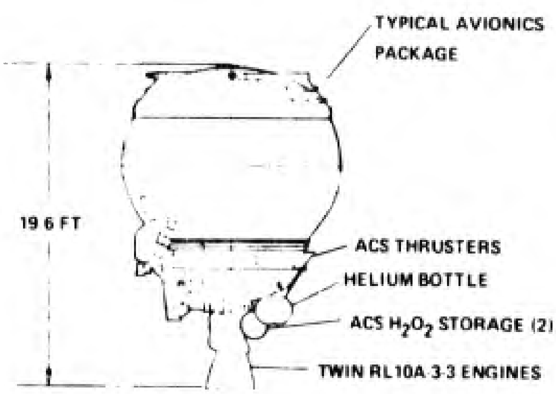


DESIGNATION	BASIC RC	22 FT RC
STAGE GROSS WEIGHT	54,879 LB	35,542 LB
P/L TO SYNC EQ	5,177 LB	—
P/L TO 12-HR ORBIT	—	15,446 LB
PLANETARY P/L	1,592 LB AT 28,000 FPS	—

EXPEND RC FOR MOST DEMANDING PLANETARY MISSIONS

REQUIRED ONLY FOR S/C LONGER THAN 32 FEET

Figure 3-4. Reusable Centaur IUS Program



STAGE GROSS WEIGHT	30,388 LB
PAYLOAD TO 12 HR ORBIT (MAX)	10,493 LB

Figure 3-5. Short Reusable Centaur IUS

design and the option of adding redundant components to increase the mission reliability well above the 0.97 requirement. Adding redundant computers and inertial components for example, would not significantly decrease performance but would enhance the reliability of payload delivery; a matter of concern when extremely costly payloads are being carried.

The following paragraphs summarize the four program characteristics.

3.1 EXPENDABLE IUS PROGRAM (BASIC)

Minimum requirement for development funding was the primary driver in selection of the baseline expendable Centaur IUS program. Configurations were sized to avoid the necessity to develop a new three-axis-stabilized auxiliary propulsion stage (kick stage). To avoid this substantial development task, we chose a program with two lengths of Centaur identical except for hydrogen tank length. The 31-foot version (EC-31) is the same length as the existing D-1T, thus avoiding almost all new engineering, tooling, and GSE.

EC-25 captures all DOD and NASA earth orbital missions and four of the NASA escape missions with a capability to deploy over 4900 pounds to synchronous equatorial orbits. This is a performance margin of greater than 1500 pounds for accommodating payload growth and for reducing transportation costs through deployment of multiple payloads.

EC-31 is used for the high-energy planetary missions and for polar and sun-synchronous missions flown from KSC. Polar and sun-synchronous missions can be flown without the use of Orbiter-dogleg maneuvers. Two extremely high-energy planetary missions to Saturn and Jupiter (PL-11 and 22) are accomplished with EC-31 and a modified version of the existing TE-M-364-4 spin-stabilized auxiliary propulsive stage which has been flown on Helios and Pioneer missions.

These stages were configured with minimum modifications which means low development costs and low risks for the National Mission Model.

3.1.1 IUS CONFIGURATION. The EC-25 configuration is a modification of the existing D-1T Centaur vehicle. Vehicle length has been shortened by removing 78 inches from the LH_2 tank cylindrical section to give an installed length under 25 feet (see Figure 3-6).

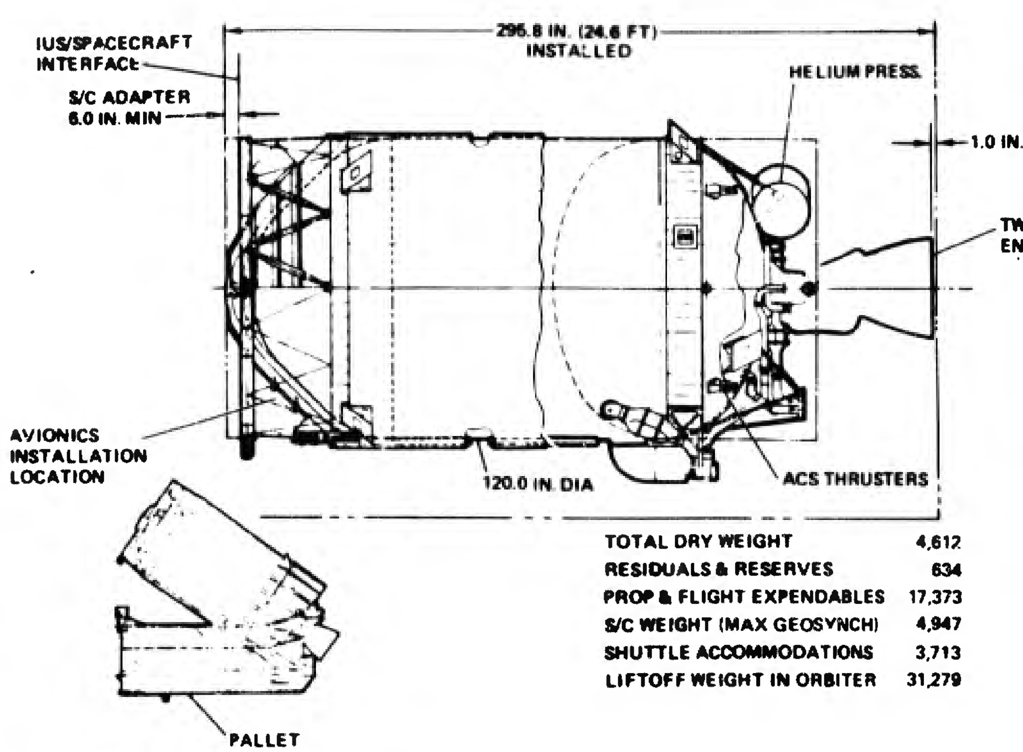
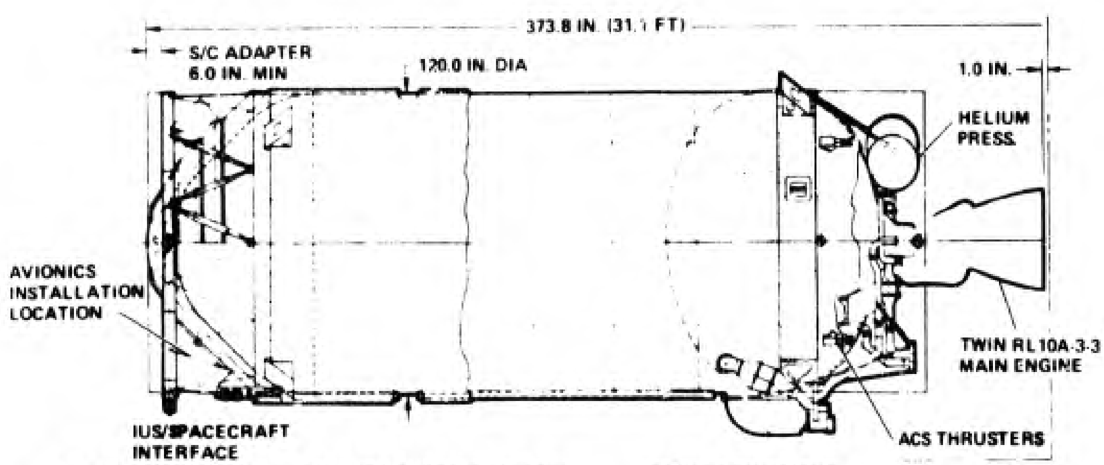


Figure 3-6. EC-25 Configuration

As shown in Figure 3-7, the EC-31 IUS is the same as EC-25 except the LH_2 tank is 6-1/2 feet longer (same as D-1T). The increased performance permits accomplishing the National Mission Model without an auxiliary stage except for two high-energy planetary flights. Two flights require use of a single spin-stabilized TE-M-364-4 auxiliary stage.

Major subsystems require few modifications to mount the vehicle in the Orbiter and to satisfy the man-rated safety requirements. Structural changes are a shorter LH_2 tank (EC-25 only), a modified Viking truss adapter, and a new aft skirt for support loads. Main engine and attitude control systems are unchanged except for modified chilldown sequence and minor valving changes required to satisfy fail-safe requirements. Fluid lines are modified to match Orbiter interfaces. The avionics system is essentially unchanged except for the addition of the DOD communications system and a new omnidirectional antenna system of eight selectable antennas. The D-1 Centaur Range Safety System, C-band transponder, and S-band transmitter have been removed. The hydrogen propellant tank insulation system consists of prelaunch conditioning multi-layer insulation (MLI) blankets, a purge bag, and deep-space radiation shield. The system is based on flight proven Centaur D-1T vehicle designs. To relive excess tank pressure during periods of zero-g coast, a zero-g thermodynamic vent and mixer package is provided in the LH_2 tank.

The IUS will be supported in the Orbiter cargo bay by a pallet structure that is left in the cargo bay after IUS deployment. The EC flight pallet (see Figure 3-8) was designed

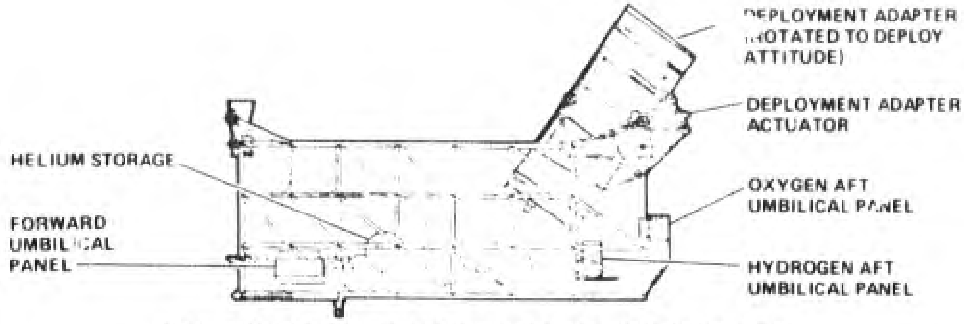


- ADD 78 INCHES TO LH_2 TANK (TO CURRENT LENGTH)
- USE CURRENT LENGTH PU PROBE, CABLES, ETC
- INCREASE PALLET LENGTH
- RERUN SOME DYNAMIC, STRESS, & THERMAL ANALYSES
- DESIGN SUPPORTS FOR EXISTING KICK STAGE

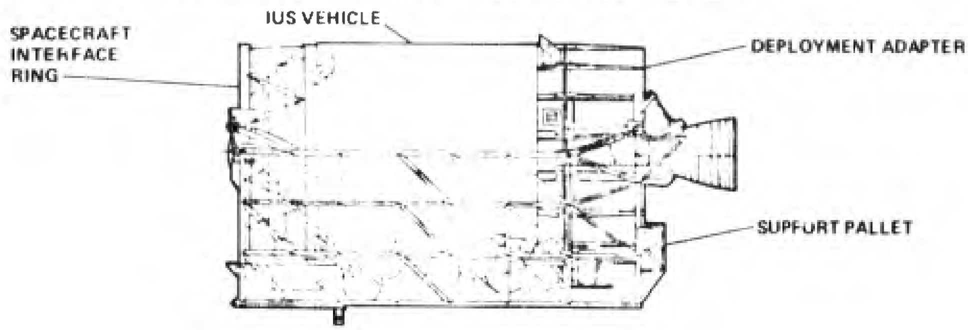
TOTAL DRY WEIGHT	4,597
RESIDUALS & RESERVES	605
PROP & FLIGHT EXPENDABLES	30,376
APS & ADAPTER	2,934
S/C WEIGHT (MAX CAPABILITY)	1,311
SHUTTLE SUPPORT (PL-11)	1,651
SHUTTLE ACCOMMODATIONS	4,817
LIFTOFF WEIGHT IN ORBITER	46,291

MINOR DDT&E TO CAPTURE NATIONAL MISSION MODEL

Figure 3-7. EC-31 Configuration



EXPENDABLE CENTAUR SUPPORT PALLET & DEPLOYMENT ADAPTER



PALLET & DEPLOYMENT ADAPTER WITH INSTALLED IUS

Figure 3-8. EC Flight Pallet

primarily to interface Orbiter cargo bay structural support requirements with the EC structure. It also serves as an interface for the EC fluid and electrical functions, and provides for special operations such as deployment and abort. The pallet consists of two major structural assemblies, the pallet truss and the deployment adapter; both of which are reusable.

The forward umbilical panel and two aft fluid umbilical panels are mounted on the pallet and are mechanically retracted by electrical motor driven actuators. The rotation pin about which the deployment adapter rotates is also driven into place by an electric motor actuator.

EC-31 is handled by adding a six-foot extension to the pallet previously described. IUS prelaunch thermal conditioning in the Orbiter cargo bay is provided by a gaseous nitrogen (GN_2) purge. GN_2 will be introduced to the cargo bay from a gas distribution ring forward of the spacecraft and at lateral locations from an Orbiter purge distribution duct. The lateral purge inlets will feed IUS gas distribution ducts. Conditioning gas will exhaust from the cargo bay through Station 1307 check valves and Station 1128 sidewall vents. Prelaunch thermal analysis has shown, for a vent flow of 364 lb/min at 75F, the cargo bay exhaust gas temperatures are above 58F. This provides very benign conditions for the exhaust gas while the forward to aft cargo bay purge flow prevents spacecraft chilling (see Figure 3-9).

Fluid interfaces with the Orbiter are provided to accommodate prelaunch loading of main propellants and gaseous helium, prelaunch drain of main propellants, main

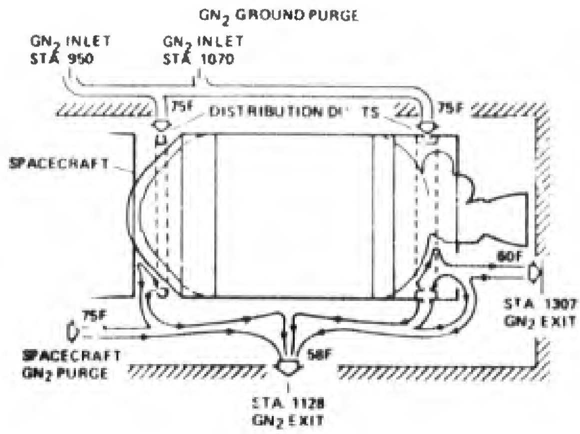


Figure 3-9. Prelaunch Thermal Control

propellant dump during the various Orbiter abort modes, and venting or relief of main and auxiliary propellants. Other IUS fluid supply, vent, or relief requirements, such as helium purge supply and battery vent are accomplished via manifolding of interfaces with like fluid systems within the IUS pallet so that the number of pallet to Orbiter interfaces is minimized.

IUS ASE consists of avionics units located on the pallet and control panels located at the mission specialist station (MSS). The pallet will include batteries for powering IUS until deployment as well as monitors and controls for IUS and pallet functions.

3.1.2 <u>AUXILIARY STAGE DEFINITION</u>. The EC-31 IUS provides the increased performance to accomplish the high-energy missions, primarily planetary, specified in the IUS Spacecraft Mission Models. This stretched EC can perform all of the planned planetary missions except for the Pioneer missions to probe Jupiter and Saturn/Uranus planets which require an auxiliary stage to provide the additional velocities. Configuration of the auxiliary stage employs an existing solid-rocket motor, Thiokol Corp. TE-M-364-4, and is spin-stabilized. This configuration is compatible with Pioneer spacecraft which in the past was launched by Atlas-Centaur Expendable Launch Vehicle with the final injection velocity provided by spin-stabilized TE-M-364-4 solid-rocket motor third stage.

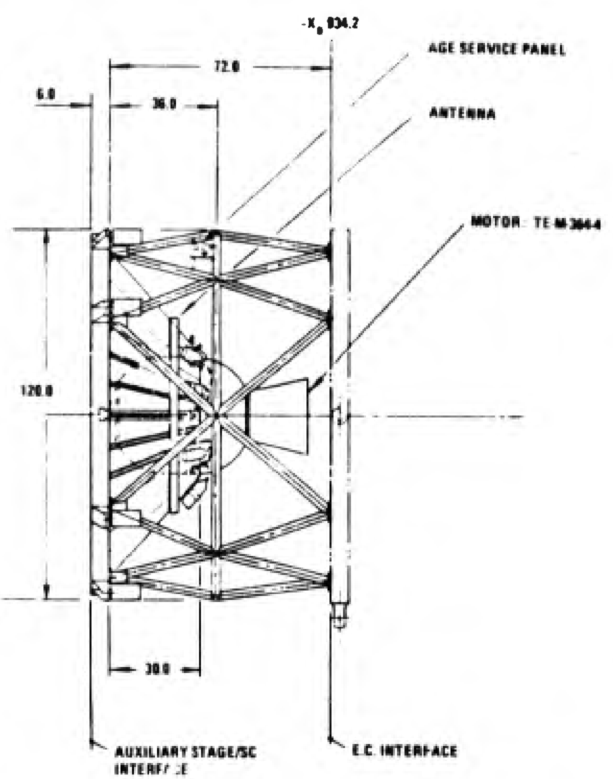


Figure 3-10. Expendable Centaur Auxiliary Stage Vehicle

The auxiliary stage consists of two major assemblies, interstage support structure and stage vehicle, as shown in Figure 3-10. Interstage support structure remains mounted to EC spacecraft interface structure throughout the flight. Separation plane between the interstage support structure and stage vehicle is the forward interface plane.

The auxiliary stage vehicle consists of four subsystems: structure (including

Table 3-2. APS Weight Summary

	Weight (lb)
Structure	165
Induced Environment Protection	10
Main Propulsion (Motor Inerts)	183
Spin System (Manifolded)	25
Separation System (Pyro Control)	19
Main Power Source (Battery)	15
Telemetry	20
Ballast & Trim	2
Contingency	30
Dry Weight	469
Residuals & Reserves	1
Burnout Weight	470
Main Thrust Propellants	2,290
Spin System Expendables	20
Expended Inerts	12
Stage Separation Weight	2,792
EC Truss Adapter	130
Separation Bolts	12
Total Installed Weight on EC	2,934

thermal protection system), avionics, solid-rocket motor, and spin system. The total vehicle weight is estimated to be 2792 pounds consisting of 469 pounds of stage weight and 2323 pounds of expendables (Table 3-2).

3.1.3 PERFORMANCE. Expendable Centaur IUS stages are carried to a 160 n.mi. circular orbit by the Orbiter launched from KSC. Shuttle launch azimuths were constrained to 35- to 120-degree limits. All EC performance calculations are based on impulsive burns. Gravity losses resulting from finite burn times are added to mission ideal velocities.

Performance capability versus delta-velocity for EC-25 is shown in Figure 3-11 and is for the geosynchronous reference mission (MR = 5.0:1, nominal I_{sp} = 445 seconds). EC-31 performance is based on the stage characteristics for the planetary mission (MR = 4.964:1, nominal I_{sp} = 445.2 seconds). The weight summary is shown in Table 3-3.

All spacecraft missions are captured by the EC-25 and EC-31 configurations including polar and sun-synchronous spacecraft launched from KSC. EC-25 deploys 4947 pounds to synchronous equatorial orbits.

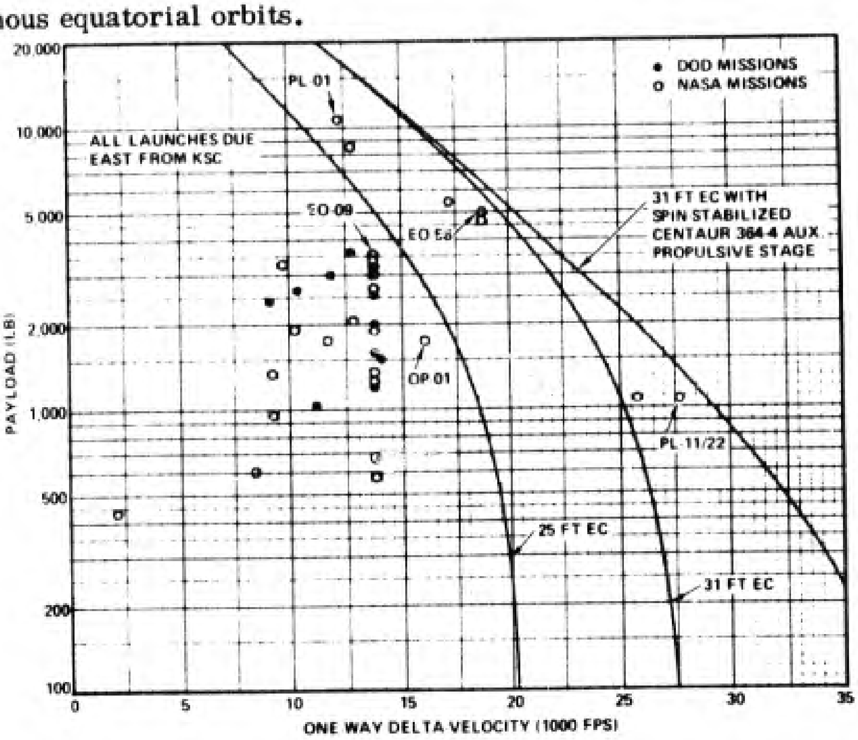


Figure 3-11. Expendable Centaur IUS Performance Capability

Table 3-3. EC Weight Summary

Configuration: / Reference Mission:	EC-25 Geosynchronous	EC-25 High Altitude	EC-31 Planetary
IUS Weights (lb)			
Dry Weight	4,612	4,991	4,597
Residuals	448	471	441
Reserves	186	196	164
Burnout Weight	5,246	5,658	5,202
Full Thrust Propellant	16,888	16,144	29,950
ACPS H_2O_2	135	174	95
Non-Impulsive Propellants	350	476	331
Loaded Stage	22,619	22,452	35,578
Spacecraft & Adapter (Max. Capability)	4,947	3,747	1,311
Auxiliary Propulsive Stage (APS)	0	0	2,792
APS/IUS Adapter	0	0	142
Separation Weight	27,566	26,199	39,823
Spacecraft RTG Kit	0	1,100	900
Spacecraft Shroud	0	0	751
Shuttle Accommodations	3,713	3,713	4,817
Shuttle Liftoff IUS System Weight	31,279	31,012	46,291

Payload capability to geosynchronous orbits for EC-25 is 4947 pounds assuming that the IUS transfers to geosynchronous at its first opportunity which is the second descending node. EC-25 payload capability to the high-altitude mission orbit is 3747 pounds. EC-31 payload capability with a 364-4 spin-stabilized APS to deploy a spacecraft on the PL-11 (Pioneer Saturn/Uranus Fly-by) trajectory is 1311 pounds.

3.1.4 DEVELOPMENT SCHEDULE. The EC program schedules reflect low-cost minimum risk development approaches and cover all program activities from start of Validation Phase through Full-Scale Development, Production, and Operations Phases. The Validation Phase follows DSARC I and spans some 19 months to DSARC II. This phase not only analyzes planned modifications to existing hardware and resolves design approaches to new hardware, but also completes all preliminary design activities in support of a formal Preliminary Design Review (PDR) preceding DSARC II.

The Full-Scale Development Phase is authorized by DSARC II which also authorizes initiation of long-lead procurement. Target date for the first Shuttle/IUS flight is June 1980.

As shown in Figure 3-12, this provides some 32 months in addition to validation for development of minimal new hardware and for modifications and verification of the basic Centaur (D-1T) vehicle as an expendable IUS for the Shuttle Program. Under this overall development approach, time is not a constraining factor and thus permits lower early-year funding levels. Some schedule compression could be allowed without compromising the target flight date.

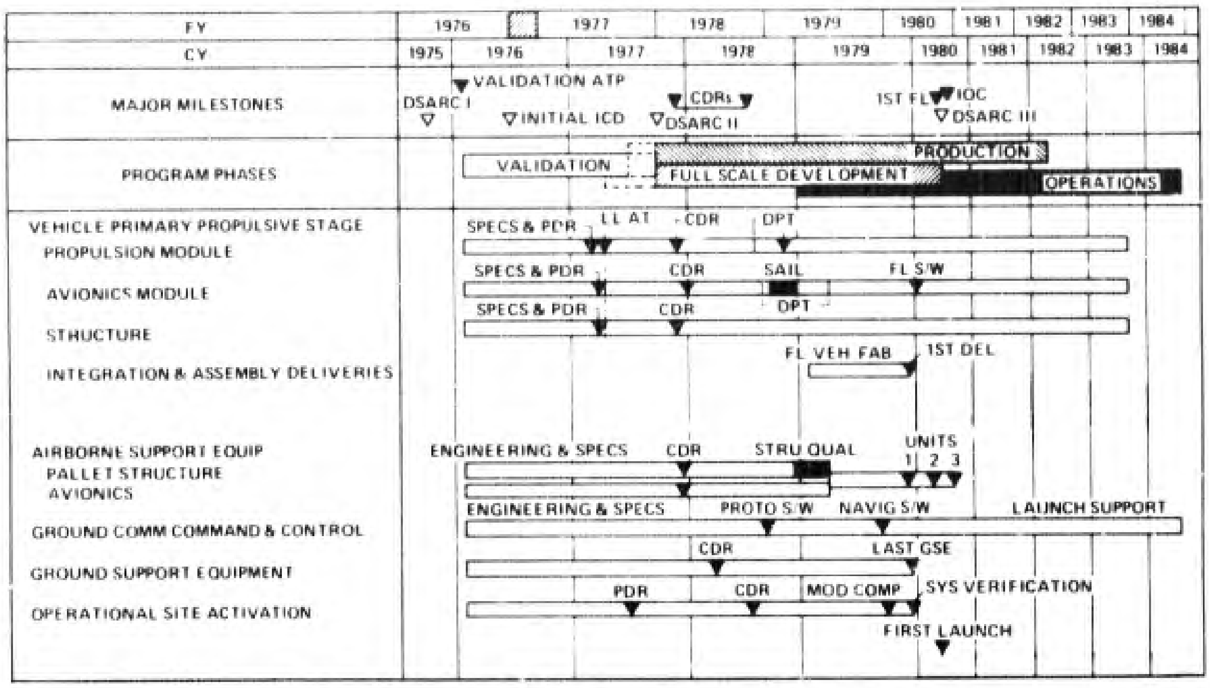


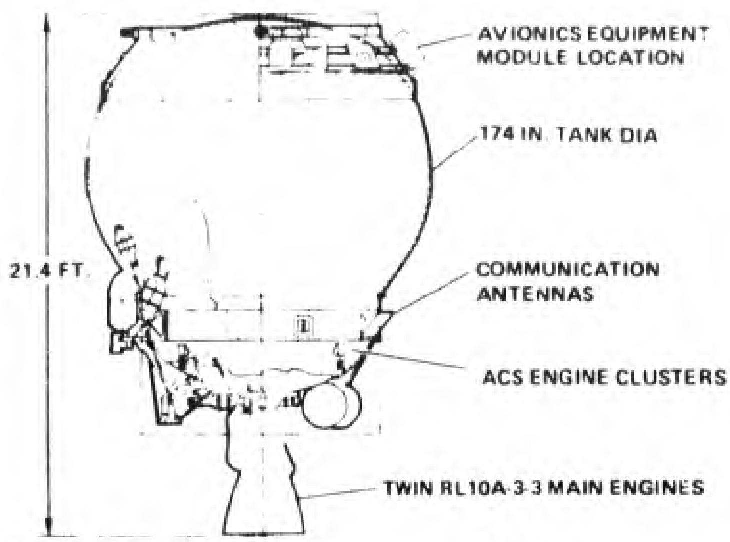
Figure 3-12. EC-IUS Development Schedule

3.2 EXPENDABLE IUS PROGRAM (SHORT)

To accommodate very long payloads a "short" expendable option was investigated (see Figure 3-13). This is a very attractive option in that a single length Centaur captures the National Mission Model without any new kick stages. This wide tank version has essentially the same propellant capacity as the current 31-foot-long by 10-foot-diameter Centaur D-1T. The short EC accomplishes all earth orbital missions and most planetary missions. Geosynchronous capability is over 11,000 pounds providing ample margin for payload growth and for reduced transportation costs through multiple payload delivery.

A modified TE-M-364-4 stage provides sufficient additional delta velocity to capture high energy planetary missions with velocity margin of over 1000 fps for these demanding missions.

3.2.1 <u>SHORT IUS CONFIGURATION.</u> The Short IUS was developed by expanding the diameter of the liquid hydrogen tank to the maximum diameter (174 inches) allowed by Shuttle Orbiter clearance, thereby allowing a reduction in tank length. The forward bulkhead and aft transition section of the LH_2 tank are the same as the Reusable IUS LH_2 tank configuration. There is no cylindrical section in the tank. Most of the subsystems and interfaces are identical to the EC-25 and EC-31 versions.



TOTAL DRY WEIGHT	5,050
RESIDUALS & RESERVES	677
PROPELLANT & FLIGHT EXPENDABLES	29,400
SPACECRAFT WEIGHT (MAX GEOSYNCH)	11,700
SHUTTLE ACCOMMODATIONS	4,771
LIFTOFF WEIGHT IN ORBITER	51,600

Figure 3-13. Short Expendable Centaur IUS Program

The Short IUS with its enlarged fuel tank prevents the use of the single pallet; therefore, the two cradle approach is used. The short EC IUS is supported in the Orbiter by a forward and an aft support cradle as seen in Figure 3-14. The aft cradle contains abort helium supply bottles, LO_2 and LH_2 umbilical panel restraction mechanisms, and the deployment adapter rotation mechanism.

3.2.2 AUXILIARY PROPULSION SYSTEM. The auxiliary propulsion system for the short EC is identical to that for EC-31.

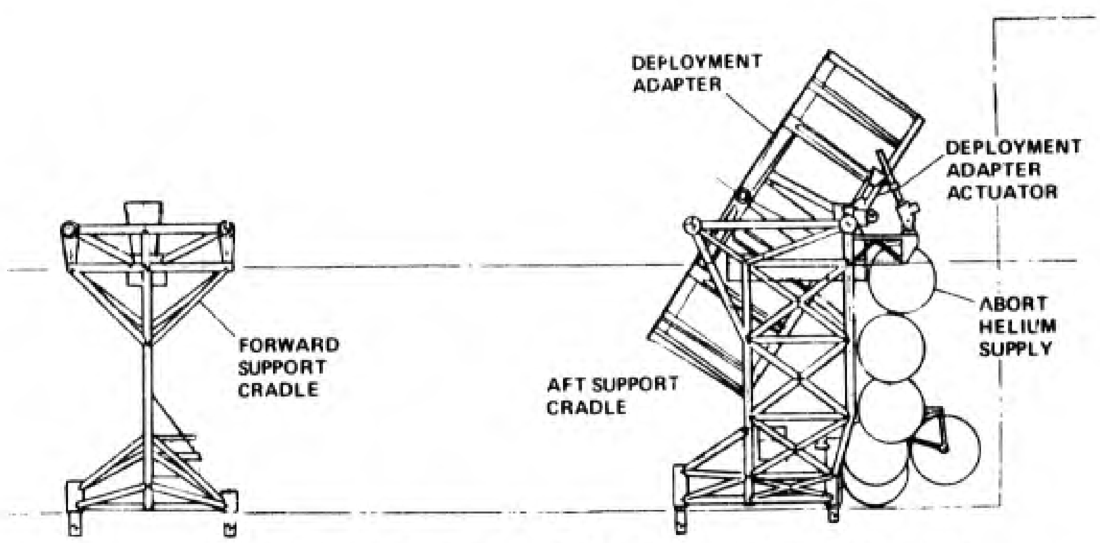


Figure 3-14. Short Expendable Centaur Support Cradles

3.2.3 PERFORMANCE. Short EC payload capability (above the 160 n. mi. circular parking orbit) is shown in Figure 3-15 (MR = 5, I_{sp} = 4.45 seconds). All spacecraft missions are captured including polar and sun-synchronous missions launched from KSC. The Short EC deploys 11,698 pounds to synchronous equatorial orbits. This is a performance margin of over 8000 pounds for accommodating payload growth and for reducing transportation costs through multiple payload deployment. The weight summary for this stage is shown in Table 3-4.

Table 3-4. Short EC Characteristics and Weights

Reference Mission	Geosynchronous
IUS Length	21.51 feet
IUS LH_2 Tank Diameter	14.50 feet
IUS LO_2 Tank Diameter	10.00 feet
IUS No. of Burns	2
IUS LH_2/LO_2 Mixture Ratio	5.0:1.0
IUS Main Engine I_{sp}	445.0 seconds
Weights (lb)	
Dry Weight	5,049
Residuals	496
Reserves	181
Burnout Weight	5,726
Full Thrust Propellant	28,828
ACPS H_2O_2	176
Non-Impulsive Propellants	376
Loaded Stage	35,106
Spacecraft & Adapter (Max. Capability)	11,698
Separation Weight	46,804
Shuttle Accommodations	4,771
Shuttle Liftoff IUS System Weight	51,575

3.2.4 DEVELOPMENT SCHEDULE. The short EC development program is similar to that shown in Figure 3-12 except that major development testing would include structural verification of the wide-tank configuration as well as the elements of ASE.

3.2.5 EC DEVELOPMENT FOR NATIONAL MISSION MODEL. All EC vehicles as developed for the DOD Program are readily usable by NASA in satisfaction of the National Mission Model.

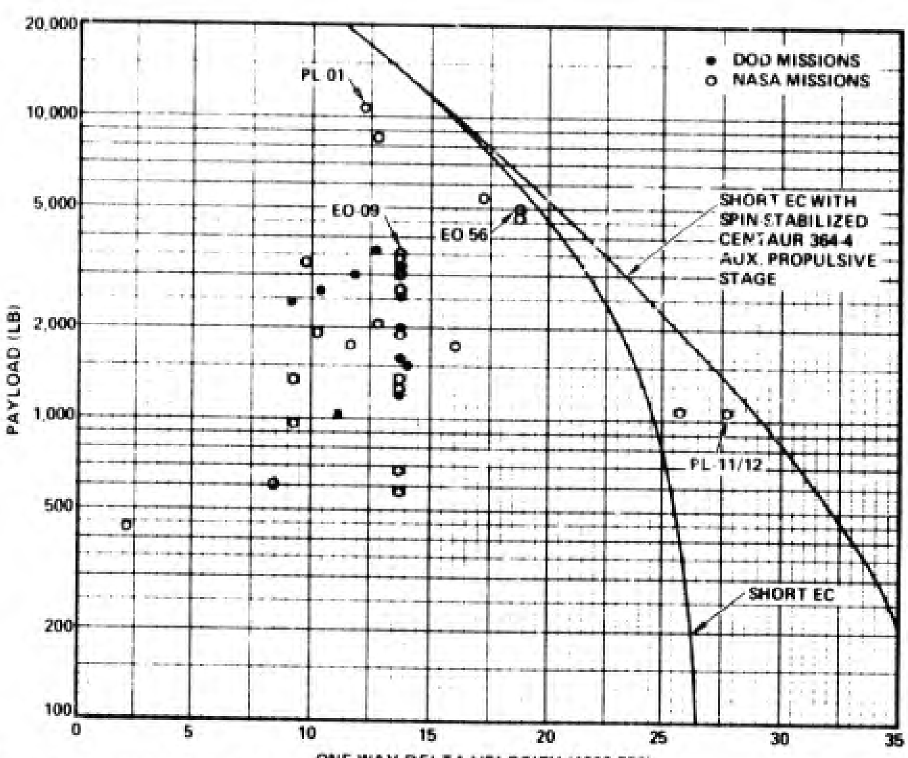


Figure 3-15. Short Expendable Centaur IUS Performance Capability

The EC concept for the National Program starts with the basic 10-foot by 25-foot Centaur IUS which performs a large number of NASA missions. For a few high energy spacecraft missions a 10-foot by 31-foot EC is required which is the size of the current Centaur. For highest energy missions a spin-stabilized auxiliary propulsion stage similar to those flown on current Centaurs is used. The development tasks, in addition to the DOD only program required to provide this National Mission Model capability, are shown on Table 3-5. These tasks require minimum RDT&E costs due to the maximum use of existing Centaur tooling, GSE, and facilities coupled with the lack of major testing requirements. The wide-tank EC requires only three of the additional tasks on Table 3-5 as the basic stage remains the same.

Table 3-5. EC National Mission Model Development Tasks

	EC	Wide Tank EC
Add 6 ft cylindrical LH_2 tank skin (existing configuration)	X	
Add segment to LH_2 tank insulation blanket	X	
Lengthen H_2 P/U probe (existing configuration)	X	
Lengthen wiring and tubing (existing configuration)	X	
Extend ASE pallet and relocate forward Orbiter interface	X	
Remove DOD communications and add STDN compatible system	X	X
Rerun some dynamic, stress and thermal analyses	X	
Modify existing auxiliary propulsion stage structure and spin system	X	X
Ground based flight operations software	X	X

3.3 REUSABLE IUS PROGRAM

The Reusable IUS program consists of two lengths of vehicles. One of the driving considerations in the length selection was to avoid requiring development of new large kick stages. A length of 28 feet was chosen as having adequate performance margin and being capable of carrying all synchronous equatorial orbit payloads. For the longest spacecraft, a second length version of the RC was selected. This length was set at 22 feet, and this vehicle is similar to the 28-foot RC with the exception of deletion of cylindrical sections from the hydrogen and oxygen tanks.

The 28-foot RC IUS (RC-28) captures all DOD missions in a completely reusable mode as well as capturing most of the NASA and non-NASA/non-DOD missions in the reusable mode. The reusable 22-foot RC (RC-22) accommodates payloads up to 38 feet long. RC-28 captures the synchronous equatorial and the lower energy planetary missions in the reusable mode. Geosynchronous payload capability in the reusable mode is over 5000 pounds.

To fly very heavy or very high-velocity NASA missions, Reusable Centaur is expended. The program selection for the current mission model involves no kick stages at all.

3.3.1 IUS CONFIGURATION. RC-28 is a modification of the existing D-1T Centaur vehicle (see Figure 3-16). The entire engine, propellant feed system, and thrust structure is essentially identical to the existing Centaur. Most of the avionics packages are the same. The hydrogen tank diameter has been increased from 10 feet to 14.5 feet to provide increased fuel capacity. The oxidizer tank forward and aft bulkheads are identical with Centaur, but a cylindrical section has been added to increase oxidizer capacity.

For the longest payloads, a modification of this stage consists of removing cylindrical sections from both the hydrogen and oxygen tanks. This vehicle is structurally similar to the Short Expendable IUS, except the mixture ratio is 6:00 rather than 5.0 as for the short EC.

Structural changes, in addition to the tank modifications, are the new configuration forward support structure and an aft skirt which are fabricated from composites to reduce weight. The front end of the RC consists of a short cylindrical stub adapter, a conical equipment module, and the standard interface ring. The aft skirt is 15 inches long and is fabricated from graphite/epoxy. The RC tank consists of a lengthened LO_2 tank and an LH_2 tank enlarged in diameter to 174 inches. The LO_2 tank consists of the existing double-walled intermediate bulkhead and existing aft bulkhead connected with cylindrical section 35 inches in length. The LH_2 tank consists of the forward bulkhead and aft transition section connected by a cylindrical section 38 inches in length. The minimum predicted tank life, based on the present Centaur program, is 45 missions.

The RL10A-3-3 for RC has two changes from the condiguration used on expendable IUS. An additional pre-start solenoid has been installed to allow independent LO_2

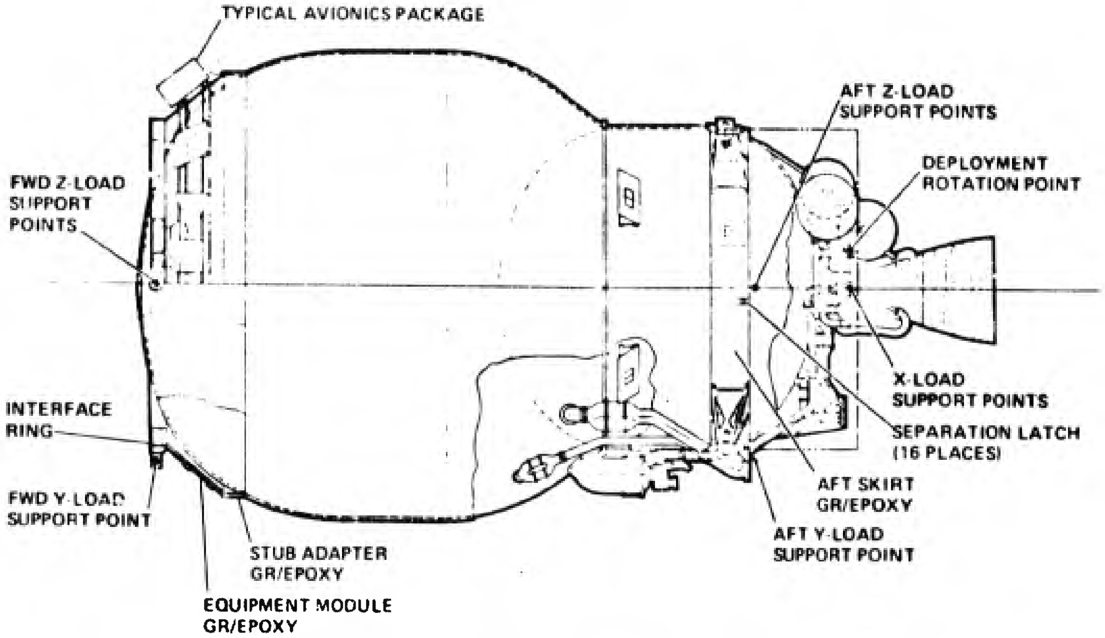


Figure 3-16. Reusable IUS Configuration, 28-foot Version

and LH_2 chilldown durations to reduce LO_2 chill dump loss. The second proposed main engine change is operation at 6.0 rather than 5.0 nominal mixture ratio. This reduces vehicle length and increases propellant mass loading within a given length constraint.

RL10 main engines for RC are uniquely suitable for IUS application in that they possess a combination of features not found in other engines. Included are: (1) multi-flight reuse without any changes to the existing RL10A-3-3 qualified configuration; (2) clean propellants with no problems resulting from propellant residue, no toxicity concerns from a personnel safety or maintenance viewpoint, and no clogging of propellant flow passages due to formation of sludges or propellant gums; (3) high performance; and (4) minimum turnaround maintenance between flights with no component replacement (such as ablative chambers) required and maintenance primarily limited to visual inspection plus data evaluation to clear the main engines for another flight.

All RC IUS main propulsion system components have demonstrated life capabilities in excess of 10 missions before the need of refurbishment. The main engine undergoes small part replacement after 10 and 20 missions with major overhaul required after 30 missions. Boost pumps have been qualified for 25 cycles of eight minutes each, 14 RC missions, while the feed ducts have an indefinite life. The RC main propulsion system is inherently reusable.

The Reusable Centaur APS uses the same basic components as Centaur D-1T. Four forward firing thrusters have been added to provide +X axis translation and assist in meeting Orbiter remote manipulator system requirements for payload dynamics prior to retrieval.

A zero-g thermodynamic vent and mixer package is provided in each propellant tank.

The RC's avionics system includes a new, redundant, DOD-compatible communication system with a redundant antenna system to provide omnidirectional capability through switching to selected antennas. Dual PCM encoders are used to provide redundant monitoring of safety critical functions. A new lightweight fuel cell provides the electrical energy needed to accomplish all missions and return. An emergency battery provides a redundant power source for operations in the vicinity of the Orbiter. An attitude and navigation update required for return is provided by a fixed-head star tracker unit for attitude update. Navigation update is provided from ground tracking by the communication system. These updates are not required to successfully deploy the spacecraft, but are only required during IUS return. Current computer memory has been doubled to accommodate software requirements for the reusable mission mode.

The RC will be supported in the Orbiter by a forward and aft cradle. Vehicle deployment will be similar to the expendable IUS.

The wide LH_2 tank has led to a dual-cradle support technique that provides the structural interface with the Orbiter. It also serves as an interface for fluid and electrical functions and provides for special operations such as deployment and abort (see Figure 3-17).

RC/spacecraft structural loads are transmitted from the RC tank to Orbiter structural support point interfaces by the forward and aft support cradles. One umbilical panel on the forward support cradle contains electrical disconnects and spacecraft RTS cooling water lines. The aft support cradle contains two fluid umbilical disconnect panels and one electrical panel.

ASE consists of avionics units located on the cradle and control panels located at the MSS. These are identical to those specified for the Expendable IUS vehicles.

3.3.2 AUXILIARY STAGE DEFINITION. No requirement was derived for an auxiliary stage vehicle to supplement the Reusable Centaur (RC) IUS vehicle performance. The RC, either in its reusable or expended operating mode, performs the missions specified in the IUS Spacecraft Mission Models. Accomplishing the high-energy outer-planet missions requires the RC to be expended. Performance of the highest energy mission, Pioneer Saturn/Uranus Flyby (PL-11), necessitates an ideal velocity above the Shuttle parking orbit of 27,700 fps. RC in its expended mode is capable of providing a total velocity of approximately 28,800 fps for the Pioneer spacecraft weight resulting in a performance margin of greater than 500 fps for a single burn RC mission when losses due to gravity are included.

3.3.3 PERFORMANCE. RC-28 deploys, in the reusable mode, all earth-orbit spacecraft where spacecraft length does not exceed the available Orbiter cargo bay length.

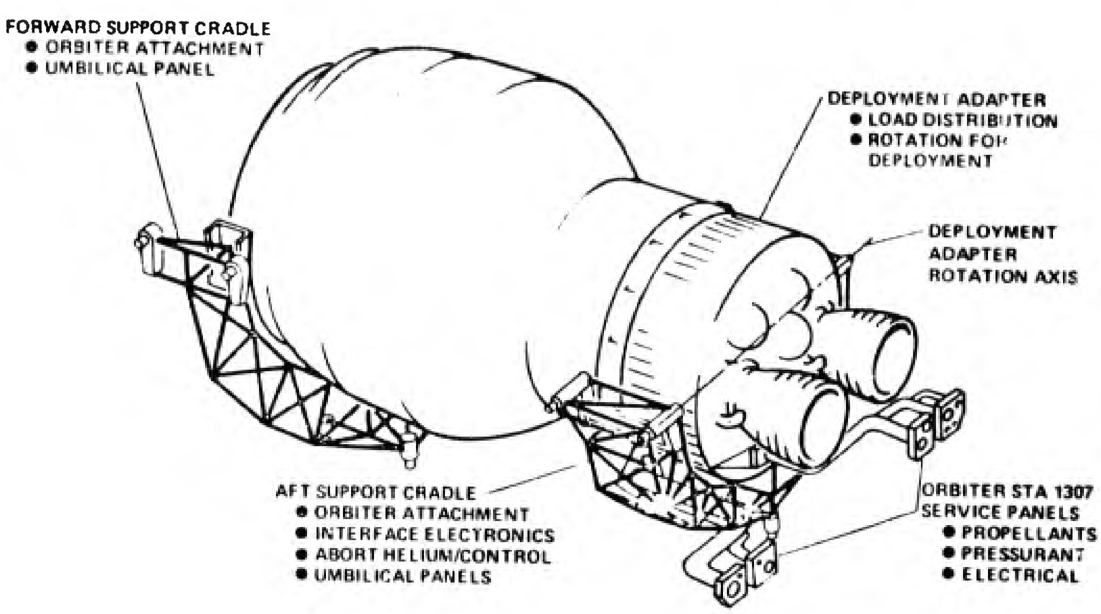


Figure 3-17. Reusable Centaur/Orbiter Interfaces

RC-28 can also deliver near-planet spacecraft to their escape trajectories in the reusable mode. RC-28 is expended to deliver a few distant-planet spacecraft to their very-high energy trajectories. RC-22 is sized to deliver long spacecraft to inclined low-energy earth orbits in the reusable mode. It can also deploy other single and multiple spacecraft to low-energy orbits in the reusable mode.

RC-28 and RC-22 payload versus delta-velocity capability is shown in Figure 3-18 in the reusable mode and in the expended mode for RC-28 (MR = 6.0, I_{sp} = 438.1 seconds). All performance values reflect the effect of equipment necessary to accomosate RC in the Orbiter Shuttle.

RC-28 is capable of deploying 5177 pounds to synchronous equatorial orbits in the reusable mode and 1215 pounds for the high altitude mission.

The RC-22 configuration is used to deliver long payloads to low-energy orbits. The mission used to define stage design is an elliptical 12-hour orbit inclined at 63.4 degrees. Capability of the RC-22 to deploy spacecraft to the design 12-hour mission orbit and return to the Orbiter is 15,446 pounds.

The weight summary for these stages is shown in Table 3-6.

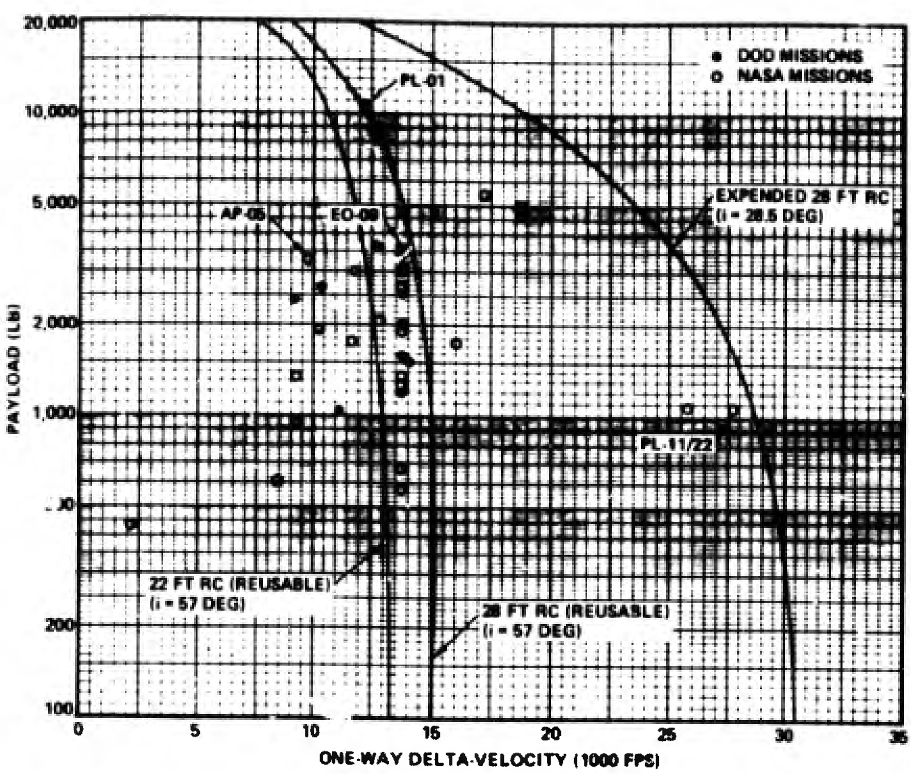


Figure 3-18. Reusable Centaur IUS General Configuration and Performance Capability

Table 3-6. RC Weight Summary

Configuration	28-ft RC	28-ft RC	22-ft RC
Reference Mission	Geosync.	High Alt.	12-Hr Period
IUS WEIGHTS (pounds)			
Dry Weight	5,263	5,263	4,886
Residuals	667	732	518
Reserves	176	176	176
Burnout Weight	6,106	6,171	5,580
Full Thrust Propellant	47,944	43,495	29,242
ACPS H_2 O_2	248	335	222
Non-Impulsive Propellants	581	1,342	498
Loaded Stage	54,879	51,343	35,542
Spacecraft & Adapter (Max. Capability)	5,177	1,215	15,446
Separation Weight	60,056	52,558	50,988
Spacecraft RTG Kit	0	1,100	0
Shuttle Accommodations	4,944	4,944	5,012
Shuttle Liftoff IUS System Weight	65,000	58,602	56,000

3.3.4 DEVELOPMENT SCHEDULE. Figure 3-19 shows the development schedule for the Reusable Centaur program. Major development tests include structural qualification and fatigue testing of the primary airborne stage as well as function and structural testing of the ASE hardware. Avionics units integration testing receives more emphasis here than for the EC including Shuttle and launch facility integration. Equipment module acoustic testing, propellant tanking, and ground-hold thermal testing are significant tests for the RC IUS. The initial RC IUS would also support site integration at KSC as well as be subjected to final system verification testing prior to the first launch.

3.4 SHORT REUSABLE IUS PROGRAM

Convair has selected a "Short" reusable vehicle which, together with the 28-foot RC IUS, forms a Short Reusable Program. The short RC IUS configuration is just under 20 feet long. By using two vehicle lengths, the RC-28 IUS delivers most of the payloads, as in the Basic Reusable program, and the Short RC IUS delivers those payloads greater than 32 feet long.

3.4.1 SHORT IUS CONFIGURATION. The Short RC IUS was developed by removing the cylindrical section from both the hydrogen and oxygen tanks on the RC-28 (see Figure 3-20). In addition, the forward bulkhead of the hydrogen tank was reshaped to increase the capacity of that tank without increasing stage length. In all other respects the Short RC structure is identical to RC-28 and RC-22.

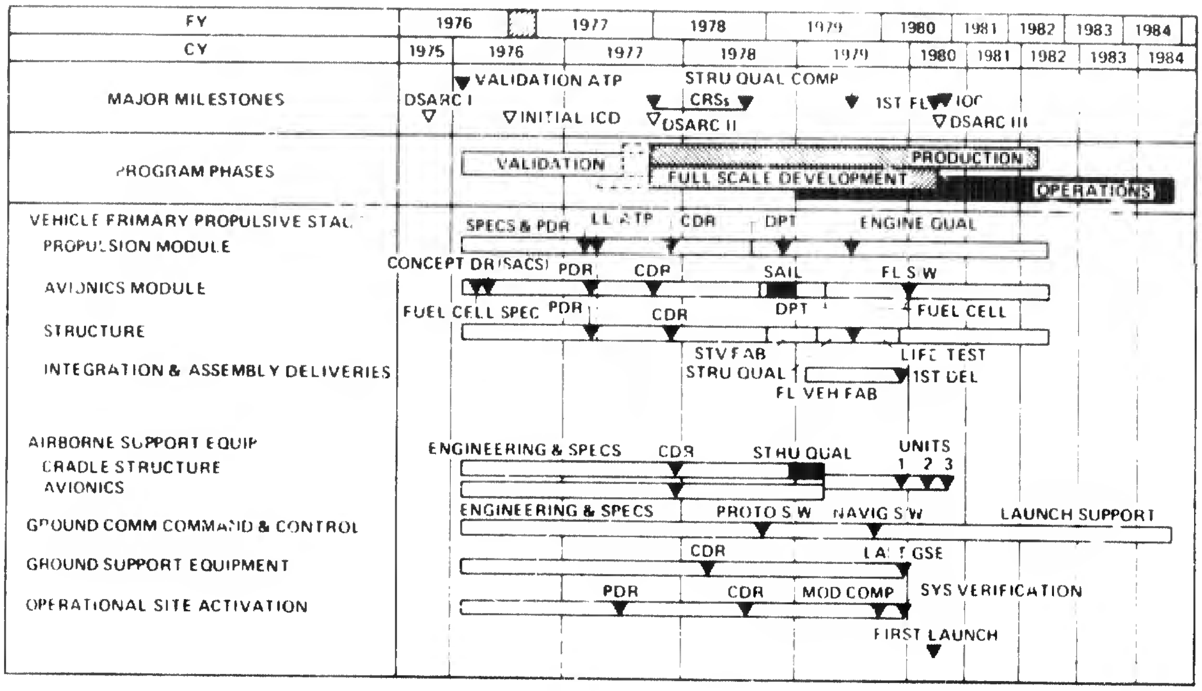


Figure 3-19. RC-IUS Development Schedule

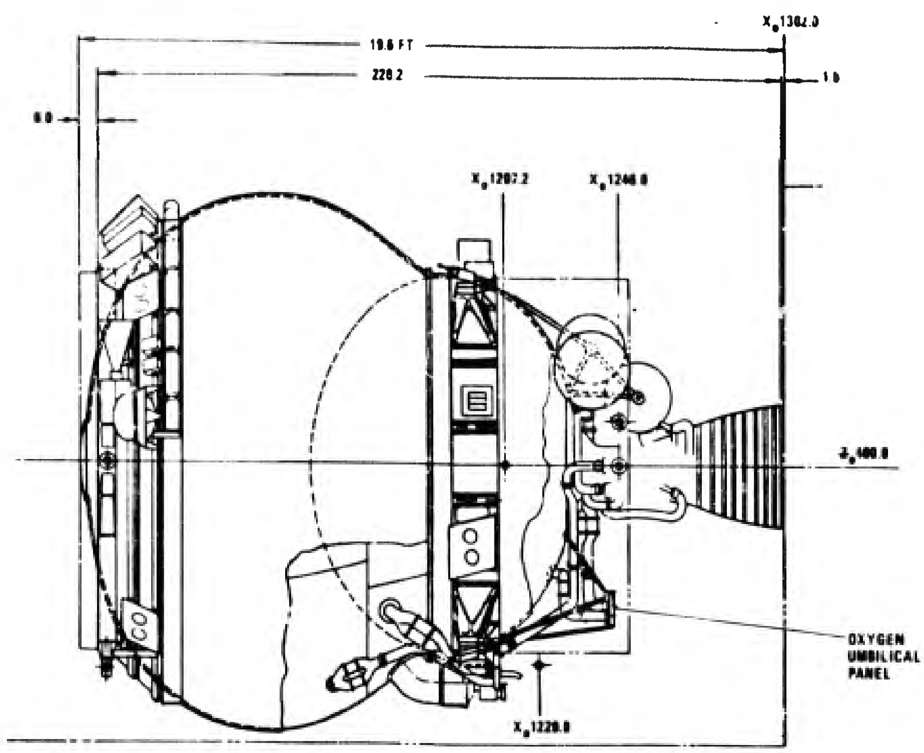


Figure 3-20. Reusable IUS Configuration, Short Version

The short RC is supported in the Orbiter by a forward and an aft support cradle. The Short RC forward support cradle is somewhat smaller than the RC forward support cradle due to lighter weights and lower loads associated with the Short RC. This forward cradle attaches to Orbiter vernier attachment locations. The aft cradle and deployment adapter are identical to the larger RC components.

Deployment and ground purge of the cargo bay of the Short RC are the same as for the longer RC vehicles.

3.4.2 AUXILIARY STAGE DEFINITION. No auxiliary stages are required for the short RC program.

3.4.3 PERFORMANCE. The short RC program consists of two configurations: an RC-28 identical to that discussed in Section 6.3 and a short configuration, which replaces the RC-22 of the basic RC program. The Short RC is tailored to deliver long spacecraft to inclined low-energy earth orbits in the reusable mode. It can also be used to deploy other single and multiple spacecraft to low-energy orbits in the reusable mode. RC-28 deploys the remaining earth orbit spacecraft (primarily geosynchronous) in the reusable mode. Low energy planetary missions can also be accomplished in the reusable mode. RC-28 is expended when a few distant-planet spacecraft are delivered to their very high-energy trajectories. Auxiliary propulsive stages are not used with the Short RC program.

Payload capability versus delta-velocity is shown in Figure 3-21 for RC-28 in the reusable and expended modes and for the Short RC in the reusable mode. Capability of the Short RC to deploy spacecraft to the design 12-hour mission orbit and return to the Orbiter is 10,493 pounds. The weight summary is shown in Table 3-7.

3.4.4 DEVELOPMENT SCHEDULE. The development schedule for the Short RC is essentially identical to that of the basic reusable program.

3.4.5 RC DEVELOPMENT FOR NATIONAL MISSION MODEL. All RC vehicles as developed for the DOD Program are readily usable by NASA in satisfaction of the National Mission Model.

The RC program requirements for providing National Mission Model capability involve developing only the STDN communication system and additional ground based flight operations software for the NASA Mission Control Center. The RC program as structured for DOD satisfies all other requirements. The 28-foot RC operated in an expendable mode performs the highest energy planetary missions without an auxiliary propulsion stage.

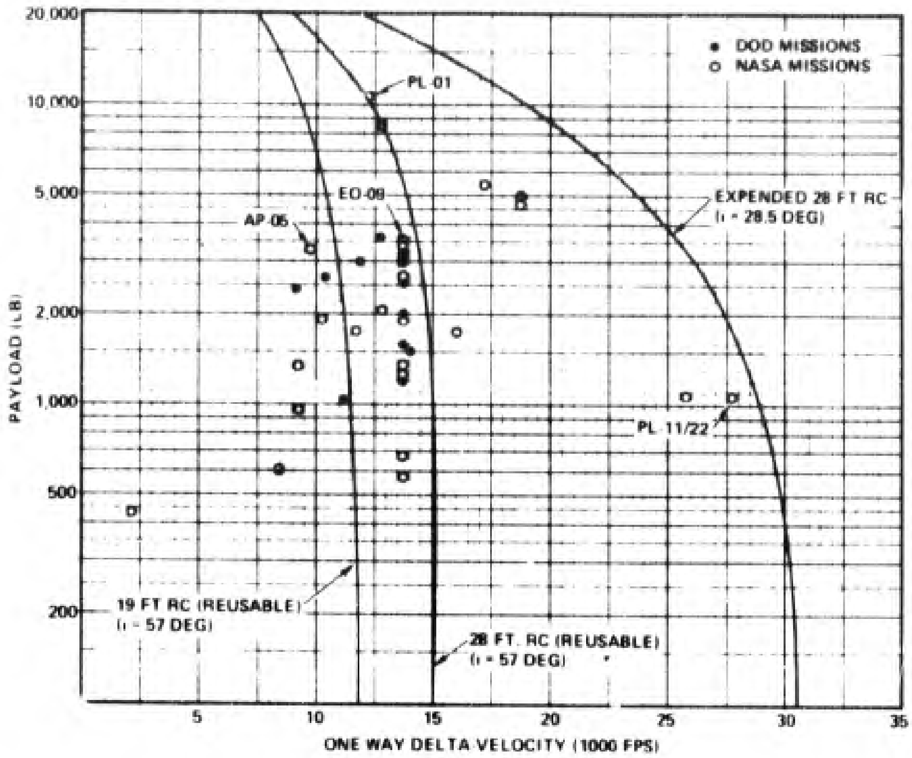


Figure 3-21. Short Reusable Centaur Program Performance Capability

Table 3-7. Short RC Dry Weight Summary (Five-burn 12-hour Period Orbit Mission)

	Weight (lb)
Body Structure	(1,773)
Fuel Tank	764
Oxidizer Tank	264
Common Tank Bulkhead	176
Structure Fwd of Tanks	381
Structure Aft of Tanks	151
Thrust Structure	37
Induced Environment Protection	(202)
Thermal Control (Passive)	202
Main Propulsion	(1,438)
Main Engine & TVC (2)	69
Fuel System	267
Pressurization System - Fuel	208
Oxidizer System	204
Pressurization System - Oxidizer	17
Common Bulkhead Vacuum System	5
Propellant Utilization System	13
Orientation, Control & Separation	(258)
Auxiliary Propulsion System	199
Separation System	59

	Weight (lb)
Prime Power Source	(93)
Fuel Cell	57
Battery	36
Power Conversion & Distribution	(180)
Power Conversion	50
Electrical Distribution	130
Guidance & Navigation	(260)
Guidance Source	86
Guidance Evaluation	134
Guidance Output	40
Instrumentation	(170)
Sensors	36
Signal Conditioning	56
Electrical Coupling	78
Communications	(96)
Contingency	(269)
Total Stage Dry Weight	4,739

SECTION 4

OPERATIONS CONCEPT DEFINITION

This section summarizes IUS ground and flight operations plans and associated logistics support based on over ten years of Centaur operations experience at ETR.

4.1 GROUND OPERATIONS

Recommended IUS ground operations are referenced in Figure 4-1 to existing and Shuttle facilities at ETR.

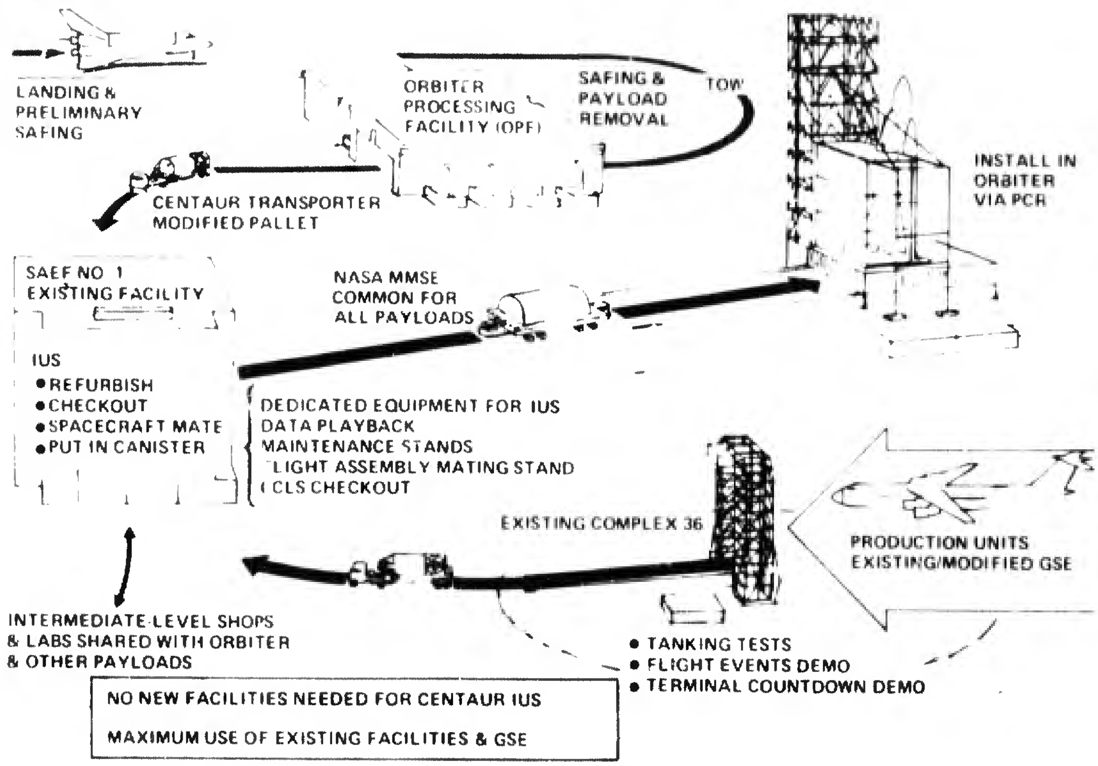


Figure 4-1. Ground Operations at KSC

The 25- and 31-foot Expendable Centaurs (EC) will be delivered to the CCAFS skid strip at ETR by C-5A aircraft using ground and air support equipment now used for Centaur D-1A and D-1T. EC flight equipment will be inspected and mated at SAEF-1 before proceeding to Centaur Complex 36A for tanking tests and checkout for the first five vehicles. EC vehicles number six and on will be completely checked out at SAEF-1 without a tanking demonstration.

All RC vehicles will be delivered to the CCAFS skid strip by Pregnant Guppy aircraft. Ground and air support equipment consists of AGE now in use for Centaur D-1A and D-1T, modified equipment, and some new equipment. All new Recoverable Centaurs

(RC) will be inspected and mated to supporting ASE at SAEF-1 on Merritt Island before proceeding to Centaur Complex 36A for tanking tests and checkout.

Following test and checkout verification of flight readiness, IUS will be returned to SAEF-1. At SAEF-1, IUS will be cleaned in the airlock, prepared and mated vertically with the spacecraft in the clean room (a class 10,000 facility), and checked out with the spacecraft as an integrated Shuttle payload. The combined IUS/spacecraft payload will then be loaded into the KSC-supplied environmentally conditioned canister for transport to Launch Complex 39 for vertical installation in the Orbiter through the Payload Changeout Room (PCR), or to the Orbiter Processing Facility (OPF) for horizontal installation and transport to Complex 39 in the Orbiter payload bay.

At Complex 39, prelaunch activities will include monitoring payload status through existing Centaur CCLS, ACPS propellant loading, and concurrent loading of the Shuttle External Tank and IUS with liquid hydrogen and liquid oxygen using the KSC Launch Processing System (LPS).

After EC launch and Orbiter return, EC ASE will be removed from the Orbiter payload bay at the OPF and transported to SAEF-1 for refurbishment and recycle prior to mating with the next EC.

After RC mission completion and Orbiter return, the RC, support cradles and deployment adapter will be removed from the Orbiter payload bay at the OPF and transported to SAEF-1 for refurbishment and mating with the next spacecraft.

No new facilities are required for IUS processing, and minimum modification of existing facilities (interior equipment only) satisfy all requirements for both EC and RC program operations.

4.1.1 OPERATIONS TIMELINES. Figures 4-2 and 4-3 show the RC ground operations for a mature system (tenth cycle). The total processing cycle requires about 20 working days, considering multiple shift operations immediately following landing and after installation at the launch pad. If the IUS/spacecraft are installed in the Orbiter horizontally at the OPF, total cycle time for IUS will be 238 work hours, landing to launch. For RC the total processing cycle from landing through launch requires 252 working hours for the pallet and 221 work hours from IUS arrival on site through launch. If the IUS/pallet/spacecraft is installed in the Orbiter horizontally at the OPF, total cycle time for the pallet would be 311 work hours, landing to launch; and 270 work hours, site arrival to launch for IUS. Times are compatible with the Orbiter 160 hour allocated timeline defined in JSC 07700, Vol. XIV, Section 5 (Change 8).

In EC programs, the first five vehicles to arrive at KSC will use a special initial processing cycle. This cycle, also used by new RCs arriving at KSC, provides for extensive testing and a cryogenic loading test at the cryogenic test and checkout facility (CTCF) at Complex 36A. These tests permit complete verification of all program

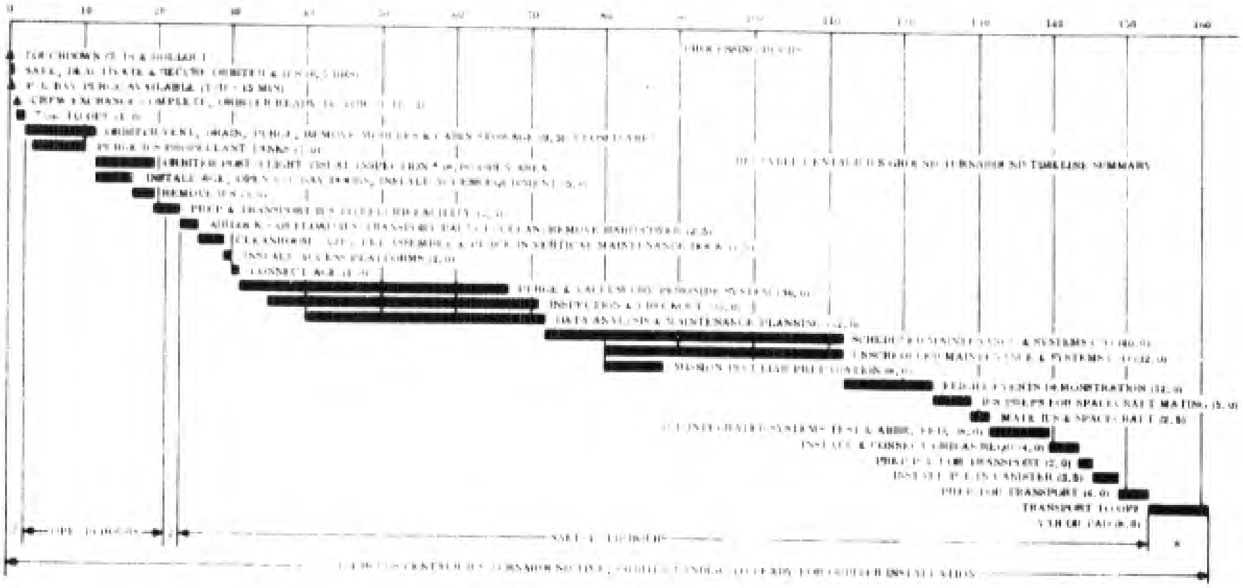


Figure 4-2. RC Turnaround

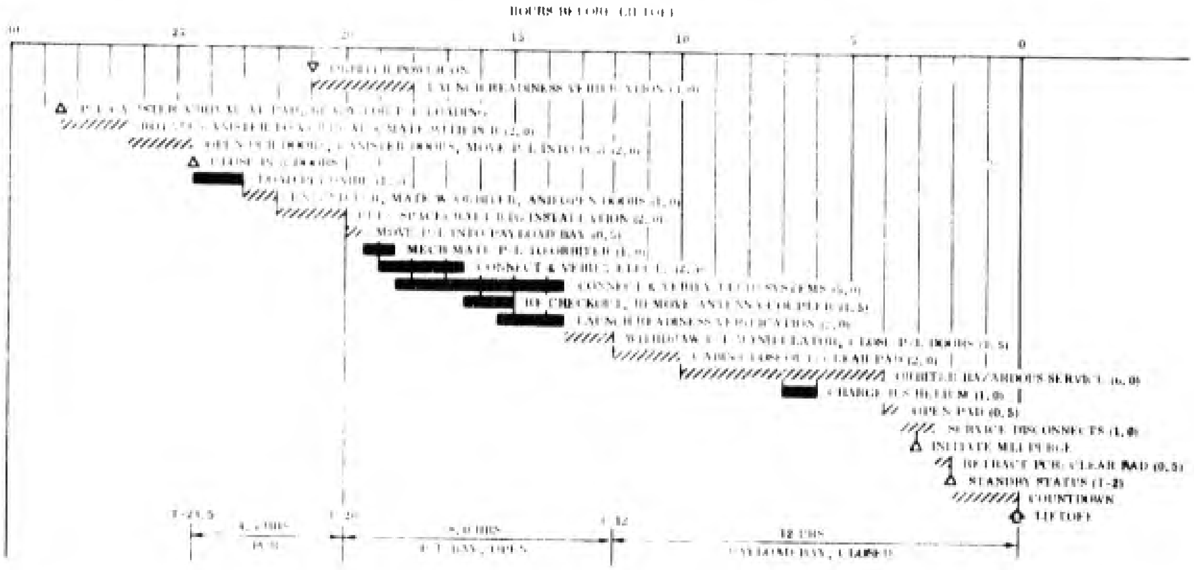


Figure 4-3. Shuttle/IUS Launch Pad Operations

software, procedures, and AGE operation. First EC planned flow time will be 106 M-days and fifth vehicle will be 40 M-days. Time for RC programs with seven vehicles will be 37 M-days on the seventh RC.

4.1.2 SAFETY CONSTRAINTS. Ground operations plans for IUS have been developed with the need for safety as a primary constraint.

Centaur IUS is never handled with main propellants aboard. Liquid hydrogen and liquid oxygen are tanked concurrently with the Shuttle External Tank (ET) at T-2 hours before liftoff using the same existing storage tanks and main propellant transfer lines now in use at Complex 39. If an on-pad mission abort occurs, main propellants are drained back to the storage tanks together with the ET propellants. After such an abort, countdown and propellant loading can be re-initiated for launch, or the IUS can be removed from the Orbiter payload bay with empty propellant tanks. This situation could occur in the case of a sudden emergency payload changeout requirement. Helium purge of the tanks results in a completely innocuous gas mixture in the systems with respect to flammability. Since IUS propellants are also non-toxic, this permits immediate safe ground crew access for systems disconnect and payload removal. The same condition prevails after in-flight abort and propellant dump. Purge to below the flammability limits of hydrogen results in disconnect capability without fear of residuals endangering ground personnel.

Centaur IUS uses hydrogen peroxide (H_2O_2) as an ACS propellant. The decomposition characteristics of H_2O_2 require a clean passivated system for propellant storage. To meet this requirement and assure a safe system, the ACS on each vehicle is passivated at the factory (EC No. 6 and on) or loaded with propellant and passivated during test and checkout procedures; then drained, purged, and vacuum dried. The system remains in this condition until final propellant loading aboard IUS in the payload Changeout Room (PCR) prior to payload installation in the Orbiter. In case of an on-pad abort, H_2O_2 can be drained back into the supply drum in the PCR if payload installation has not yet occurred. If the vehicle has been installed in the payload bay, H_2O_2 can be drained into the water dilution/retention tank in the MLP for later dump into the flame bucket. For an in-flight abort, hydrogen peroxide will be dumped prior to landing. After removal from the payload bay, Centaur will be transported to SAEF-1 and the ACS flushed, purged, and vacuum dried in preparation for recycle and launch.

At no time during ground operations will vehicle or ASE pressurization supply bottles be at more than half normal operating pressure; well within permissible limits for personnel safety. Bottles will not be charged to flight pressure until final countdown.

Propellant tank pressures on the ground are held to less than 35-percent of design pressure. This is ten psig for the hydrogen tank which permits ground handling and transportation within the Convair design requirement of 2.5g for Z_o loads with spacecraft attached.

Centaur IUS propellant tanks are filled, drained, and dumped through one liquid hydrogen FD&D line, one liquid oxygen FD&D line, and one liquid oxygen topping line (See Figure 4-4). To eliminate discharge of liquid or gaseous propellants at the T-0 disconnect panel at liftoff, or subsequently when IUS deploys from its deployment adapter in the Orbiter payload bay, these lines are purged with helium back into the propellant ground supply lines upon completion of tanking and just prior to liftoff.

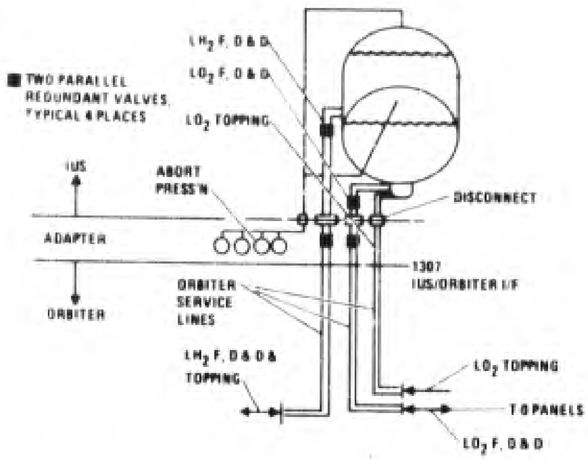


Figure 4-4. IUS Propellant Lines

4.1.3 MONITORING AND CHECKOUT. Monitoring, checkout, and control of Centaur IUS will be performed through the combined installations of the LPS and the Centaur computer controlled launch set (CCLS). The division of functions between CCLS and LPS is summarized in Table 4-1. The sequence of monitoring, test, and checkout operations at Complex 39 is: power application and safing validation, IUS system functional tests, IUS tanking, transfer of control to LPS, prelaunch and launch monitor, and recycles and aborts.

Table 4-1. LPS and CCLS Function Summary

CCLS Functions	LPS Functions
DCU Communications IUS SCU Control IMG Power On Monitor IMG Initialization SIU Monitor and Control PU Monitor and Control Finalize IUS Launch Preps CCLS Controls Using 267.7 Kbps Final Countdown Monitor	Power Application Pallet SCU Control IMG Power On Tanking Control Tank Pressurization Do DCU Communications Final Countdown Monitor

4.1.4 MAINTENANCE AND REFURBISHMENT. Maintenance and refurbishment (M&R), will be provided by Convair under the MIL-STD-1538 concept. M&R plans and approach are based on maximum use of Centaur operational procedures, personnel, facilities, and aerospace ground equipment (AGE) in conforming to the concept of DOD Instruction 4100.35G for logistics support.

The IUS system primary maintenance will be accomplished at SAEF-1 with support from the adjacent Convair spares control facility and the spares facility in San Diego. The IUS plan provides for maintenance on three levels, defined as:

1. Organizational maintenance is performed at ETR on the IUS subsystems, AGE, and related ASE in direct support of turn-around preparation and will be limited to remove and replace or repair in-place actions.

2. Intermediate maintenance is performed at ETR in direct support of the reburbishment cycle including scheduled and unscheduled maintenance required to inspect, service, calibrate, replace, repair, modify, and reevaluate subsystems or components removed during organizational maintenance.

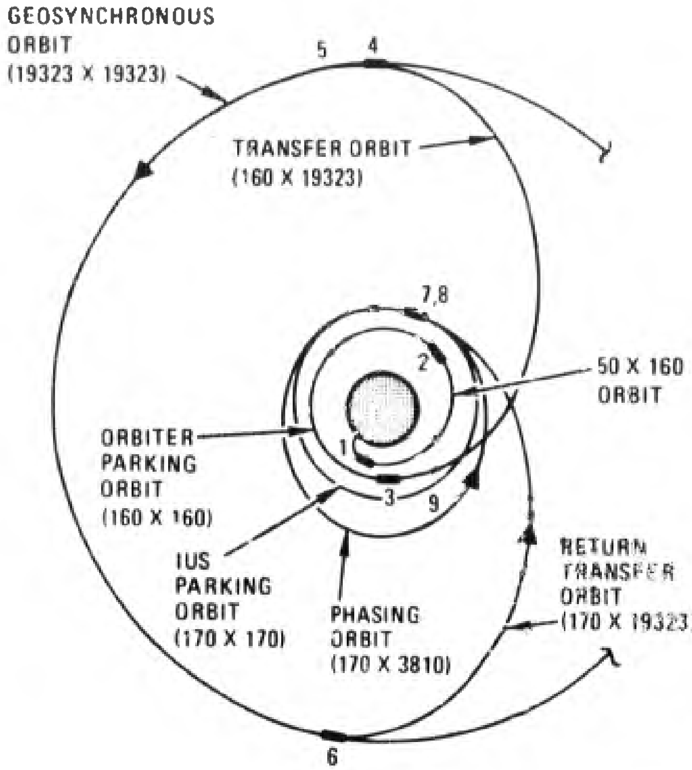
3. Depot maintenance is performed at the contractor or vendor plant for repair, overhaul, rebuild, or modifications of components or end items.

Candidate M&R methods include scheduled, on -condition, condition monitoring, and flight monitoring concepts. Aircraft experience with application of these concepts indicates that hard-time controlled disassembly, inspection, and/or overhaul is ineffective in detecting or preventing random failures, occasionally is the cause of failures, and is unnecessarily expensive. Our commercial experience shows that on-condition and condition monitoring concepts provide more effective methods of condition assessment and reliability control. But on-condition inspection and tests are highly demanding on maintenance resources and often no problems are found to exist. Condition monitoring has proven to be the lowest cost and most effective means of condition assessment because actual operation provides the best functional check. However, condition monitoring is dependent on having extensive Operational Flight Instrumentation for obtaining maintenance information. Extensive equipment modifications, added instrumentation, and maintenance recording units required for condition monitoring were found to be inappropriate for IUS. Therefore, IUS will selectively use scheduled replacement and on-condition processes but is primarily based on flight monitoring and turn-around revalidation.

4.2 FLIGHT OPERATIONS

Reference missions, developed to represent the National Mission Model for fiscal years 1981 to 1984, include geosynchronous, high altitude, and planetary. Ascent for all missions consists of Orbiter insertion into a 50 by 160 n.mi. orbit followed by circularization into parking orbit at 160 n.mi. apogee.

The RC geosynchronous mission is a typical IUS mission (See Figure 4-5) with first burn at the second descending node. Deployment is just prior to first burn, so that a one-way doppler position and velocity update from Hawaii and Vandenberg Tracking Stations can be used to increase spacecraft placement accuracies. After RC first burn at the second descending node, RC and spacecraft coast for 5 hours and 15-minutes on a Hohmann transfer ellipse to geosynchronous orbit. A second burn at geosynchronous altitude positions RC and spacecraft in a 19,323 n.mi. circular orbit. The RC maneuvers to the required attitude and separates the spacecraft. The EC reference mission is identical to the RC and ends at this point with the EC backing away from the spacecraft. An 11-hour coast period for RC follows to ensure that at the end of return transfer to parking orbit the planes of RC and Orbiter orbits are aligned. RC receives position and velocity update information just prior to its third burn (return transfer burn). At 170 n. mi., perigee of the transfer



SEQ. NO.	EVENT	G.E.T. (HR)
1	50 x 160 N.MI ORBIT INSERTION	0.18
2	ORBITER CIRCULARIZATION AT 160 N.MI.	0.77
3	TRANSFER ORBIT INSERTION	1.96
4	GEOSYNCHRONOUS ORBIT INSERTION	7.22
5	DEPLOY PAYLOAD	7.28
6	RETURN TRANSFER ORBIT INSERTION	18.74
7	PHASING ORBIT INSERTION	24.02
8	IUS CIRCULARIZATION AT 170 N.MI.	26.81
9	ORBITER/IUS DOCKING COMPLETE	29.48
10	INSERTION TO EARTH RETURN ORBIT	46.16
11	FINAL TOUCHDOWN; MISSION COMPLETE	47.04

Figure 4-5. RC Reference Geosynchronous Mission

ellipse, RC retroburns for a phasing maneuver to position itself 10 n.mi. above and slightly ahead of the Orbiter for rendezvous. A fifth and final burn fixes RC in this position. RC systems are safed and the Orbiter initiates rendezvous and docking procedures for retrieval. Other RC reference missions are similar in procedure.

Centaur IUS is capable of performing its missions without major requirements levied on the Orbiter. It is fully compatible with Orbiter Case 1 ascent, as described in SR-IUS-100, with the Shuttle System abort modes and with recovery operations. No Orbiter dog leg trajectories are required due to Centaur IUS delta velocity capability. Only the mission specialist needs thorough familiarity with the Centair IUS systems for normal mission operations.

4.2.1 LAUNCH OPERATIONS. All systems are given a thorough checkout prior to and after Centaur IUS installation in the cargo bay. One hour prior to liftoff, the monitor and control system is switched to flight monitor mode and the navigation system is gyro-compassed for azimuth alignment. Two minutes prior to liftoff, Centaur IUS time is matched to Orbiter time and primary hydrogen vents are closed. The hydrogen tank is pressurized to help support launch loads. Following that, all purges are terminated and air-conditioning systems turned off. Eight seconds prior to liftoff, navigation and guidance systems are initialized. At liftoff, the hydrogen tank is switched to inflight vent; shortly after liftoff, the primary LH_2 vent is unlocked.

4.2.2 IUS DEPLOYMENT. First burn for Centaur IUS occurs at the second descending node. This provides a period of 20 minutes or more available after parking orbit insertion for the Orbiter crew to perform Orbiter operations. IUS checkout and deployment is 40 minutes maximum; actual operation could probably be done in less time if necessary or desired. The deployment sequence, Table 4-2 is constructed such that no event is performed unless previous operations indicate that the event being performed will be successful.

4.2.3 IUS RETRIEVAL. Docking and retrieval operations, basically the reverse process of deployment, are shown on Table 4-3. Figure 4-6 shows the RC just after RMS attachment.

Figure 4-6. RC Retrieval by Orbiter RMS

4.2.4 MISSION COMMUNICATIONS. The entire deployment and first main engine start sequence are monitored by the Orbiter crew with ground tracking used to provide one-way doppler data to the Orbiter which provides Centaur IUS with a position and velocity update. RC requires ground tracking to provide a position and velocity update prior to the decent transfer orbit and phasing orbit.

Communications opportunities, summarized in Table 4-4 for the geosynchronous mission, reflect DOD-SCF and NASA-STDN networks defined in SR-IUS-100 for 1980. TDRSS can provide global coverage, except for the keyhole over the Indian Ocean at 160 n. mi. In addition, TDRSS provides coverage up to about 6500 n. mi. TDRSS, compatible with existing ground stations, does provide additional coverage for tracking or communications if desired.

4.3 LOGISTICS

The logistics objective is to provide support that will ensure operational readiness at IOC and low cost through efficiencies achieved during program life. Convair will operate the system to achieve this objective. The Convair operation and support concept was selected as the lowest cost approach because the experienced launch, maintenance, and support personnel and management systems with associated spares and material that are currently performing Titan/Centaur and Atlas/Centaur operations and support are ready and available for transition to IUS. Only minimum changes are needed to adapt Centaur support methods to the concept of DOD Instruction 4100.35G Guide for Logistics Support. EC and RC receipt to launch cycles are nearly the same, except for the turn-around maintenance on the returned RC. Logistics

Table 4-2. Centaur IUS — Deployment Timeline

Event	Start Time Hour	Minute	Second
Predeployment Operations			
Checkout manipulator system	1	6	50
IUS-SC status check	1	11	0
Orient Orbiter for IUS deployment	1	12	0
Activate fuel cells/power changeover	1	13	0
Engine flight control check	1	16	0
Verify GNC	1	17	0
Deployment arm/safe switch to arm	1	18	0
DOD contact opportunity	1	18	44
Disconnect IUS forward umbilicals	1	20	0
Retract fluid umbilicals (2)	1	21	0
Release IUS-Orbiter support latches	1	22	0
Disable zero-g vents	1	24	0
IUS/SC Removal from PL Bay			
Rotate IUS out of cargo bay	1	24	0
Activate IUS/Orbiter RF links	1	28	0
DOD contact opportunity	1	28	24
Position and velocity update	1	29	0
Retract electrical umbilicals	1	30	0
Final IUS status check	1	30	30
Connect manipulator arm to IUS	1	31	30
Actuate separation latches	1	33	20
Deploy IUS/SC			
Extend manipulator	1	33	30
Release IUS from RMS	1	38	30
Orbiter APS burn-sep. to safe distance	1	38	30
Enable zero-g vents	1	39	30
Enable IUS att. control w/rf uplink	1	40	0
Enable main engine start	1	46	0

Table 4-3. Centaur IUS — Retrieval Timeline

Event	Start Time Hour	Minute	Second
Return Rendezvous Orbit			
MECO, boost pumps off	26	48	40
LH_2 propellant dump	26	48	45
Establish Orbiter-IUS rf links	26	50	45
Close main propellant isolation valves	26	57	44
Open main engine valve — dissipate prop	26	57	44
Close main engine valves	26	59	44
Shutdown main prop. — prevalves	26	59	54
Enable safety reaction control system	26	59	54
Orbiter to IUS, Rendezvous			
Rotate deployment adapt to dockint att	27	0	54
Extend manipulator arm	27	1	44
Perform RZ Burn	27	13	44
Final burn maneuvers (braking) a d adj	27	59	14
Orbiter — IUS Docking			
Verify all IUS subsys (except APS) safe	29	6	54
IUS fine attitude hold	29	9	24
Attach manipulator to IUS	29	12	24
Inhibit IUS APS sys (RMS contact sw)	29	12	24
Retract IUS onto adaptor W/RMS	29	15	54
Post Retrieval Operations			
Connect electrical umbilicals	29	19	54
Verify C&W monitor thru umbilical	29	20	24
Switch to pallet battery power	29	20	54
Turn off RF link	29	21	4
Rotate IUS into cargo bay	29	24	14
Latch IUS/adaptor to orbiter	29	27	14
Deploy adapt arm-safe sw to safe	29	27	44
Connect remaining umbilicals	29	28	14
Purge LH_2 tank, repress. 22 psi	29	28	44
Avionics off (guid, dms, instmn)	29	29	14

Table 4-4. RC Geosynchronous Communications Coverage

Mission Orbit (n. mi. × n. mi.)	Communication Coverage	Tracking Station	Time in Hours Start	Stop
50 × 160	No NASA Coverage			
	No AF Coverage			
160 × 160	NASA Coverage	GDS — Goldstone	1.49	1.57
		ROS — Rosmon	1.62	1.69
	AF Coverage	HTS — Hawaii	1.31	1.42
		VTS — Vandenberg	1.47	1.57
160 × 19,323	NASA Coverage	ORR — Orroral	2.58	7.23
	AF Coverage	IOS — Indian Ocean	2.10	7.23
		GTS — Guam	2.85	7.23
19,323 × 19,323	NASA Coverage	ORR — Orroral	7.23	18.73
	AF Coverage	IOS — Indian Ocean	7.23	18.73
		GTS — Guam	7.23	18.73
19,323 × 170	NASA Coverage	ORR — Orroral	18.73	19.37
		ORR — Orroral	23.33	23.87
	AF Coverage	CTS — Guam	18.73	19.91
		IOS — Indian Ocean	18.73	23.60

support plans are therefore quite similar. Transportation and handling and maintenance support plans were discussed under ground operations.

4.3.1 CREW SIZE. A single-shift, five-day work week was used for IUS support crew sizing with manpower levels adequate to support joint Orbiter/IUS multiple shift operations which occur immediately following Orbiter landing and during the final prelaunch operations after payload installation at the launch pad. Manpower levels were adjusted to consider concurrent operations on more than one IUS as a result of projected launch rates. Direct IUS launch operations support manpower levels by skill category are shown in Table 4-5. Since planned operations tasks, duration, and frequency are essentially the same for all IUS versions, crew requirements would be the same.

Table 4-5. Centaur IUS Crew Size

Skill Category	Crew Size	Skill Category	Crew Size
Engineering		Technical/Inspection	
Administration	4	Mechanical	35
Mechanical	10	Electrical	14
Electrical	5	Flight Control	4
Flight Control	6	Instrumentation	9
Instrumentation	5	Subtotal	62
Reliability/QC	2	Operations Support	
Design/Data	10	Material	8
Procedures/Schedules	2	Data Processing	3
Safety	1	Shops	6
Subtotal	45	Subtotal	17
TOTAL CREW 124			

4.3.2 TRAINING. Since Centaur IUS and associated ground operations are very similar to those of current Centaur, experienced well-trained Convair personnel exist. Centaur launches (such as an upper stage for expendable vehicles) will continue through IUS introduction, hence trained factory and launch site personnel will be available for IUS. New Convair personnel will be given on-the-job training to provide replacements and the current Convair foreman/supervisor certification program will be continued to ensure trained IUS ground operation personnel.

Space Shuttle flight crew and ground based flight control personnel will complete a basic 80-hour IUS familiarization and functional training program. A standard IUS training manual will be developed for this course. On completion of the basic two-week training, the mission specialists and ground controllers will be given specialized training.

Mission specialist training requiring equipment will be conducted at the SAIL. One of the three Datacraft systems, one of two PCM decommutators, and the IUS prototype equipment module (PEM) with associated pallet equipment and MSS caution and warning panel will be removed from San Diego facilities and reinstalled at the SAIL. This equipment relocation is also required for avionics testing and associated software development at the SAIL. Since flight controllers will be trained on actual installed consoles, no special equipment is required.

4.3.3 IUS SPARES SUPPORT PLAN. The spares support plan (based on contractor self-support concept of MIL-STD-1538, coupled with the spares procurement procedures of SAMSO Exhibit 67-1) deals primarily with post-production spares support of the IUS, ASE and AGE procured, manufactured or otherwise furnished by Convair for the IUS Program. As the Atlas/Centaur and Titan/Centaur programs phase out, existing Centaur spares support capability will shift to the IUS program. IUS spares support costs during the transition period will, therefore, be limited to the cost of using our existing capability, plus peculiar requirements, resulting from the addition of IUS missions to the Atlas/Centaur and Titan/Centaur schedule. Spares support costs beyond 1982 will be borne by the IUS program. This plan offers considerable savings and greatly reduced risk over a completely parallel capability for IUS program spares support.

SECTION 5

SYNOPSES OF PLANS

This section contains synopses of the more significant programmatic plans relating to development, production, and operations of the Expendable and Reusable Centaur IUS configurations and programs.

5.1 PROGRAM MANAGEMENT PLAN

The IUS will be a mainline program at the Convair San Diego Facility and will receive direct management attention from General Dynamics Corporate Office (see Figure 5-1). Director of the IUS Program will have total authority within the Convair organization for successful accomplishment of the IUS program. He is the final authority on technical/management decisions, has full control over funds and schedules, and will be the principal contact with the USAF/SAMSO program manager.

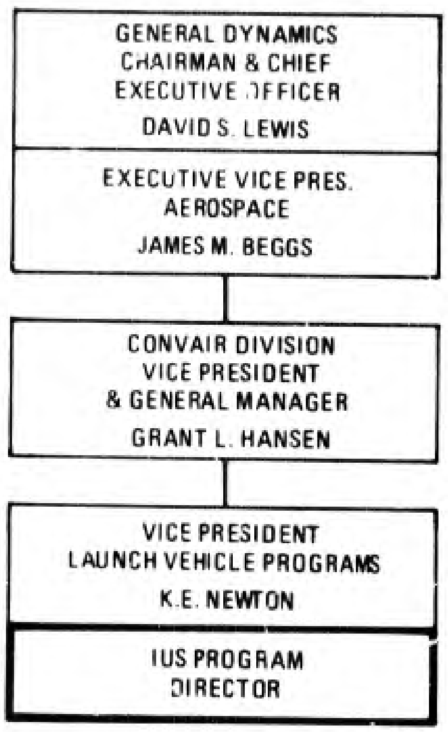


Figure 5-1. IUS Program/Corporate Organization

A conventional form of program/functional matrix management organization will be used. The program office will be comprised of (in addition to the Program Director) WBS Element Managers and Program Functional Managers with responsibility assignments to provide effective total program coverage.

Formal planning, authorization, and control documentation is provided by the Convair Integrated Management System second generation (CIMS II). CIMS II is a Convair internal performance management system developed to meet the objectives of DODD 5000.1 in compliance with the C/SCS criteria of DODI 7000.2.

The CIMS II program controls will be imposed on all subcontractors who have variable price contracts. Existing procurement practices ensure that selected subcontractors' management systems will produce timely and accurate performance measurement data compatible with CIMS II reporting requirements.

5.2 SYSTEMS ENGINEERING PLAN

The Centaur IUS System Engineering Management Plan (SEMP) describes a fully integrated engineering management effort from validation through operations. It is structured using the general criteria presented in MIL-STD-499A as a guide. The basic approach and relationship of the SEMP to the Centaur IUS program is shown in Figure 5-2. The transition from IUS System Requirements to an operational IUS system is supported by technical System Engineering (SE) and by System Engineering Management (SEM). Provisions of MIL-STD-499A will be tailored by the contract statement of work to optimize its effectiveness. At that time the proposed SEMP will include recommendations for further tailoring of the Plan to the Centaur IUS tasks. Those portions of the SEMP proposed to become contractual requirements will be denoted.

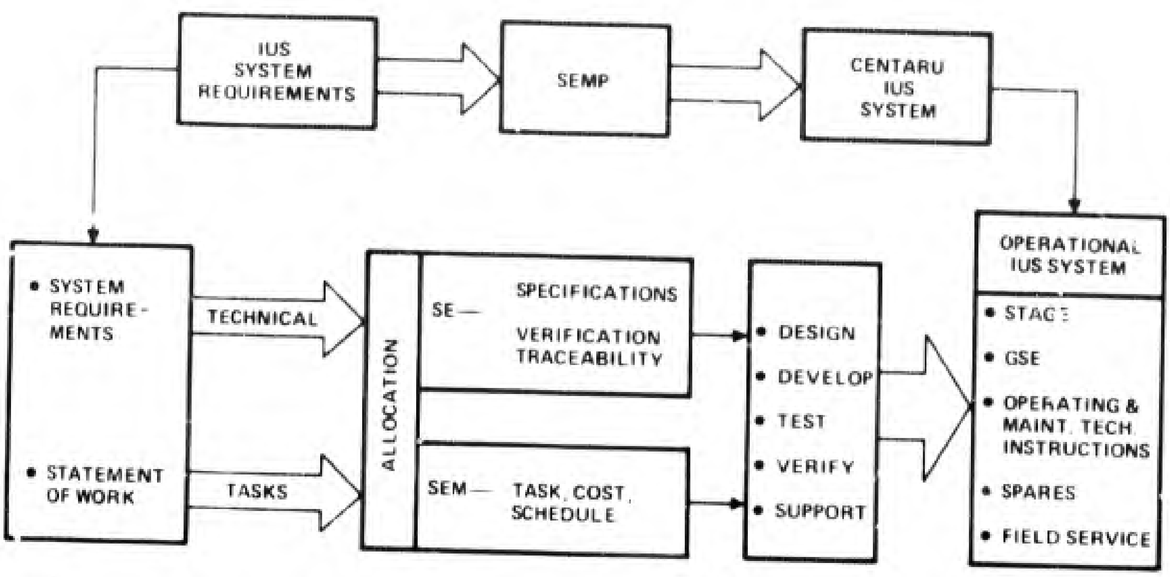


Figure 5-2. Basic Approach to Centaur System Engineering Management Plan

5.3 SYSTEMS EFFECTIVENESS PLAN

The systems effectiveness program includes all the disciplines needed to define, control, and evaluate the system design and operation throughout all program phases. The program brings together the assurance disciplines (reliability, parts, materials, processes, quality assurance, maintainability, human engineering, and system safety) and other essential program disciplines such as design, procurement, manufacturing, and test into an effective team to provide low risk and high probability of program success.

Convair's systems effectiveness program on Atlas implements SAMSO-LVV-002 in the Mission Assurance Plan (MAP). MAP will require only minor modification to implement the requirements of SAMSO for IUS. MAP addresses each customer requirement. It identifies prime support and monitoring organizational responsibilities for each task; includes flow charts and/or narrative to describe task accomplishment; defines audit criteria for scheduled task assessment, and further identifies reports and/or detailed procedures applicable to each subject.

5.4 TEST PLANS

Integrated Test Plans (ITP) have been prepared as a part of the Centaur IUS System Study for both Expendable and Reusable Centaur IUS. The ITP is similar to the Centaur Unified Test Plan currently in use on the Centaur D-1 program. Primary attention in the Centaur development test program has been directed toward cost effective programs in recognition of overall IUS program projected funding constraints. Current Centaur test philosophy and criteria along with Centaur test experience were used as a basis for determination of Centaur IUS test requirements.

5.4.1 EXPENDABLE CENTAUR IUS TESTING. Structural testing of Centaur IUS vehicle is not required for the basic program since the shortened LH_2 tank for the 25-foot version is a proven technique that has been demonstrated on both Atlas and Centaur programs and the 31-foot version utilizes the existing Centaur D-1 tank structure.

The LH_2 tank enlargement to 14.5-foot OD for the short EC is of sufficient magnitude to warrant structural requalification. A dedicated structural test vehicle (STV) is required. The flight pallet/adapter assembly is a new design that will require structural testing. Testing differs for the short EC only in that the test article includes a support cradle in lieu of the pallet.

Propulsion hardware tests are minimal for all Expendable Centaur Programs and are accomplished at the component level. The auxiliary propulsive stage used consists of off-the-shelf hardware; and therefore, requires little development or qualification testing.

Avionics integration will commence with bench level tests, the most significant of which will involve verification of compliance with TEMPEST requirements. Integrated tests with Orbiter avionics will be accomplished at the Shuttle Avionics Integration Laboratory (SAIL) facility at JSC in Houston, Texas.

The first flight Centaur IUS and its flight pallet will be erected at existing Centaur Launch Complex 36 at ETR for a series of vehicle level development and prelaunch validation tests. Complex 36A will be modified to provide for cryo tanking test and checkout of Centaur IUS vehicles. These launch readiness tests will be conducted at Complex 36A on the first five flight articles. Subsequent vehicles will not require a cryo tanking as a part of launch readiness.

5.4.2 REUSABLE CENTAUR IUS TESTING. The LH_2 tank enlargement to 14.5-foot OD for Reusable Centaur programs is of sufficient magnitude to warrant structural requalification. A dedicated 28- by 14.5-foot OD structural test vehicle (STV) is required. This article will include the new design graphite/epoxy adapters and equipment module. Additional testing of the 22-foot configuration will not be required. The flight support cradle/adapter assembly is a new design that will require structural testing.

To requalify the RL10A-3-3 main engines for RC IUS missions, a 15-month test program will be conducted by PWA utilizing two engines assembled from existing surplus NASA-owned development hardware. PWA's E-6 single engine test stand at West Palm Beach will be utilized for these tests which will involve a total of 120 hot firings.

To provide high confidence in the predicted vibration levels to be utilized as RC IUS avionics qualification criteria it is desirable to test with the new graphite/epoxy equipment module. The test article will be the structural qualification Equipment Module with mass-simulated electronic components attached.

Avionics integration will commence with bench level tests; the most significant of which will involve verification of compliance with TEMPEST requirements. Integrated tests with Orbiter avionics will be accomplished at the Shuttle Avionics Integration Laboratory (SAIL) facility at JSC in Houston, Texas.

The first flight Reusable Centaur IUS and its flight ASE will be erected at existing Centaur Launch Complex 36 at ETR for a series of vehicle level development and prelaunch validation tests. Complex 36A will be modified to provide for cryo tanking test and checkout of Centaur IUS vehicles. It is planned that following these special tests each Centaur IUS/Flight Support Assembly will be subjected to the standard Centaur launch readiness tests.

5.5 PRODUCTION PLAN

All structural assembly of the Expendable or Reusable IUS stages and fabrication of subsystems and support equipment will be done within existing Convair, San Diego facilities. Figure 5-3 depicts these facilities for the Expendable version.

The manufacturing approach for the Convair Centaur Interim Upper Stage (IUS) is based on a plan of established production sequences, tools, and facilities for expedient manufacture during development which needs only minimum revision with new component tooling to satisfy the IUS production requirements.

The manufacturing sequence for a basic Expendable Centaur IUS vehicle is essentially the same as Centaur D-1A or D-1T. Because of the structural similarity and quantities produced, either model will blend into Centaur D-1A or D-1T production flow with minimal interruption or expense.

The major tool requirements within the existing Centaur family considered for IUS application are exemplified in Figure 5-4. Fabrication of graphite/epoxy (G/E) body structure elements pertaining to the stub adapter, equipment module, spacecraft ring, aft skirt, and deployment adapter (ASE) for the reusable version will be provided new tooling.

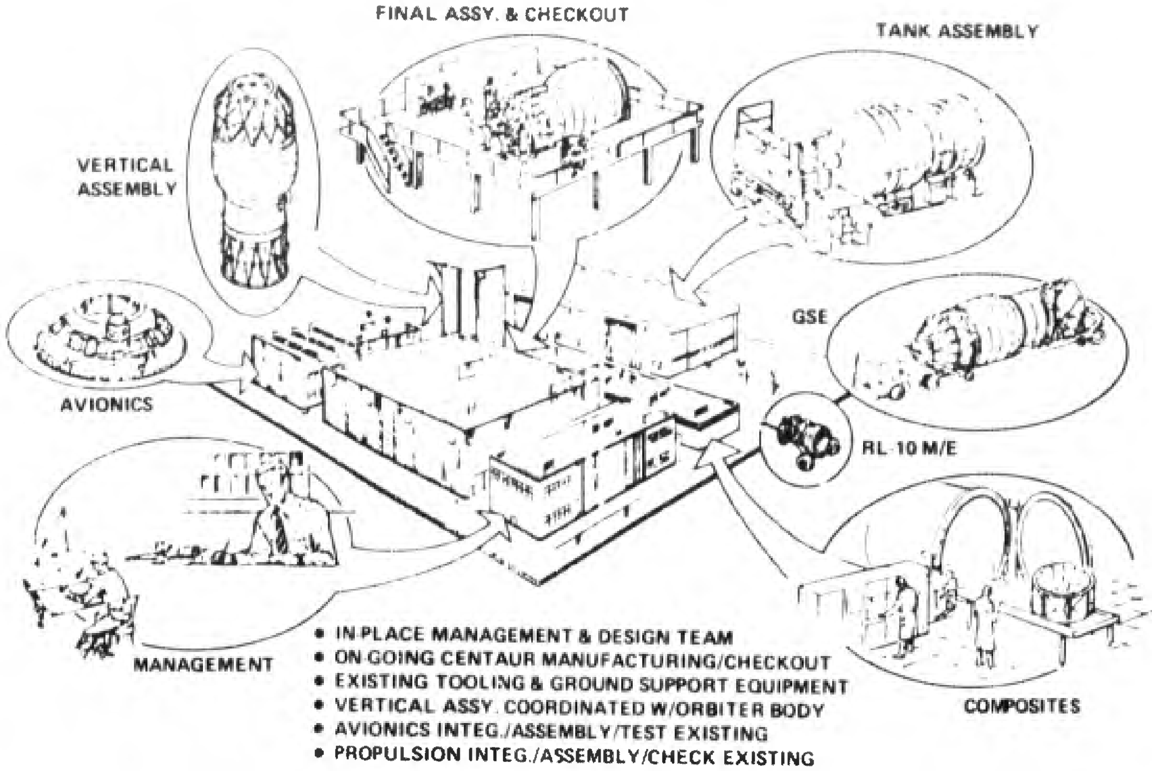


Figure 5-3. Available Facilities – Expendable Centaur IUS

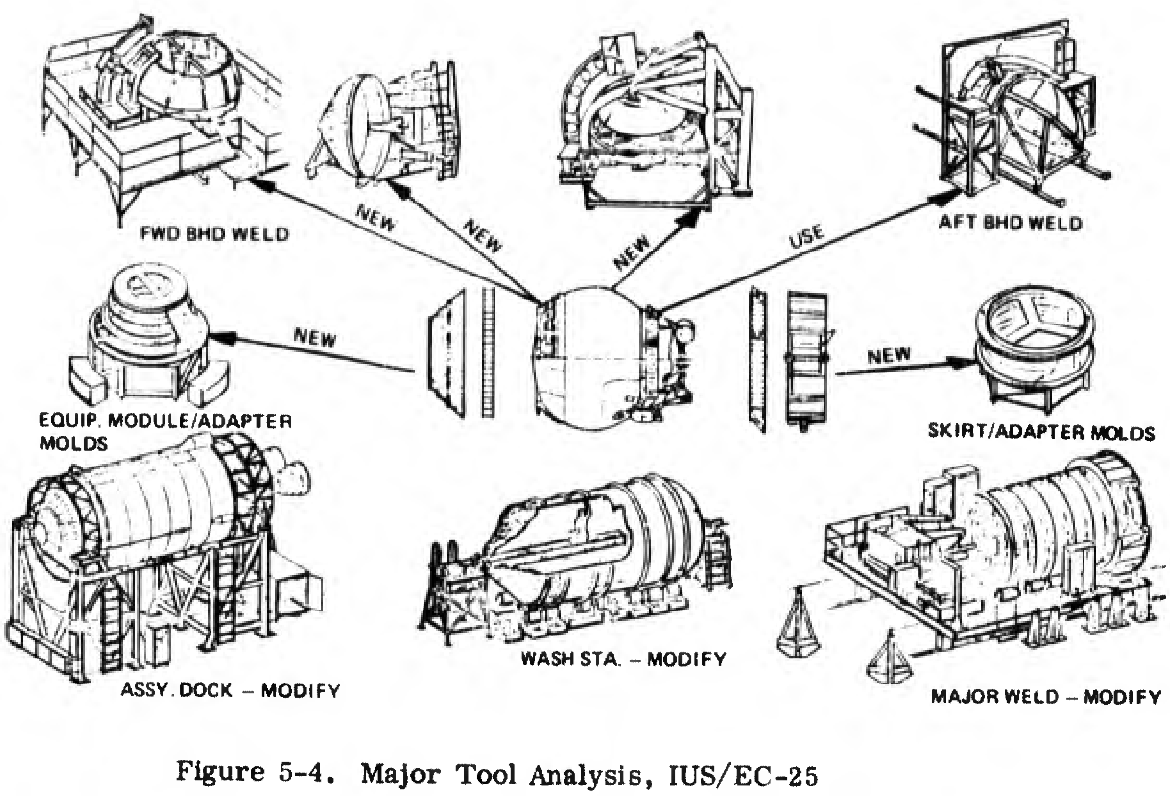


Figure 5-4. Major Tool Analysis, IUS/EC-25

5.6 REAL PROPERTIES FACILITIES PLAN

Existing real property will be utilized to produce the proposed IUS vehicles. The following facilities will be used:

1. General Dynamics Convair Division plants and test sites located in San Diego, California, for design, test, and manufacture.
2. Shuttle Avionics Integration Laboratory (SAIL) facility at JSC in Houston, Texas, for avionics integration tests.
3. MSFC S-2 structural test facility at Huntsville, Alabama, for all primary stage structural requalification tests.
4. ETR complexes 36A and 39 plus supporting facilities as specified in the Operations Plan.

Except for minor modifications of some ETR facilities, no additions or modifications are planned.

5.7 TRANSPORTATION PLAN

Air transport of the 10-foot-diameter expendable vehicles will be by C-5A Galaxy using the same equipment and procedures now in use for transport of Centaur D-1A and D-1T vehicles from Miramar NAS (five miles from the factory) to the Skid Strip at Cape Canaveral Air Force Station (CCAFS), ETR.

C-5A aircraft do not have sufficient cargo compartment vertical clearance (13-feet, 6- inches) to permit transport of the 14-foot, 6-inch-diameter vehicles. The RC IUS vehicles will, therefore, be transported by the Pregnant Guppy cargo aircraft now owned by American Jet Airways.

5.8 INTEGRATED SUPPORT PLAN

Convair will provide total system IUS operation and support consistent with the MIL-STD-1538 concept. Experienced launch, maintenance, and support personnel and management systems with associated spares and material currently performing Titan/Centaur and Atlas/Centaur operations and support can be ready and available for transition to IUS.

SECTION 6

CONCLUSIONS

The criteria of low risk and minimum cost are satisfied by the Centaur in the best possible way. High performance is the best insurance to protect against current and future changes in space requirements.

The paragraphs below summarize the significant features of Centaur IUS as they relate to these areas and benefits resulting from selecting Centaur as the IUS. These benefits are valid on a 3 to 4 year IUS program and are further enhanced if the national requirements for longer operational time periods are considered.

Centaur's inherent high performance is the basis for assuring a low risk IUS program while providing significant benefits in the following areas:

- HIGH PERFORMANCE ALLOWS LOW RISK DESIGN APPROACH

  A low risk design approach has been followed which minimizes changes from the D-1T Centaur. For each program Centaur's high performance enables configuration candidates to be defined without resorting to high risk weight reductions and/or major engine modifications, and allows incorporation of all necessary features to provide a safe man-rated vehicle. This performance margin will also permit increased redundancy to further enhance reliability. The fact that the Shuttle program has committed to accommodating a cryogenic upper stage means that most of the interfaces required by Centaur IUS are already planned and being incorporated into Shuttle.

- SIMPLE, FLEXIBLE OPERATIONS ARE INHERENT

  Specific examples of potential operational advantages due to the outstanding performance capability of the Centaur are:

  a. Simplified ground and flight operations through the use of a single stage for all DOD missions (no kick stage). A simple flight proven spin-stabilized kick stage is used for a few high energy missions with the Expendable Centaur.

  b. Accommodation of multiple spacecraft to reduce IUS and Shuttle flights.

  c. Delivery of spacecraft to polar orbits from ETR as a backup from WTR.

d. Spacecraft placement into final orbital positions to simplify spacecraft design and cost.

e. The inherent capability to accommodate reusability, spacecraft growth, and potential spacecraft servicing.

- PERFORMANCE MARGIN MINIMIZES TRANSITION RISK

Transition from expendable launch vehicles to the Shuttle is an important and complex subject. There are many unknowns associated with integrating current and future spacecraft into the Shuttle all of which have potential impact on spacecraft volume, weight, schedule, and cost. Recent studies have indicated that potential spacecraft weight increases of 30 percent are possible due to lateral loads encountered at SRM ignition, Shuttle environmental and safety requirements, and to taking advantage of Shuttle capability. Since T-IIIE Centaur has the highest performance in the present expendable launch vehicle stable, it is a logical candidate for consolidation of appropriate DOD missions during transition and STS backup. This will guarantee uninterrupted capability for important national security missions, and the resulting performance margins will eliminate risk due to Shuttle related payload growth and avoid costly weight reduction modifications to the spacecraft.

- MINIMUM CHANGES PROVIDE LOW COST SOLUTIONS

The basic stages proposed are derived from the D-1T Centaur, presently in production, with minimum modifications for use with the Shuttle. The inherent high performance obviates the need for new costly auxiliary propulsion systems, major hardware revisions, or major propulsion modifications, thereby minimizing RDT&E funding requirements. In addition, this high performance, coupled with the use of clean cryogenic propellants, provides the basis for reusability with the associated reduction in life-cycle cost. Life-cycle cost becomes a very important criteria if the Space Tug is delayed as now predicted, and the IUS operational span becomes greater than three to four years.

We found that use of the multiple payload capability of the high performance Centaur candidates provided a greater reduction in Shuttle flights than tandem staging of either the Centaur or lower performance shorter stages. This high multiple payload capability of the Centaur as an IUS would provide the government with a hedge against increased Shuttle operations costs.

Many of the Centaur IUS tasks/costs have a direct relationship to similar tasks/costs experienced on the recently completed Centaur D-1T development/production which provides high confidence in our estimated resource requirements.

Centaur has the performance and mission flexibility to accomplish both the DOD and National missions at low risk in a simple operational mode at the lowest cost with a further advantage of good growth potential, and offers a capability which will result in many years of successful operation.