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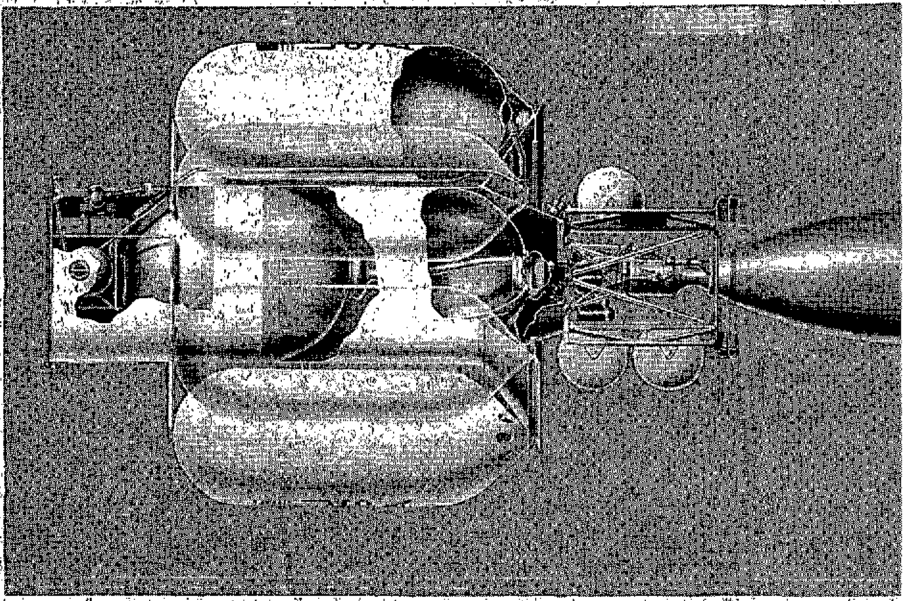
REUSABLE AGENA STUDY

FINAL REPORT



TECHNICAL

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LOCKHEED MISSILES & SPACE COMPANY, INC.
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REUSABLE AGENA STUDY
FINAL REPORT – TECHNICAL

Prepared for
National Aeronautics and Space Administration
Marshall Space Flight Center
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Contract No. NAS8-29952

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ABSTRACT

This study is concerned with the application of the existing Agena vehicle as a reusable upper stage for the Space Shuttle. The primary objective of the study is to define those changes to the Agena required for it to function in the reusable mode in the 100 percent capture of the NASA-DoD mission model. This 100 percent capture is achieved without use of kick motors or stages by simply increasing the Agena propellant load by using optional strap-on-tanks. The required Shuttle support equipment, launch and flight operations techniques, development program, and cost package are also defined.

FOREWORD

This final report of the Reusable Agena Study was prepared for the National Aeronautics and Space Administration George C. Marshall Space Flight Center by Lockheed Missiles & Space Company, Inc., in accordance with Contract NAS8-29952.

The study effort described herein was conducted under the direction of National Aeronautics and Space Administration Study Manager, Mr. James B. Brewer. The report was prepared by the Lockheed Missiles & Space Company, Inc., Sunnyvale, California under the direction of Mr. Warren K. Carter, LMSC Study Manager, assisted by Mr. W. Mimnaugh, Mr. D. A. Douglass, Mr. J. E. Piper, Mr. C. V. Hopkins and Mr. S. S. Sagawa. The study results were developed during the period from June 1973, through November 1973, and the final report was distributed in January 1974.

This report consists of two volumes:

Volume I	Executive Summary
Volume II	Technical Report

References have been made as appropriate to the more detailed data contained in the Data Dump documentation furnished to the National Aeronautics and Space Administration on September 25, 1973.

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ABBREVIATIONS AND ACRONYMS

ACPS	Attitude Control Propulsion Subsystem
ACS	Attitude Control System
A/D	Analog to Digital
ADEPS	Automated Computer-Controlled Data Evaluation and Processing System
AFSCF	Air Force Satellite Control Facility
AGE	Aerospace Ground Equipment
AGS	Ascent Guidance System
AKM	Apogee Kick Motor
Al	Aluminum
ASP	Agena Service Panel
AU	Astronomical Unit
BAC	Bell Aerosystems Company
BBA	Baseband Assembly
BUSS	Backup Stabilization System
C&C	Command and Control
CBSS	Cargo Bay Support System
CDR	Contract Design Review
CEA	Control Electronics Assembly
C of F	Construction of Facilities
CG	Center of Gravity
CIV	Computer Interface Unit
CKAFS	Cape Kennedy Air Force Station
CPU	Central Processor Unit
CRT	Cathode Ray Tube
D/A	Digital to Analog
DDT&E	Design, Development, Test, and Evaluation
DM&I	Data Management and Instrumentation
DMS	Data Management System

EDB	External Data Bus
EPS&D	Electrical Power Supply and Distribution
ERTS	Earth Resources Technology Satellite
ETR	Eastern Test Range
FCE	Flight Control Electronics
FOSR	Flexible Optical Surface Reflector
FPR	Flight Performance Reserve
FV	Fill Valve
GC	Guidance Computer
GFE	Government Furnished Equipment
GN&C	Guidance Navigation and Control
GSE	Ground Support Equipment
HDA	High Density Acid
HPR	Hot Pump Restart
HSA	Horizon Sensor Assembly
IDB	Internal Data Bus
IGS	Inertial Guidance System
IMU	Inertial Measurement Unit
IOC	Initial Operational Capability
IOP	Input/Output Processor
IOU	Input-Output Unit
IRFNA	Inhibited Red Fuming Nitric Acid
ISA	Inertial Sensor Assembly
I_{sp}	Specific Impulse
KSC	Kennedy Space Center
LMSC	Lockheed Missiles & Space Company, Inc.
LPS	Launch Processing System
LSV	Latching Solenoid Valve
MCC	Mission Control Complex
MCO	Maintenance and Checkout
MDM	Multiplexer/Demultiplexer
MEU	Main Electral Umbilical
MLI	Multilayer Insulation

MMH	Monomethyl Hydrazine
MPR	Main Power Relay
MS	Mission Specialist
MSS	Mission Specialist's Station
MU	Memory Unit
NCC	Network Control Center
NDT	Non-Destructive Test
N_2O_4	(or NTO) Nitrogen Tetroxide
OMS	Orbital Maneuvering System
OX	Oxidizer
Pc	Chamber Pressure
PCB	Printed Circuit Board
PCM	Pulse Code Modulation
PCU	Power Control Unit
PDR	Preliminary Design Review
PIV	Propellant Isolation Valve
P/L	Payload
PR	Pressure Regulator
PSS	Payload Specialist's Station
PTV	Propulsion Test Vehicle
QA	Quality Assurance
QD	Quick Disconnect
QTV	Qualification Test Vehicle
RCS	Reaction Control System
RDM	Remote Decoder-Multiplexer
REM	Reaction Engine Module
RF	Radio Frequency
R/R	Replacement/Refurbishment
RSS	Root Sum Square
RTLS	Return to Launch Site
RTS	Remote Tracking Station
SAM(S)	Shuttle Attached Manipulator (System)
S/C	Spacecraft

SCC	Stress Corrosion Cracking
SCO	Subcarrier Oscillator
SCS	Satellite Control Section (LMSC hardware)
SGLS	Space Ground Link System
SM	Service Module
SO	Silicone Oil
SOT	Strap-on Tank
SPS	Secondary Propulsion System
SRV	Space Repairable Unit
STA	Star Tracker Assembly or Structural Test Article
STDN	Space Tracking and Data Network
SV	Solenoid Valve
TCI	Thrust Chamber Ignition
TCS	Thermal Control Subsystem
TLM	Telemeter
TVC	Thrust Vector Control
UDMH	Unsymmetrical Dimethylhydrazine
USB	Unified S Band
VAB	Vehicle Assembly Building
VAC	Vacuum
VAFB	Vandenberg Air Force Base
VDC	Volts D C
VV	Vent Valve
WBS	Work Breakdown Structure
WTR	Western Test Range
ϵ	Expansion Ratio or Emissivity
ΔP	Delta Pressure
ΔV	Delta Velocity

Section 1
INTRODUCTION

The Reusable Agena Study was conducted by the Lockheed Missiles and Space Company, Inc., for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center (NASA/MSFC) under Contract NAS8-29952. It represents a comprehensive study effort to develop configuration, performance, and cost and schedule data for a Reusable Agena for consideration as an interim Space Tug vehicle.

1.1 BACKGROUND AND SCOPE

The Space Tug is a propulsive stage that is carried into low earth orbit as an upper stage for the Space Shuttle. The primary function of this Space Tug is to extend the Space Shuttle operating capability to include higher altitude orbits, geosynchronous orbits, and into interplanetary energy levels. This Reusable Agena Study is intended to define a reusable Shuttle/Agena Upper Stage configuration with low development and operating costs, high performance capability, and to be retrievable for return to earth for refurbishment and reuse.

Work performed on this Reusable Agena Study was based upon operational Agena data accumulated during the more than 300 Agena flights to date. Expendable Agena Upper Stage data, developed during two previous contracts (NAS9-11949 and NAS3-16787), were also used as baseline data.

The recommended Shuttle/Agena Upper Stage configuration described in this document was selected with consideration of mission accomplishment capability, low design, development, test and evaluation (DDT&E) cost, low operating cost, low risk, high reliability, and safety. The Agena Upper Stage configuration requires modification of the existing Agena only in the areas of propulsion and structures. Maximum use was made of existing, proven hardware to minimize cost and risk.

The required Shuttle interface hardware and operational procedures were also defined, along with schedules and programmatic data. Safety guidelines were established for both launch base and flight activities.

1.2 STUDY OBJECTIVES

The specific objective of this Reusable Agena Study was to establish a realistic Shuttle/Agena Upper Stage configuration that meets NASA and Department of Defense (DoD) mission requirements for an interim Space Tug. This configuration has been documented in terms of configuration definition, performance, Shuttle interface, schedules, and cost data.

1.3 STUDY GUIDELINES

The following guidelines were used in the conduct of this study.

- The Agena Upper Stage will be designed to be returned to earth in the Shuttle for reuse. Refurbishment will be accomplished with minimum cost and ground turnaround time. This requirement does not preclude using the Agena Upper Stage in the expendable mode.
- The Agena Upper Stage will be sized in accordance with Shuttle payload capabilities and NASA/DoD mission requirements.
- Dimensional allowances will be within Shuttle cargo bay specifications including dynamic envelope limits.
- The Agena Upper Stage will meet the necessary safety criteria incident to being carried in and operating in the near vicinity of the manned Shuttle.
- The Agena Upper Stage will be capable of being safely loaded with propellants and gases in the Shuttle cargo bay on-pad, on-pad outside of the Shuttle, or at a remote loading site.
- The Agena Upper Stage will be capable of safely venting any overpressurized tanks.
- All primary and secondary structural components, subject to critical load conditions while in the cargo bay, will be designed to man-rated safety factors. For structural components subject to critical load factors outside of the cargo bay, unmanned safety factors will be followed. MSFC Handbook 505 will be used for more specific structural guidelines.
- The Agena Upper Stage communication system will be compatible with available NASA and DoD ground and space networks.

- The Shuttle/Agena Upper Stage will not exceed 35 feet (10.67 m) in length.
- The mission completion reliability design goal will be 0.97 for all mission phases.
- The Agena Upper Stage will be passive cooperative during Shuttle/Agena terminal rendezvous operations. The Shuttle will perform the terminal rendezvous, docking and retrieval of the Agena Upper Stage.
- After retrieval, the required Shuttle/Agena interfaces will be established.
- Care will be taken to avoid contaminating either the payload or the Shuttle.
- The Shuttle has the capability to provide a navigation (state vector) update prior to deployment.
- The Agena Upper Stage will use a Bell Aerospace Company (BAC) 8096 earth-storable main engine or derivatives thereof.
- Consideration will be given to increased propellant options, kick stages, and/or tandem stages.
- The baseline mission will be delivery of a payload to geosynchronous altitude and return to the Shuttle orbit without a payload.
- A no micrometeoroid penetration probability if 0.995 will be a design goal.
- All costs will be expressed in CY 1973 dollars.
- Consideration will be given to a building block concept.

1.4 STUDY PLAN

Data from current Agena programs, and results of the Study of the Compatibility of the Agena Upper Stage with Space Shuttle (Contract NAS3-16787) and Shuttle/Agena Study (Contract NAS9-11949) formed the starting point for this present Reusable Agena Study. Initial study inputs also included the mission model provided by NASA/MSFC, Shuttle payload accommodations document, overall Tug system/subsystem design requirements, and data from related study efforts such as Tug Operations and Payload Support Study (TOPSS), Shuttle Orbital Applications Requirements (SOAR), Payload Effects, Ground Operations, and BAC 8096 Engine Study.

The two major phases of the study effort were configuration design and program definition. The overall technical approach to accomplishing these two phases is illustrated in Fig. 1-1. In early July 1973,direction was received to consider a building block concept that would provide configurations that best fit the needs of each user without a lower performance user having to assume the additional cost of the higher performance stage requirements.

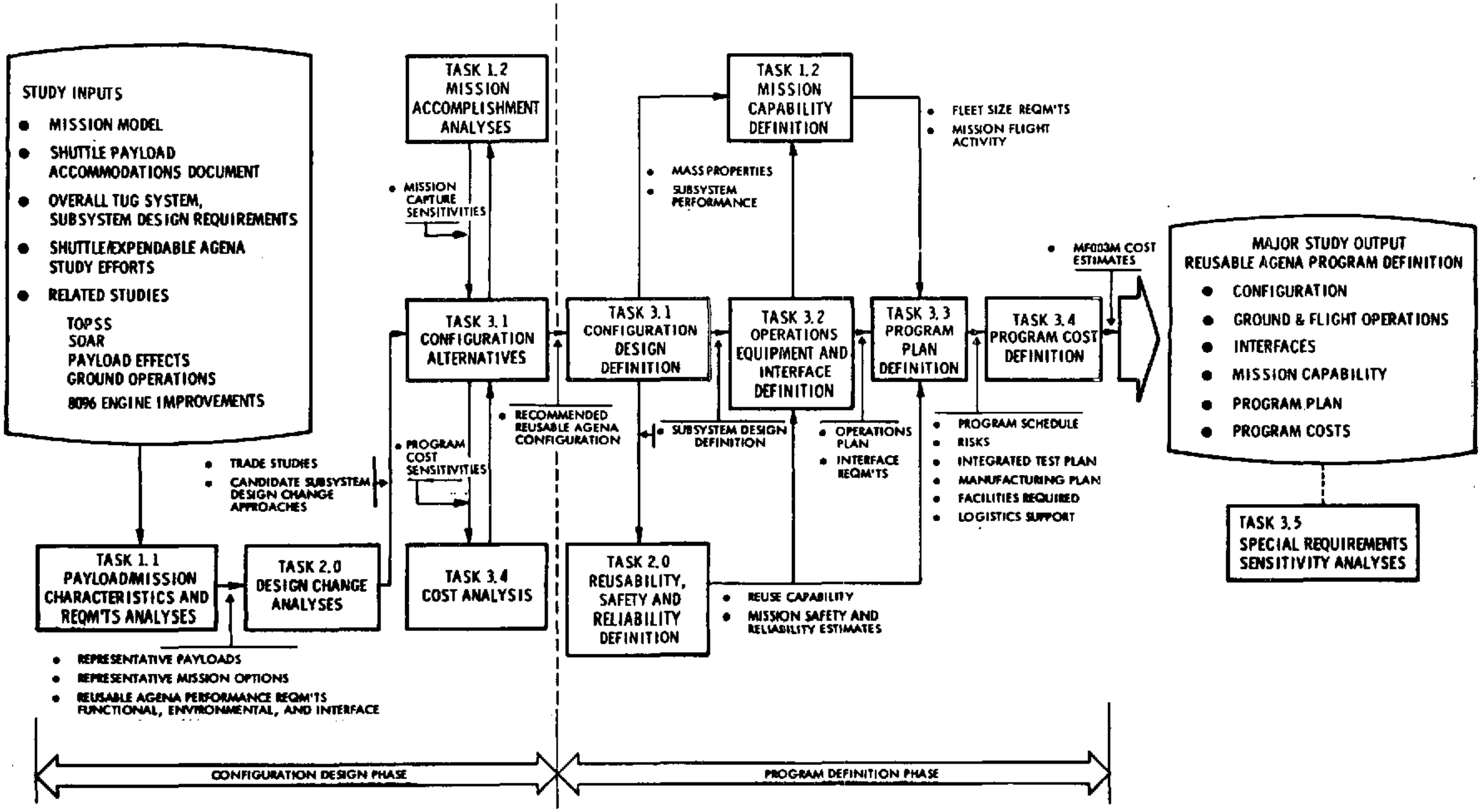

Fig. 1-1 Overall Technical Approach

The objectives of the first task, Mission Requirements/Objectives Analysis were to: (1) define functional, interface, and environmental requirements that define the envelope of required Shuttle/Agena Upper Stage performance at both the component/subsystem and system levels, and (2) evaluate the capabilities of candidate Agena Upper Stage configurations to accomplish the mission model.

The second task, Design Change Analysis, involves three steps: (1) definition of the Agena subsystem changes resulting from an increased propellant capacity, higher performance main engine, and Shuttle compatibility, (2) definition of subsystem design concepts, and (3) assessment of these concepts for reusability, safety, and reliability.

The third task, Shuttle/Agena Upper Stage Definition, was concerned with the preparation of a program definition of the selected Agena Upper Stage configuration along with a complete cost estimate.

The results of these three tasks have been documented in this final report.

1.5 RECOMMENDATIONS FOR ADDITIONAL WORK

During the course of this study several areas were identified as being in need of additional work as follows:

Payload Interface Effects. The presence of at least one payload in the cargo bay, along with the Agena, will impact the Shuttle/Agena interface. Identification of these affected interface areas and definition of the interface effects on the Agena is needed. Some typical examples are: (1) payload predeployment checkout needs may impact time sequence selected for Agena state vector update and planned ground communication time spans, or (2) required payload statusing prior to initiation of Agena first burn may impact time span prior to first Agena burn.

Launch Base Operations. Several launch base operations areas need further definition/clarification before initial definition of Agena launch base operations can be completed. The availability and capability of Shuttle related propellant loading/flushing/handling facilities is a key item. Definition of Shuttle facilities along with the capability for processing and handling the Agena is also needed. Shuttle event/flow charts tied to GSE, facilities, and time spans will be of great assistance. Pad payload changeout procedures, GSE, and facility definition is also needed.

Orbital Deployment. On-orbit deployment needs much greater definition. Shuttle deployment limitations in terms of ground position, altitude, orbital position, geocentric positions, orbit times, sun-lines, earth shadow effects, etc., need definition. The deployment and post-deployment sequence of events including Shuttle limitations are needed. In addition to the above general information, the following specific questions need to be answered:

- What are Shuttle deployment limitations as a function of inclination and ground position?
- What is range-time sequence history during Shuttle-Tug separation process?
- What are Shuttle related safety requirements during deployment?
- What are visual, line-of-sight limits and capability during deployment?
- What are relative attitude requirements between Shuttle and Agena as related to antenna pattern and RF line-of-sights limits?
- What are reasonable, average response lag times between detection of an Agena unplanned motion and transmittal of a countermeasure command to the Agena?
- What is required range from Shuttle for Agena first burn?

Agena Retrieval. The retrieval operation involves several interface areas that need further definition such as: (1) the time history of the relative motion and attitude between the Shuttle and Agena, (2) the time history of the range between the Shuttle and Agena versus Shuttle sequence of events, (3) the exact time history sequence of events associated with Shuttle attached manipulator (SAM) attachment to the Agena, (4) the visual, line-of-sight, time history during SAM attachment to the Agena and (5) the safety-related Agena functions for which Shuttle real-time RF link control is needed.

Shuttle Attached Manipulator System (SAMS) Characteristics. SAMS characteristics and performance envelopes are critical design drivers for the Agena deployment and retrieval operation. Information is needed in the following areas:

- SAMS performance characteristics, tip speeds, acceleration/deceleration, dispersion, dispersion rates
- Mass effects on the above
- Dimensions, reach envelopes, motion restrictions
- Failure modes
- Safety features

Mission Specialist Station/Payload Specialist Station (MSS/PSS) Description. The Agena Service Panel can be an integral part of either the MSS or PSS. To avoid possible redundancy in caution and warning monitors and controls and deployment/retrieval monitors and controls, a detailed definition of the functions displayed and controlled by these two stations is needed.

The on-pad and ascent Agena status monitoring and emergency control of the Agena is dependent on the human factors characteristics of these two stations. Human factors data are needed to define these procedures.

Section 2
SUMMARY

2.1 INTRODUCTION

A summary of the work performed during the course of the study is presented in this section including a description of both a nominal Shuttle/Agena Upper Stage and an augmented dual string concept. More detailed information is contained in ref 2-1.

2.2 REQUIREMENTS AND GUIDELINES

The Shuttle/Agena Upper Stage concepts described in this report satisfy the NASA/ MSFC Tug system/subsystem design requirements (ref 2-2) for an interim evolved Tug concept. These requirements apply to the vehicle and its subsystems, ground and flight operations, Shuttle interfaces, safety and programmatic/cost data. Those applicable requirements and guidelines, considered as essential to the conduct of the study, are as follows:

- Maximum use will be made of existing or in-development components.
- A mission accomplishment reliability goal is 0.97.
- Weight figures reflect a 10 percent across-the-board contingency.
- Performance figures reflect a 1.7 percent flight performance reserve.
- The communications system will be fail operational/fail safe.
- Crash landing can be sustained with empty propellant tanks.
- The maximum payload weight is 6,000 pounds (2722 kg).
- The minimum synchronous equatorial payload capability for delivery and return of the empty stage to the Shuttle orbit is 3,500 pounds (1588 kg).
- The injection accuracy requirement applicable to return to the Shuttle orbit for retrieval will be: vertical ±15 nm (27.8 km) at zero inclination error, cross range ±0.15 degrees at zero altitude error, and maximum down range 69 nm (127.8 km).

- Fail safe for crew survival on all functions except primary structure and pressure vessels.
- Fail operational/fail safe for critical command and control circuitry and ACPS.

2.3 NOMINAL SHUTTLE/AGENA UPPER STAGE CONCEPT

Figure 2-1 depicts a Shuttle/Agena Upper Stage concept equipped with six strap-on propellant kit tanks (SOT). The core vehicle is the 5-foot (1.52 m) diameter Agena stage that is currently flying ascent and spacecraft type missions. For application as a Shuttle reusable Upper Stage, only the Agena propulsion subsystem requires modification. The other Agena subsystems, including avionics, will use existing or already in-development components for the most part, with functional subsystem design identical to that of existing Agena subsystems.

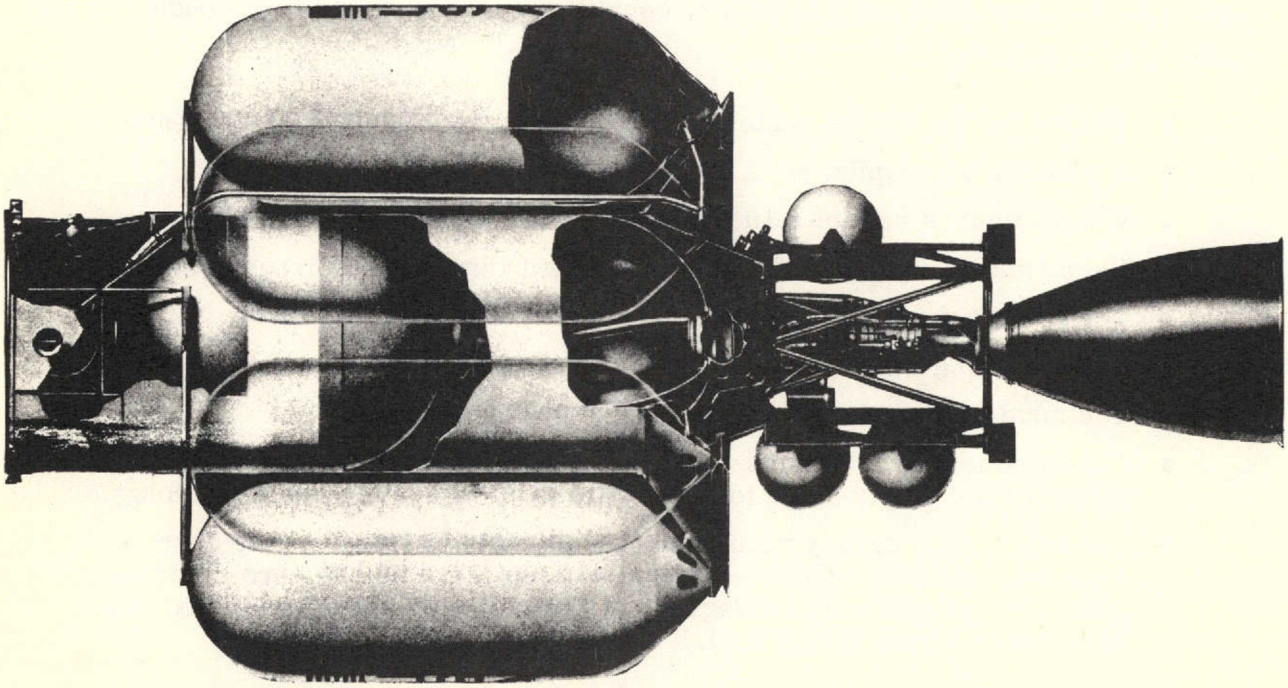

Fig. 2-1 Shuttle/Agena Upper Stage Concept, With Strap-on Tank Option

The Agena Upper Stage core vehicle operates in the reusable mode with or without the strap-on tank (SOT) option. For example, the core vehicle alone can fly all scheduled missions from the Western Test Range (WTR) in the fully reusable mode without the SOT option and without resorting to the use of kick motors or stages.

The addition of the six strap-on tanks, as depicted in Fig. 2-2, extends the propellant capacity of the core vehicle from a nominal 15,000 pounds (6800 kg) of high density acid (HDA) and monomethyl-hydrazine (MMH) to 56,000 pounds (25400 kg) of propellant.

The primary rocket engine used for the Shuttle/Agena Upper Stage is the Bell 8096L using HDA/MMH as the propellant. The Agena is currently flying with a Bell 8096 engine that uses HDA and unsymmetrical-dimethyl hydrazine (UDMH) as the propellant. The 8096L engine is a direct, low-cost modification of this engine (Fig. 2-3).

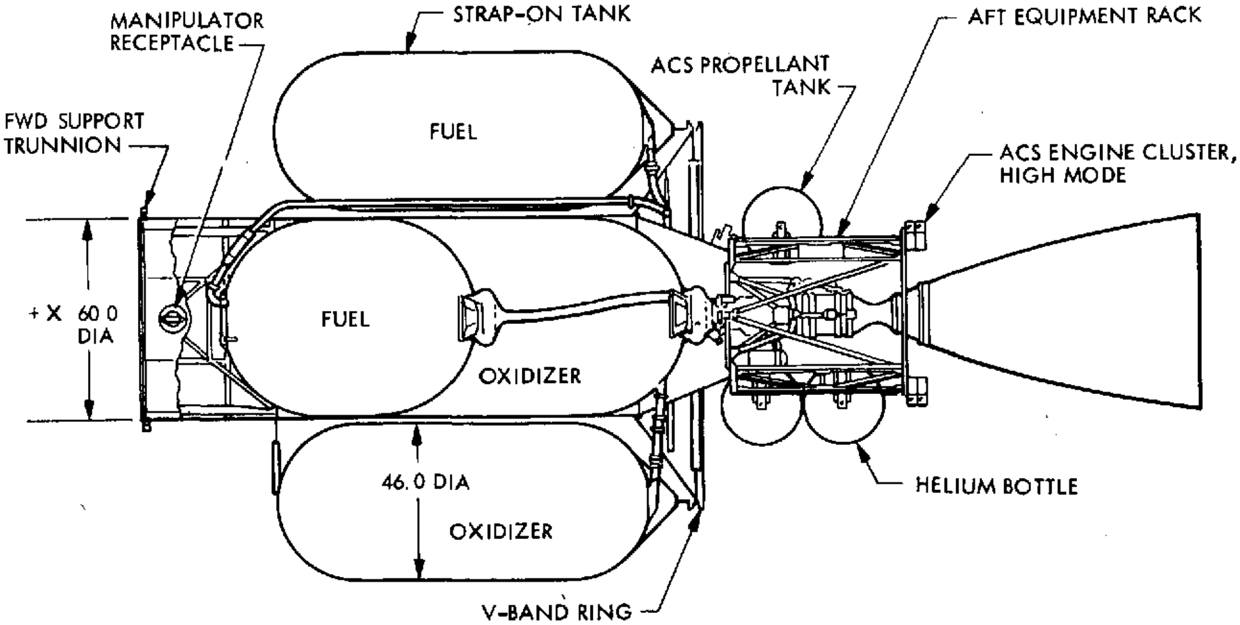

Fig. 2-2 Inboard Profile of Shuttle/Agena Upper Stage Concept With Strap-on Tank Option

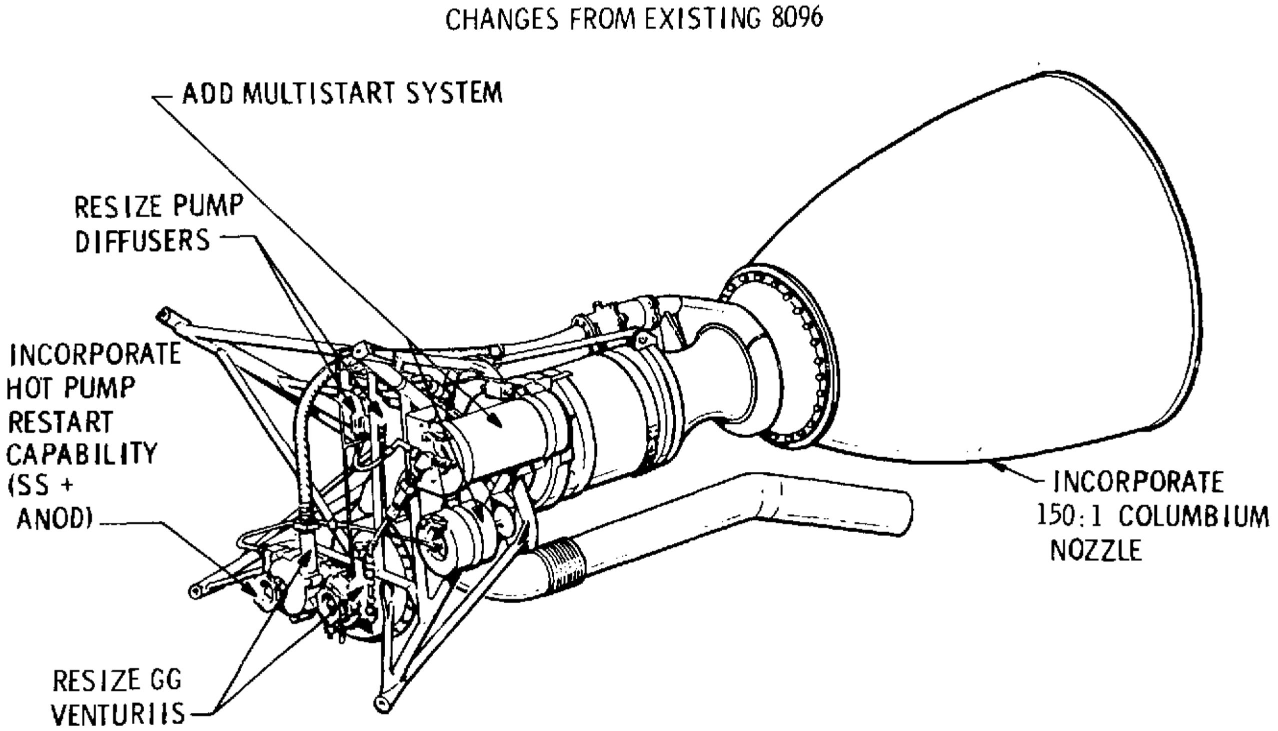

Fig. 2-3 Minimum Agena Engine Changes

The resized venturis achieve engine performance balance without changing the turbopump. Analyses and tests conducted to date on turbopump heat soakback indicate that some oxidizer (HDA) boiling will occur in the pump during periods of approximately 15 minutes to 3 hours after engine shutdown if a restart is initiated during this timespan. This boiling can be eliminated by changing the oxidizer pump bearing support to stainless steel and coating the oxidizer pump inlet housing with 10 mils (0.0254 cm) of anodized aluminum.

The current Agena engine uses solid grain start charges to provide options of 1, 2, or 3 engine starts. The flight-proven Gemini Agena Target Vehicle multiple-start tank system design is used on the Bell 8096L engine. These tanks are refilled, under pressure, during each engine burn and are ready for immediate restart for subsequent engine burns.

The avionics system is based mainly on existing or in-development components. A Nominal and an Augmented system are proposed as alternatives.

Nominal Avionics Concept. For guidance and navigation purposes a Honeywell inertial measurement unit and Autonetics DF224 computer are used in combination with two Ball Brothers CT401 star trackers. This combination permits an accurate navigation update prior to each engine burn and also permits attitude re-initialization after long coast periods or power-down phases. A tape recorder is used to record data essential to the refurbishment analysis following Agena retrieval and return to the launch base.

For safety purposes during the Agena retrieval phase redundant RCS thrusters and a separate, 2-hour hydrazine tank are provided along with backup attitude control electronics and sensors and a redundant communications system.

Augmented Avionics Concept. In the Augmented avionics concept, redundancy is provided in the form of dual Honeywell IMUs, a dual string computer, and a set of low-level RCS thrusters. A horizon sensor is added in combination with a single star tracker. The backup attitude control electronics and sensors can be omitted because the dual IMUs and dual string computer together with redundant thrusters provide backup attitude control capability.

The concept weight summary, Table 2-1 presents summary weights for both the Augmented Shuttle/Agena Upper Stage and the Nominal single string concept. The concept weights also reflect two contingency allowance approaches: one at a full, across-the-board 10 percent contingency allowance, and the second at a 2 percent contingency on existing hardware and 10 percent on new or modified hardware.

2.4 SHUTTLE INTERFACE DESCRIPTION

The two key Shuttle interface equipment items are the Agena Cargo Bay Support Structure (CBSS) and the Agena Service Panel (ASP). The CBSS is depicted in Fig. 2-4 for support of the Shuttle/Agena Upper Stage with strap-on-tank option.

Table 2-1

CONCEPT WEIGHT SUMMARY, lb (kg)

	Nominal Agena Upper Stage		Augmented Agena Upper Stage	
	2/10% Contingency	10% Contingency	2/10% Contingency	10% Contingency
Structure	1295	1295	1253	1253
Propulsion	768	768	774	774
Avionics	617	617	770	770
Thermal Control	57	57	57	57
Contingency	175	274	194	280
Dry Weight	2912 (1321)	3011 (1366)	3048 (1383)	3134 (1421)

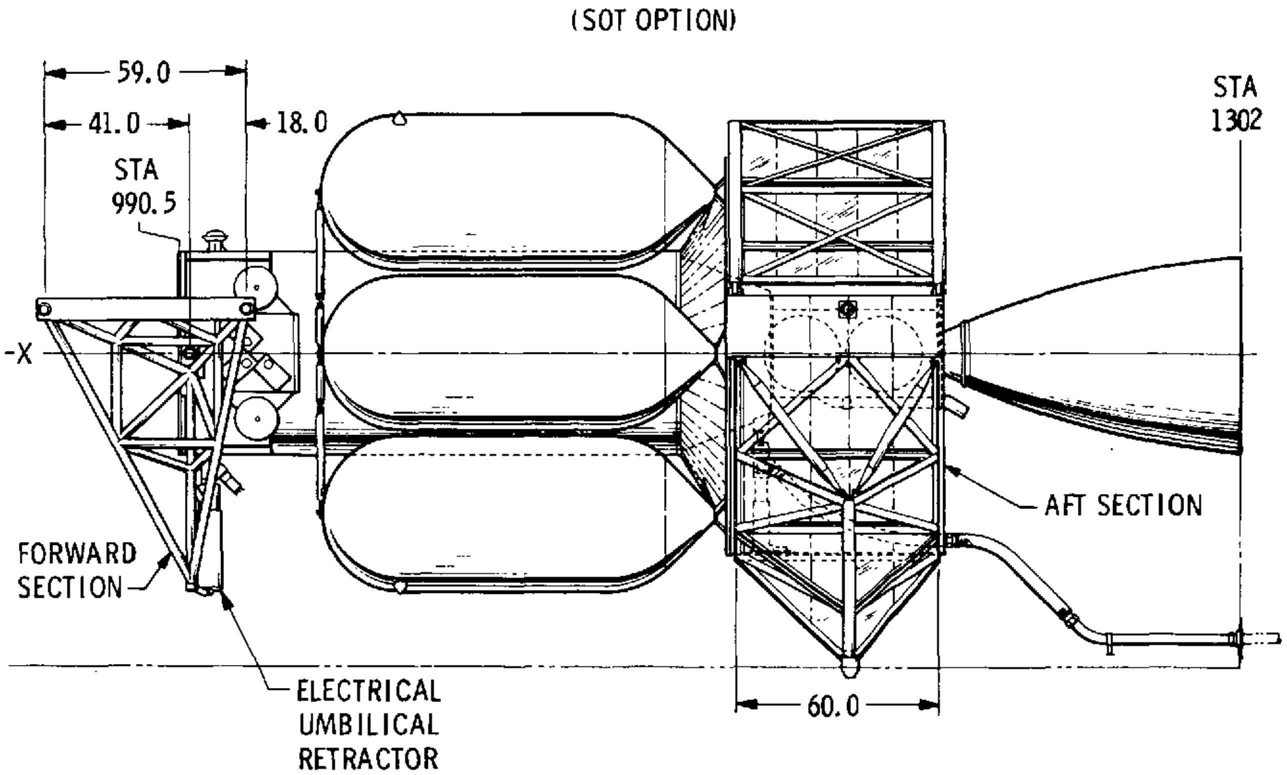

Fig. 2-4 Cargo Bay Support Structure

This structure consists of welded aluminum tubular members that can be easily and simply modified with a kit to support the 5-foot (1.52 m) diameter core vehicle alone (without the SOT option).

Release of the Agena Upper Stage from the support structure for deployment is accomplished by the following 4 steps (Fig. 2-5):

- Attach the Shuttle attached manipulator (SAM) to the Agena/payload combined manipulator attachment located on the Agena forward equipment rack.
- Retract the Agena emergency dump and electrical umbilical connection.
- Pull the support structure clamping latch and clamshell pins (Fig. 2-5).
- Open the clamshell doors.

Completion of these four steps permits immediate deployment of the Agena/payload by the SAM.

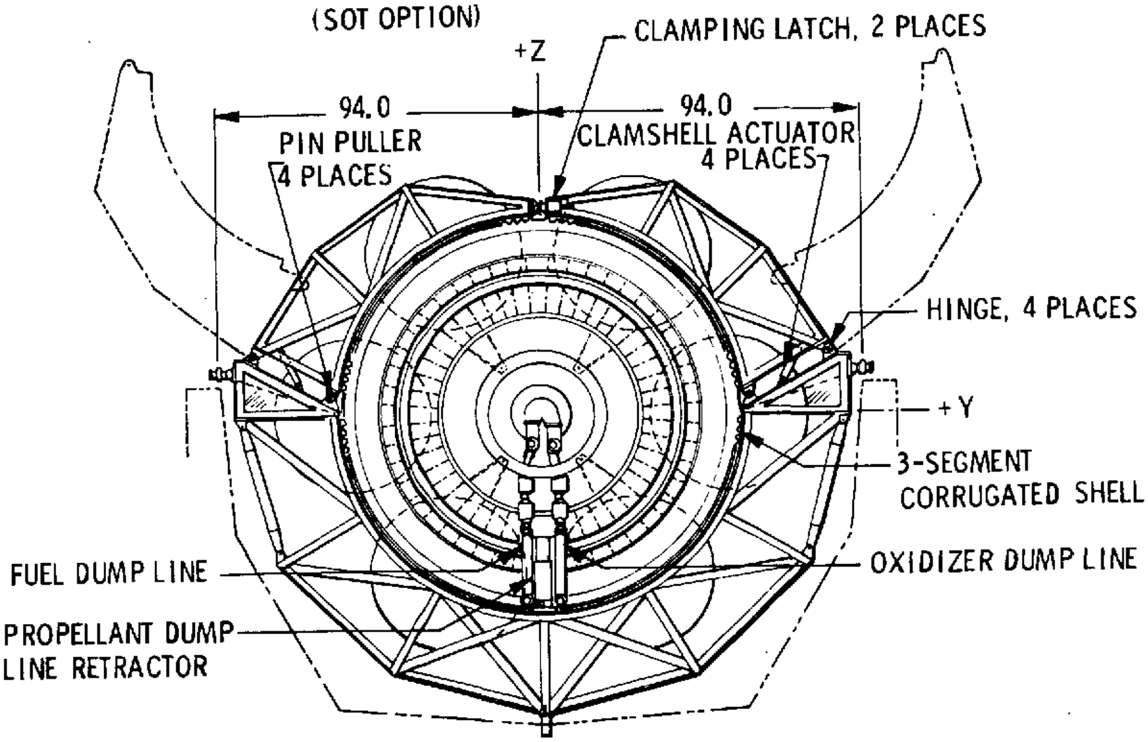

Fig. 2-5 Cargo Bay Support Structure

The Agena service panel (ASP) is used to monitor Agena and support equipment status, monitor safety parameters, perform orbital predeployment checkout, and to control emergency dump. This panel is located in the upper deck of the pilots compartment and could be placed in the mission specialist station (MSS) console.

Figure 2-6 presents a schematic diagram of the ASP interfaces and its functional relationship with the Agena and the MSS.

Note that if the ASP is installed in the MSS the ASP/MSS interface is eliminated.

Safety data from both the Agena and support equipment is monitored directly on the ASP fixed display panel (Fig. 2-7) with no intermediate signal processing required. Telemetry data must, of course, be decommutated and scaled by the ASP minicomputer before being displayed. A CRT is provided for the routine and emergency display of decommutated telemetry data parameters as a part of the predeployment, post-deployment, and preretrieval status and safety checks.

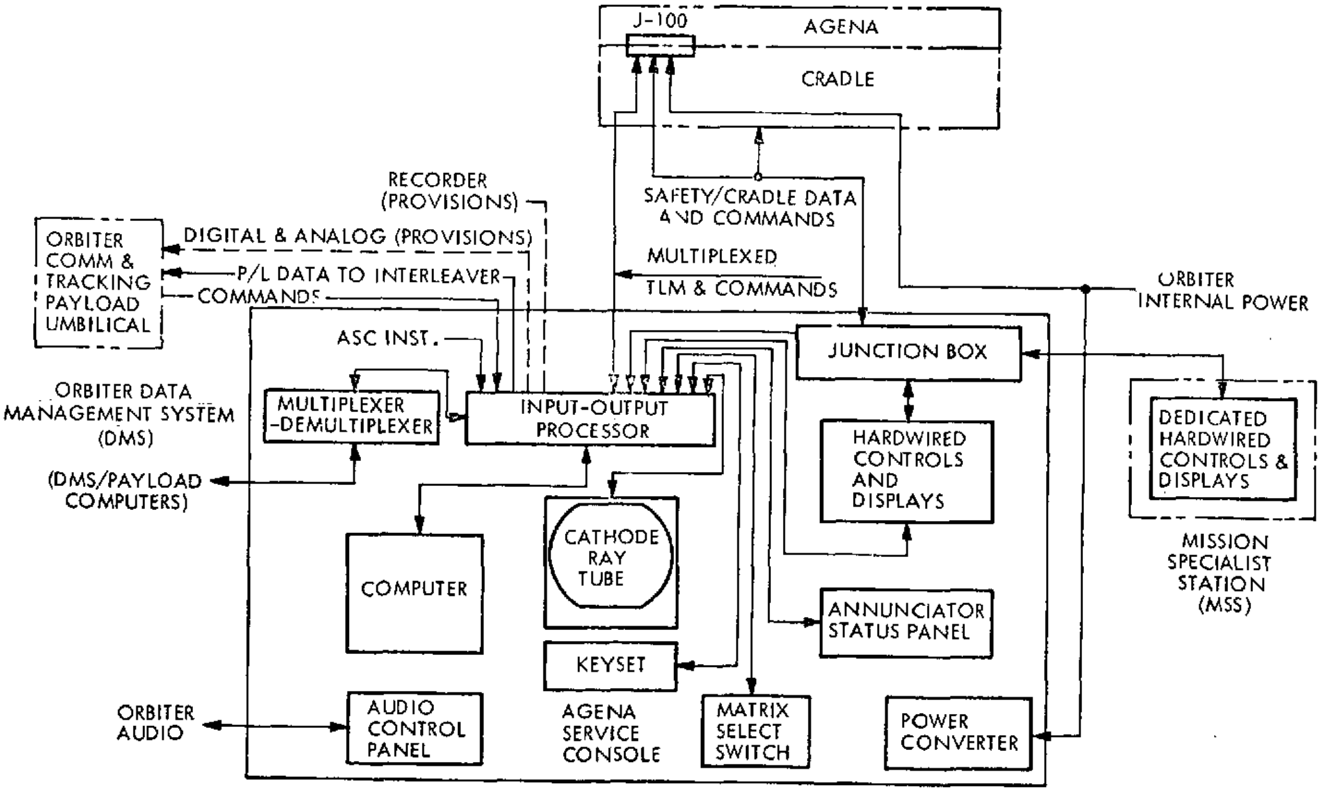

Fig. 2-6 Agena Service Panel Schematic

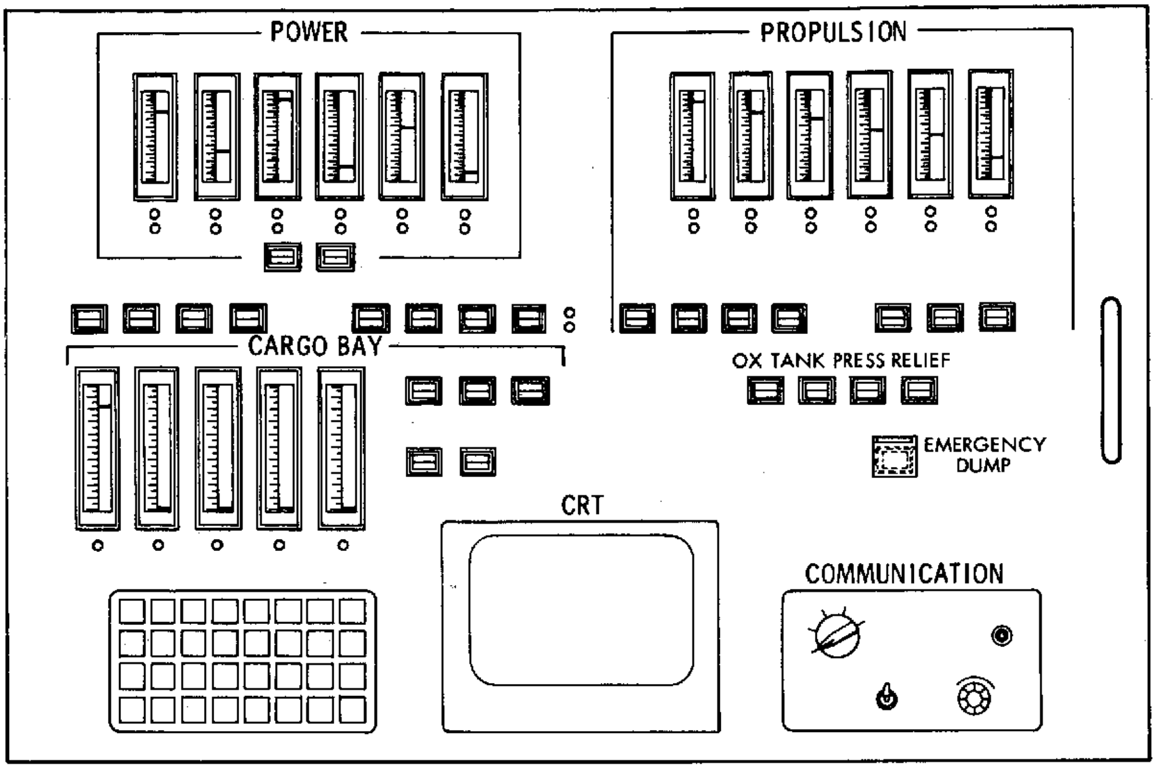

Fig. 2-7 Agena Service Panel

Table 2-2 presents a weight summary for all support equipment required by the Shuttle/Agena Upper Stage.

Table 2-2

SHUTTLE/AGENA UPPER STAGE SUPPORT EQUIPMENT WEIGHT (LB)

	Core Only	Core and Strap-on Tank Option
Agena/Payload Support Structure	1,240 lb	1140 lb
Dumpline Retractor	103	103
Dumplines and Fittings	17	17
Electrical Umbilical Retractor	56	56
Umbilical Cabling	30	30
Deployment Control and Instrumentation Wiring	7	7
Agena Service Panel	183	183
Total	1636 lb (742	1536 lb (695

2.5 GROUND OPERATIONS

One approach to Agena Upper Stage launch site processing is depicted in Fig. 2-8. This sequence is paced by Shuttle processing spans and events and as a consequence requires 110 hours for refurbishment following removal from the Shuttle cargo bay. The balance of the processing time, 136 hours, is used for servicing, systems test, and propellant loading activities that are common to both new Agena vehicles and those being refurbished.

The first phase in the processing of a retrieved Agena is performed in a propellant flushing facility, where the propellant tanks, plumbing, and rocket engine are flushed and cleaned. The SOTs, if used, are also cleaned here. After cleaning and reassembly these mechanical systems are recertified for flight through a combination of pressure, leak, and functional checks.

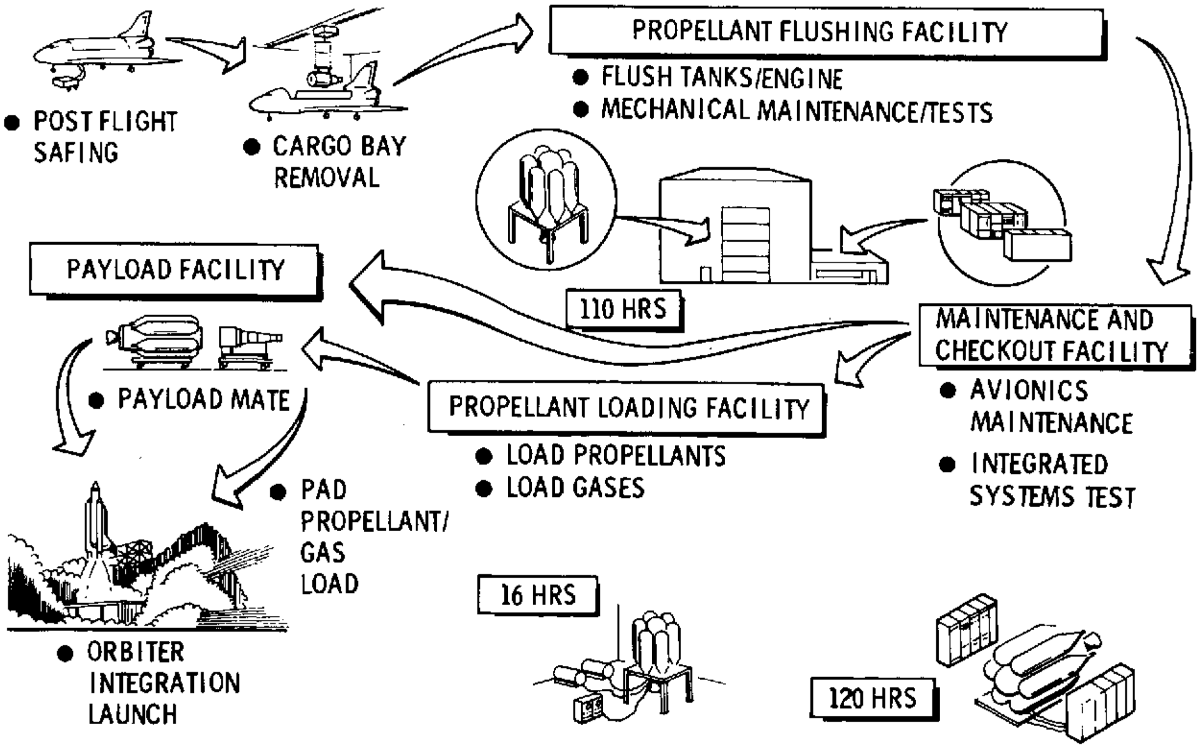

Fig. 2-8 Shuttle/Agena Upper Stage Ground Operations Summary

The Agena is then moved to a maintenance and checkout facility for performance of avionics system maintenance. An integrated system test is then conducted to certify flight readiness of the Agena Upper Stage.

The Agena Upper Stage can be loaded with propellants and high pressure gases either before or after mating with the Shuttle. However, the Agena/Shuttle interface will be simpler if loading is accomplished prior to mate. It is therefore proposed to load Agena propellants and gases either in the general pad area or at a remote facility.* The payload (from the Agena standpoint) can be mated before or after propellant loading, or even after the Agena is mated to the Shuttle.

A survey of facility and ground support equipment (GSE) has been completed at both launch bases. This survey identified: (1) existing GSE and facilities that could be used as-is for the Shuttle/Agena Upper Stage core and SOT propellant option, (2) GSE that required modification, and (3) new GSE requirements.

The survey shows that the requirements for both launch bases (Table 2-3) can be satisfied with existing facilities. Equipment rearrangement and relocation only is required for facility activation in support of Agena Upper Stage operations.

The SOT propellant option is not needed for reusable Agena Upper Stage operations at VAFB. It follows that GSE modifications or additions are minimal. The SOT propellant option is needed for reusable Agena operations from Cape Kennedy, therefore new Agena handling equipment and enlargement of the capacity of propellant conditioning, loading, and storage equipment is needed. Table 2-4 presents a summary of the GSE needs for both launch bases.

2.6 FLIGHT OPERATIONS

Figure 2-9 presents a summary of a typical Agena Upper Stage flight operation. During the mission the Agena requires state vector updating after deployment from the Shuttle and during the Agena mission.

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*The Shuttle hypergolic loading facility is a prime candidate for this Agena function.

Table 2-3

AGENA GROUND OPERATIONS FACILITY REQUIREMENTS

	Existing Facility Utilization	
	ETR	WTR
Propellant Flushing Facility High Bay Area – 50 Sq Ft • Floor Space – 3200 Sq Ft • 5-Ton Bridge Crane • 2 Vertical Stands Mechanical Check-out Area • Floor Space – 3200 Sq Ft • High Pressure Test Area • Hydraulic/Pneumatic Test Units	S/C Supt-Bldg M7-1210/12 KSC Hangar E CKAFS	Flushing – Bldg 1140 – VAFB Mech Maintenance Bldg 8310 - VAFB
Maintenance and Checkout Facility – MCO-60,000 Sq Ft Office – 8000 Sq Ft • Test Complex/Shops/5-Ton Crane • Storage/Receiving/Inspection • Communication/Data Processing • Administrative • Engineering • Records	VAB-Low Bay KSC Hangar S CKAFS	Bldg 8310 VAFB
Propellant Loading/Dumping Facility – Launch Pad • Transfer Units/Controls • Concrete Pad – 1400 Sq Ft • Tower Shelter – Lines Propellant Off-Loading Facility 4000 Gallon Stainless Steel Tanks – Two • 15 Ft Underground • Vent Stacks – Drain Lines	New Installation	New Installation

Table 2-4

AGENA GROUND SUPPORT EQUIPMENT SUMMARY

Type/Element	ETR				WTR	
	Core		SOT		Core	
	New	Exist	New	Exist	New	Exist
• Servicing Equipment						
• Trailers – Flushing/High Pressure		X		X		X
• Test Carts – Hydraulic/He/N_2		X		X		X
• Control Units – Propellant/He/N_2		X		X		X
• Propellant Transfer Equipment	X		X		X	
• Handling Equipment						
• Vehicle Transporter/Dollys		X	X			X
• Access Platforms/Lift Slings		X	X			X
• Test and Checkout Equipment						
• Test Station – Power/RF/Timing Consoles		MOD		MOD		MOD
• Simulators – Payload and Orbital	X		X		X	
• Guidance – Control and Monitoring	X		X		X	
• Propulsion Test Sets		X		X		X
• Automatic Data Evaluation Processing Sys						
• TLM/Data Processing Ground Station		MOD		MOD		MOD
• CDC 3100 Computer System	X		X		X	
• Software						
• Vehicle		MOD		MOD		MOD
• Data Processing		MOD		MOD		MOD

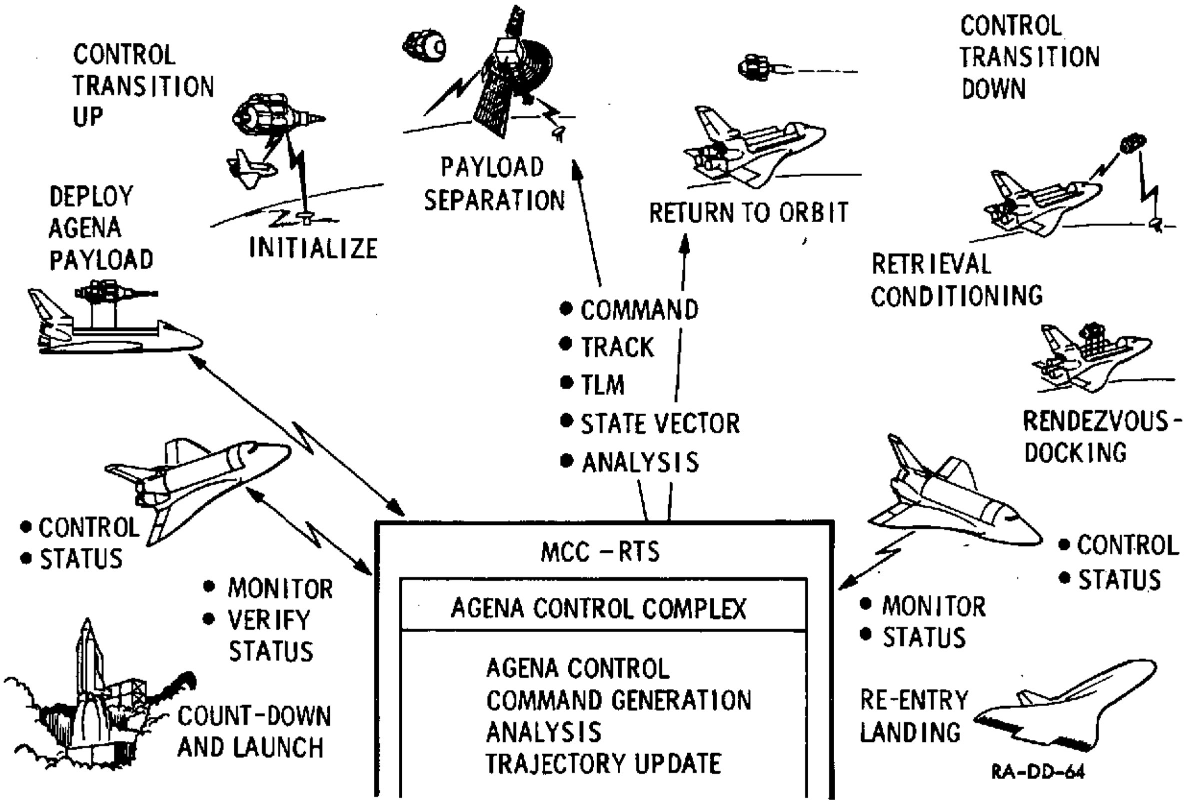


Fig. 2-9 Mission Flight Operations Overview

While in the Shuttle cargo bay the Agena is monitored, statused and controlled by the Agena Service Panel (ASP). After Agena deployment the ASP continues to monitor and display Agena parameters via RF link through the Shuttle communication system. Ground monitoring of the Agena status is also accomplished following deployment and throughout the mission.

After injection into the desired orbital position the payload is separated and the Agena initiates transfer back to the Shuttle orbit rendezvous position.

After reaching the desired Shuttle rendezvous position all residual Agena propellants (except for the attitude control thruster hydrazine supply) are expelled and the Agena enters a passive, stabilized, cooperative and safe mode for retrieval by the Shuttle.

2.7 PERFORMANCE

The Shuttle/Agena Upper Stage 5-foot (1.52 m) diameter core vehicle alone (no strap-on tanks) can accomplish all scheduled missions (1980-1990 mission model) from VAFB in the reusable mode and without resorting to kick motors (Fig. 2-10).

At Cape Kennedy (ETR) all planned synchronous equatorial missions can be accomplished in the reusable mode by the addition of the strap-on tank propellant option to the Agena Upper Stage with no kick motor required. Higher energy missions from Cape Kennedy can be accomplished by either of two mission modes: (1) operating in the expendable mode (again no kick motor is needed) or (2) operating in the reusable mode but with the addition of a kick motor.

Specific payload capability performance numbers are presented in Table 2-5 for both the Nominal Shuttle/Agena Upper Stage and the Augmented concept.

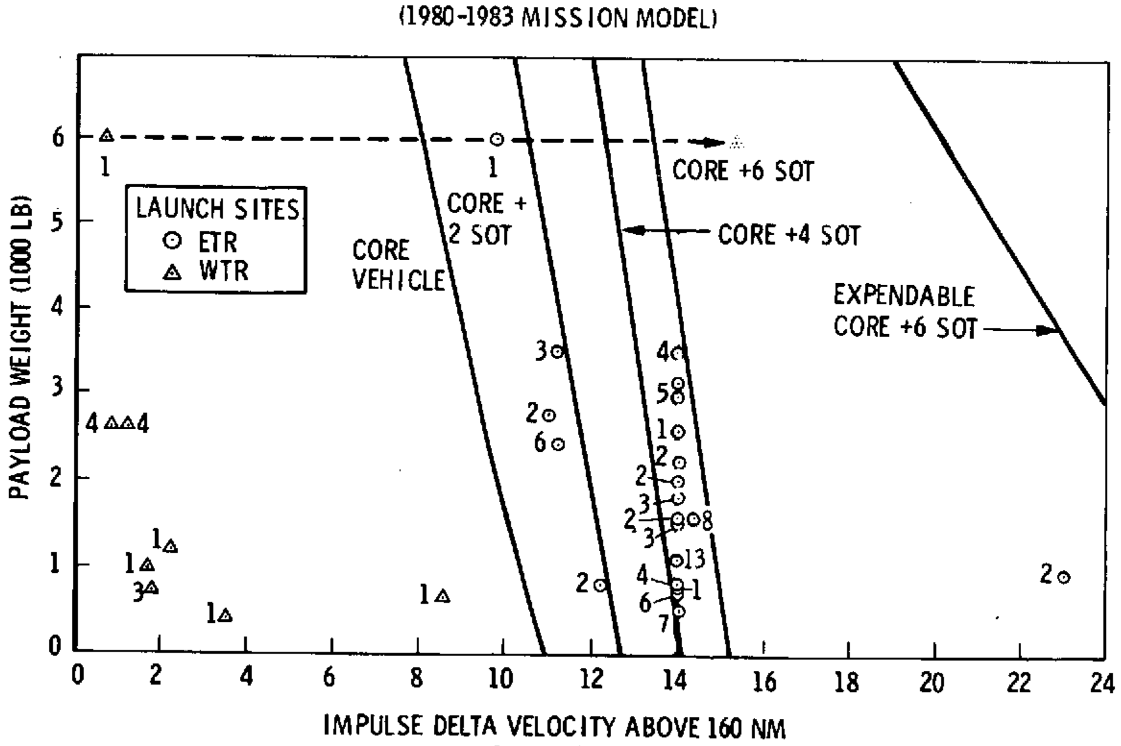


Fig. 2-10 Shuttle/Agena Upper Stage Mission Assignment

Table 2-5

SHUTTLE/AGENA UPPER STAGE PERFORMANCE
(SYNCHRONOUS EQUATORIAL)

Configuration	Nominal Single String lb (kg)		Augmented Dual String lb (kg)	
	2/10% Weight Contingency	10% Weight Contingency	2/10% Weight Contingency	10% Weight Contingency
5 Ft Diameter Core Plus Optimum Kick Motor	2,890 (1309)	2,710 (1228)	2,870 (1305)	2,700 (1225)
Core Plus SOT Option	3,895 (1768)	3,362 (1525)	3,560 (1615)	2,980 (1352)
Core Plus SOT Option Plus Optimum Motor	10,930 (4959)	10,838 (4916)	10,763 (4881)	10,610 (4813)

2.8 SAFETY

There are three areas of concern with respect to Agena safety:

- Main propellant tank pressure control
- Emergency propellant dump
- Agena retrieval by the Shuttle

Main propellant tank pressure control is ensured by several safeguards. The primary goal of these safeguards is to ensure the integrity of the common bulkhead between the fuel and oxidizer tanks. Several approaches and backups are used to reach this goal:

- A pressure controller commands oxidizer vented and oxidizer pressurant supply regulator closed if Δ pressure across the common bulkhead is less than plus 5 psi.
- Individual pressure regulators are provided to control helium gas pressurant flow to fuel and oxidizer tanks.
- Pressurant supply valves are automatically closed to shut off helium flow to counteract a leaking or sticking regulator or excessive tank pressures.
- Quad redundant vent/relief valves are provided for fuel and oxidizer tanks.
- The load carrying capability of the common bulkhead permits a minus Δpressure of 5 psi (3.45×10^4 N/m^2) across the bulkhead without compromising safety.
- While Agena is in the cargo bay the computer, located in the Agena service panel, continuously monitors main propellant tank pressures and controls helium shutoff valves and vent valves.
- The emergency dump system can be utilized as a backup to control tank pressure.

Emergency propellant dump can be accomplished on-pad, during Shuttle ascent, or on orbit. The most critical case is during Shuttle ascent. For ascent, Agena propellant dump is accomplished during the Shuttle thrusting portion of the trajectory. With 3.25 inch (8.26 cm) diameter dump lines through the Shuttle Orbiter to exit points in the Shuttle aft area, complete Agena propellant dump (including full SOT propellant option) can be achieved in 280 seconds. In the worst case (initiation of the Shuttle abort at T + 80 sec) Agena dump is completed above 170,000 foot (51800 m) altitude.

As indicated previously in the flight operations section, all Agena residual propellants (except for attitude control thruster hydrazine tank) are expelled prior to initiation of rendezvous by the Shuttle. Fully redundant Agena communications system ensure the capability to determine Agena safety and health status prior to rendezvous and retrieval. A backup hydrazine tank and attitude control thrusters along with a retrieval mode sensor package (completely separate from the primary Agena inertial measurement unit) ensures maintenance of Agena attitude control throughout the retrieval sequence.

2.9 PROGRAM DEFINITION

For program definition purposes a Shuttle/Agena Upper Stage IOC date of July, 1980, was assumed. Per study guidelines, the first Agena flight from VAFB was assumed to occur in 1983.

Table 2-6 presents an overall, program level summary schedule, showing all of the major events occurring over the life cycle of the Shuttle/Agena Upper Stage. The core vehicle and the strap-on-tank propellant option are developed in parallel with both building block configurations available at IOC.

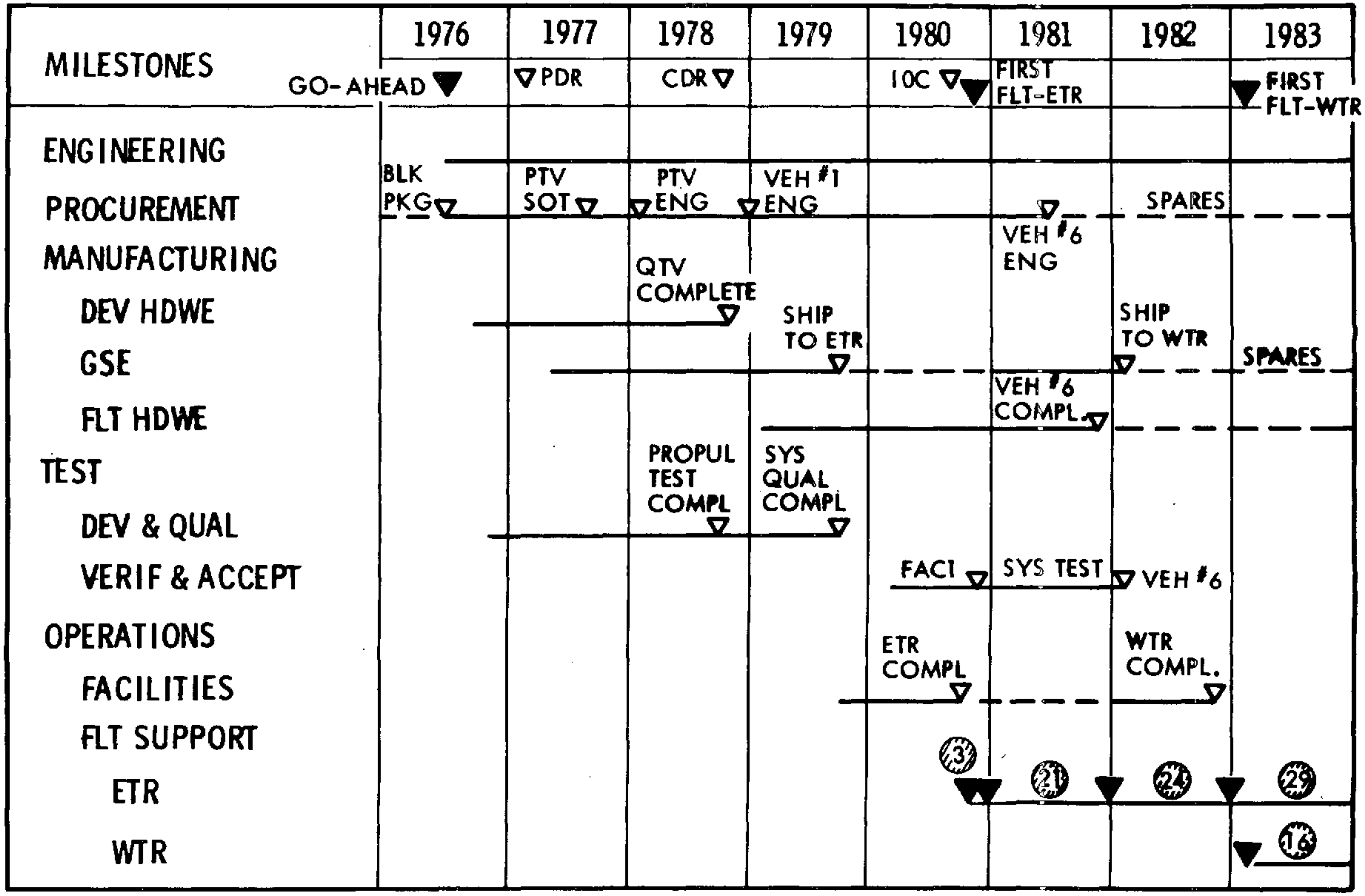
2.10 SPECIAL MISSION CONSIDERATIONS

The Agena with appropriate clearances including the cargo bay support structure (CBSS) requires no more than 26 feet (7.9 m) of the Shuttle 60-foot (18.3 m) cargo bay envelope. This leaves an ample 34 feet (10.4 m) of clear length for payload use. This length readily accommodates dual spacecraft for missions requiring dual placements. Multiple spacecraft placement with a single Agena is a very effective way of fulfilling specialized mission objectives at lower mission cost.

Studies have also shown the technical feasibility of packaging, side-by-side, either two or three 5-foot (1.52 m) diameter core vehicles (no SOT option) each mated to an individual spacecraft, to be flown one at a time from the Shuttle. Figure 2-11 depicts one concept of such a multiple Agena mission in progress. This type of flexibility is possible because of the 5-foot (1.52 m) diameter size of the core Agena Upper Stage.

Table 2-6

OVERALL AGENA UPPER STAGE MASTER SCHEDULE



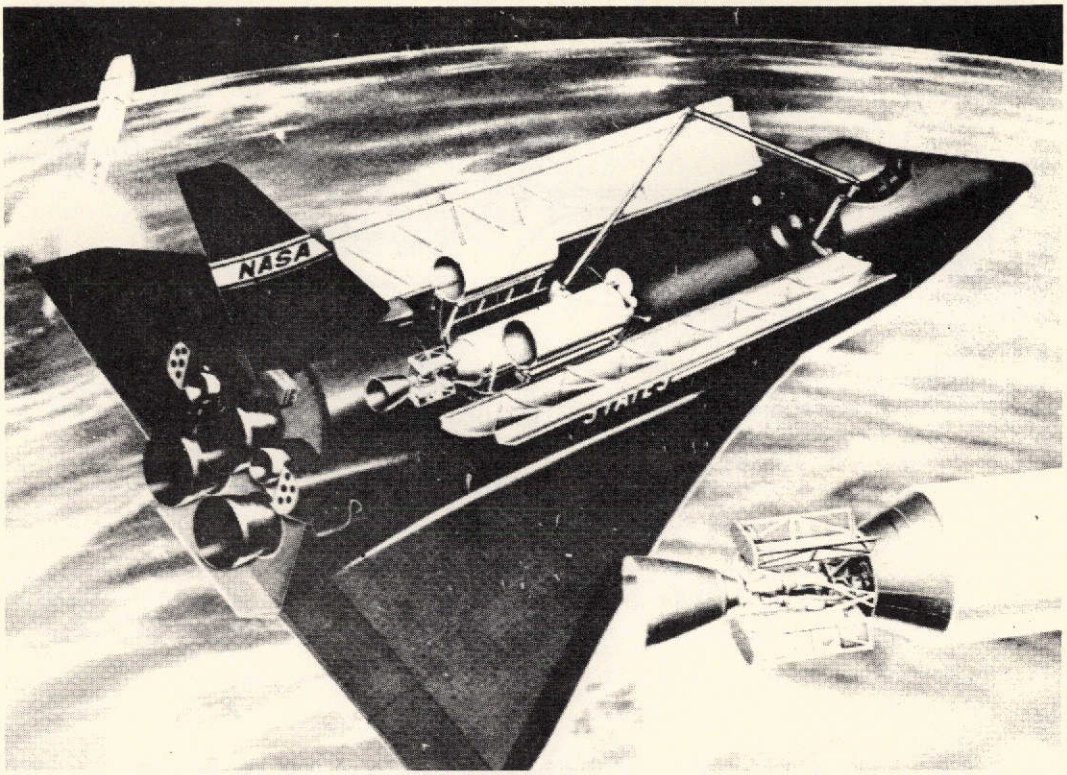


Fig. 2-11 Multiple Agena Deployment

It is conceivable that payloads in excess of 34 feet (10.4 m) may become a reality. Figures 2-12 and 2-13 present expendable and reusable Agena Upper Stage concepts for accommodating synchronous equatorial mission payloads 40 feet (12.2 m) in length.

For the expendable mode the main engine nozzle expansion ratio is decreased to 21:1, giving an overall Agena vehicle length of 19.9 feet (6.07 m) with an engine I_{sp} of 291 seconds and a payload capability of 10,290 (4953 kg) pounds. For the reusable mode a folded, convoluted nozzle is used with an expansion ratio of 80:1 with an engine I_{sp} of 317 seconds and a synchronous equatorial payload capability in the reusable mode of 2,690 pounds (1220 kg).

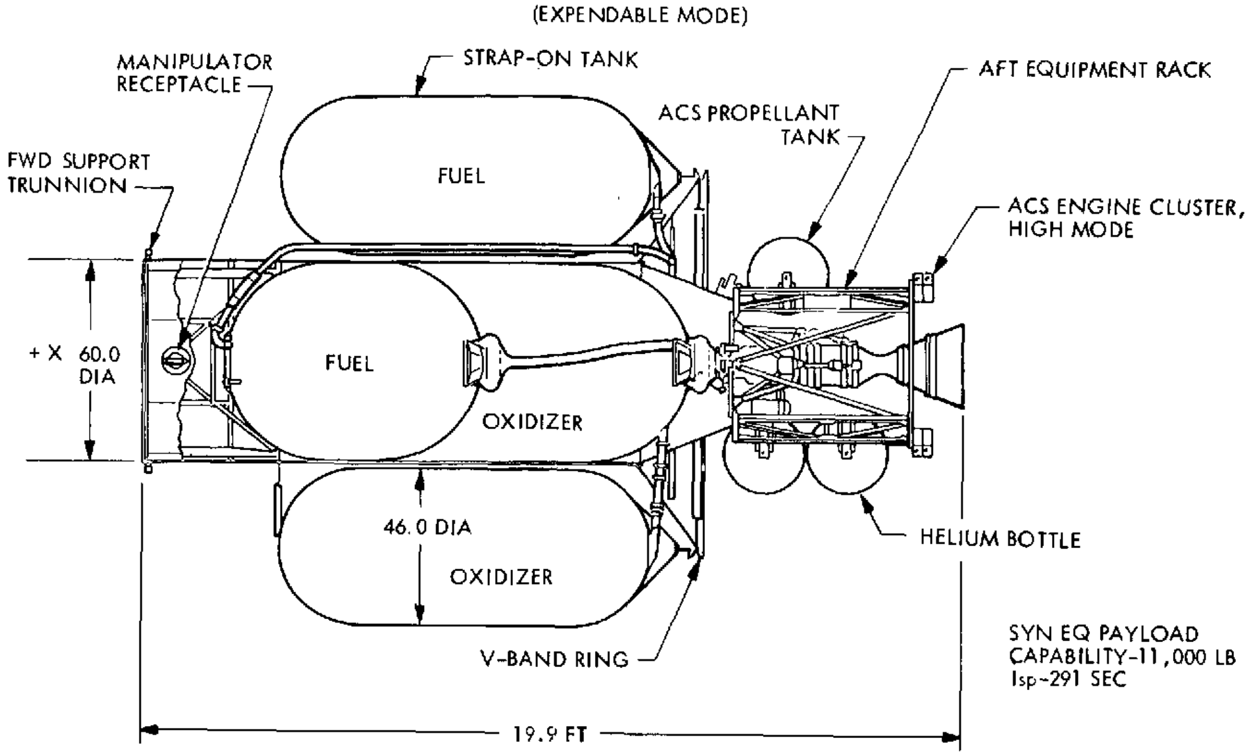


Fig. 2-12 Agena Upper Stage Long Payload Configuration (Expendable)

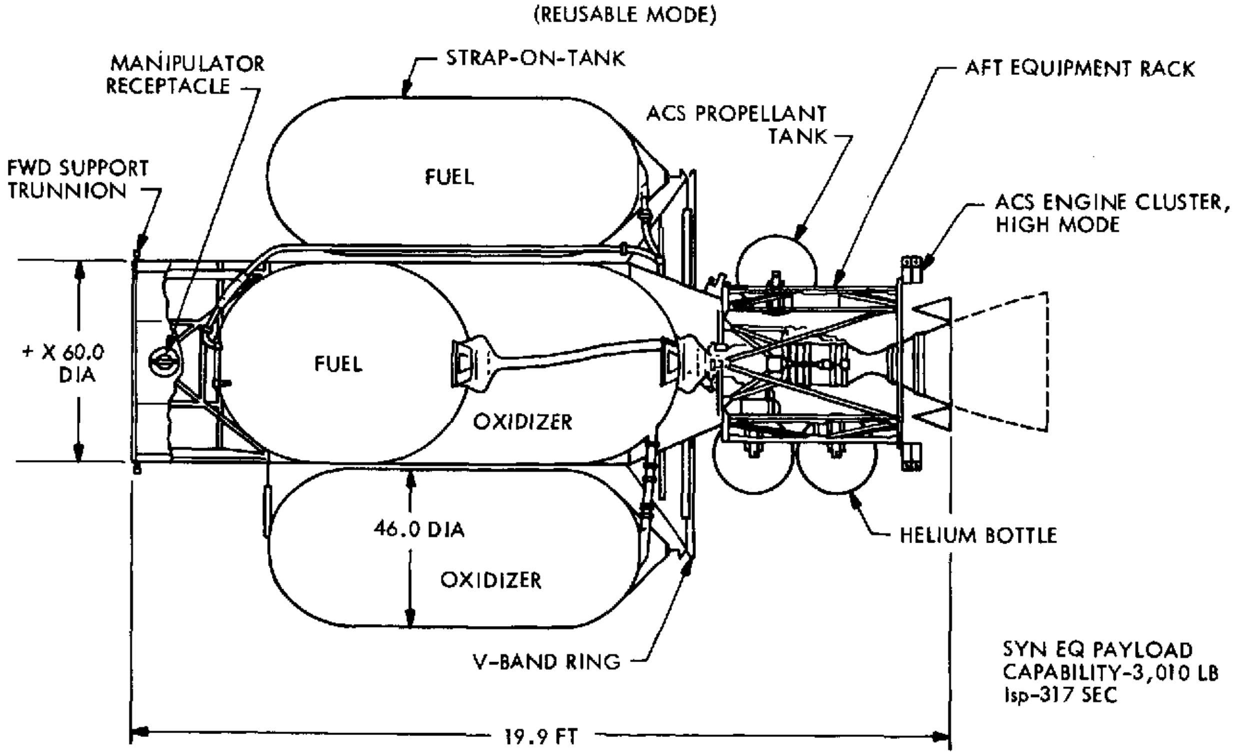


Fig. 2-13 Agena Upper Stage Long Payload Configuration (Reusable)

2.11 COSTS

NOMINAL CONFIGURATION

The complete Shuttle/Agena Upper Stage with the strap-on-tank propellant option and including GSE for both KSC and VAFB, all required Agena software and including the cost of GFE can be developed for $49.8 million (in 1973 dollars and without fee).

The costs for the production (investment) phase of the program includes the costs of a fleet of 6 vehicles and the necessary spares to support refurbishment during the initial year of operation. Four complete sets of Shuttle interface hardware is also included in the total production cost of $54.1 million.

Operations costs cover a 93-flight, 4-year program of operations at Kennedy Space Center and one year of operation at VAFB. All flights from VAFB use the core stage alone and are operated in the reusable mode for all flights. The total 4-year operations costs, including 3 years of spares provisioning, is $81.5 million.

AUGMENTED CONFIGURATION

The augmented Shuttle/Agena Upper Stage with the strap-on-tank propellant option and including GSE for both KSC and VAFB, and all required Agena software, can be developed for $52.5 million (in 1973 dollars and without fee).

The corresponding production cost is $57.8 million and the operation costs for a 4-year program of operation at both KSC and VAFB are $84.1 million.

Section 3

SYSTEM ANALYSIS

3.1 REQUIREMENTS

This section presents a summary of the system and subsystem primary requirements. Additional requirements, criteria, and groundrules applicable to subsystems, programmatics and cost, safety, and mission operations are presented in subsequent sections.

3.1.1 General System/Subsystem Requirements

Mission Types. The Agena Upper Stage must be capable of performing spacecraft placement missions in the time period specified by the launch frequency requirements. Spacecraft retrieval or round-trip missions are not required. The placement missions fall into three classes: low orbit (mostly high inclination), synchronous and other high delta-velocity orbital missions, and planetary. Representative mission timelines and delta-velocity budget data are provided in other sections of this report and in ref 2-1. These data represent the spectrum of NASA/DoD missions that dictate Agena requirements. The Agena Upper Stage may be configured in any one of three spacecraft delivery modes: (1) delivery and return of Agena for reuse, (2) delivery with a kick stage and return of Agena for reuse, and (3) using the Agena as an expendable stage (with or without kick).

Spacecraft Delivery Modes. The Agena must have the capability to deploy the DoD and the NASA spacecraft identified as "current design" in the System Study Data Package, ref 2-2.

Spacecraft Support. Spacecraft delivered in the deployment mode will place no functional support requirements on the Agena other than to meet the physical interface, placement accuracies, and tipoff rate effects. Spacecraft weights given in the mission model are to include an allowance for weight of adapters between the spacecraft and the Agena.

Multi-Spacecraft Delivery. Multi-spacecraft delivery is permissible. This capability can be considered in conducting the capture analysis, fleet size determination, cost analysis, and mission accomplishment activities of the study, provided that the spacecraft appear in the same year on the launch frequency tables. DoD and NASA spacecraft are not mixed on the same flight, and the maximum number of spacecraft on any one flight is three.

3.1.2 Vehicle Design Requirements

The requirements that most significantly drive vehicle design are provided in Table 3.1-1.

Table 3.1-1
VEHICLE REQUIREMENTS AND GROUNDRULES

Item	Requirements/Ground Rules
Hardware and Design	Maximum use of existing hardware or hardware currently under development
Payload Placement	Goal – 100 percent of 1980-83 current design payloads and return empty
Reliability	0.97 mission completion success goal
Meteoroid Damage	0.995 probability of no penetration
Length Limit	<35 feet (10.67 m)
Propulsion	BAC 8096 engine
Safety	• Fail operational/fail safe for critical command circuitry and RCS Operation • No single Agena failure will jeopardize flight or ground crews • Monitor and control capability will be provided to the Orbiter crew • Agena will not preclude Shuttle intact abort • Factors of safety will meet MSFC-HDBK-505
Reusability	• Goal of 20 uses (NASA) • Reusable with planned removal and replacement plus on-condition maintenance (AF)
Payload Performance	• 1.7 percent flight performance reserve (NASA) • 1.0 percent flight performance reserve (AF) • 10 percent weight contingency (NASA) • 10 percent on new equipment and 2 percent on existing or modified equipment (AF)

3.1.3 Shuttle and Spacecraft Interface Ground Rules and Requirements

Significant interface requirements relative to the Orbiter and to the spacecraft identified in the mission model are summarized in Table 3.1-2.

Table 3.1-2

SHUTTLE AND SPACECRAFT INTERFACE REQUIREMENTS AND GROUND RULES

Item	Requirements/Ground Rules
Shuttle Interface	• Installation per JSC 07700A
	• Satisfy ascent and landing loads, communications, CG, induced environment per JSC 07700A
Spacecraft Placement/ Interface	• Meet attitude orientation for spacecraft communications, thermal and attitude control
	• Accuracies Tangential <60 nm (110 km) <20 FPS (6.1 MPS) Normal <20 nm (37 km) <50 FPS (15.2 MPS) Radial <70 nm (130 km) <70 FPS (21.3 MPS)
	• Dynamics Rate <0.1 degree/second Velocity <5 FPS (1.5 MPS)
	• Supply physical interface for spacecraft diameters of 5-15 feet (1.5-4.6 m) and lengths of 7-25 feet (2.1 - 7.6 m)
	• Provide spinup when required

3.1.4 Functional Requirements

Primary requirements related to vehicle/system functions and operations are shown in Table 3.1-3.

Table 3.1-3

FUNCTIONAL/OPERATIONAL REQUIREMENTS

Item	Requirements/Ground Rules
Flight Monitor and Control	• Level III autonomy with Orbiter command override • Capability of monitoring by Orbiter or remote station • Critical operations readiness determined by Orbiter or ground station from Agena-provided data • Fault isolation and switching by Orbiter or ground station • Secure data provisions
Ground Response	• T-2 hour reassignment • Remove from Orbiter, replace and return to standby status within 10 hours
Orbiter Retrieval	• Orbiter rendezvous 160 nm (296 km) Down range 69 nm (128 km) Inclination ±0.15 deg Altitude ±15 nm (28 km) } (Air Force) 40 nm (74 km) ahead of Orbiter 10 nm (18.5 km) above Orbiter | NASA • Retrieval Alignment ±3 degrees Rate ±1 deg/sec

3.1.5 Mission Requirements

Key mission requirements affecting vehicle design are summarized in Table 3.1-4.

Table 3.1-4

MISSION REQUIREMENTS AND GROUND RULES

Item	Requirement/Ground Rules
Communications	STDN and AFSCF compatibility
Mission Life	6 days duration
Altitude	100 nm to 58,000 nm (185 to 107,450 km)
Propulsion	• Up to 8 propulsion starts • 10 to 500 second burns • Up to 1,200 seconds duration • Restarts after 0.17 to 9 hours

3.2 DESCRIPTION OF CURRENT AGENA SUBSYSTEMS AND RELATED LMSC HARDWARE

Several ascent and orbital configurations of the Agena vehicle exist to satisfy variable using-program requirements. As a basis for understanding the Agena and as a reference for tracking changes needed to satisfy Agena Upper Stage design requirements a description of the Ascent Agena vehicle is presented in ref 3-1. This section provides summary descriptions of the Ascent Agena subsystems and software for ready reference while reviewing the report. Descriptions of those assemblies of the orbital Agena and the satellite control section (SCS) which have application to the Agena Upper Stage are also included in this section.

3.2.1 Vehicle Overview

The Agena is the launch vehicle third stage and comprises the Agena vehicle, a booster adapter, and a payload fairing. Agena subsystems are: spaceframe, propulsion, guidance and flight control, electrical power, tracking and communications, flight termination, booster adapter and payload fairings. Supporting an onboard digital computer, are software programs used for flight and system test operations. Summary discussions of these subsystems and software are as follows:

3.2.2 Spaceframe

The three major assemblies of the spaceframe are shown in Fig. 3.2-1. The forward section is a sixty-inch (1.52 m) diameter cylindrical rack structure 40 inches (1.02 m) long, consisting of rings, longerons, and internal tubular trusses with load bearing external beryllium skins and doors. The doors are removable to provide easy access to components for checkout or replacement.

The electrical power and telemetry components are mounted in the forward section in modules to simplify checkout and replacement; non-modular equipment can be removed without disturbing other components. The semi-monocoque forward section has eight hardpoints for mounting the payload (spacecraft and adapter). The loads on these hard points are distributed to a ring located on the aft end of the rack structure which mates with the propellant tank section.

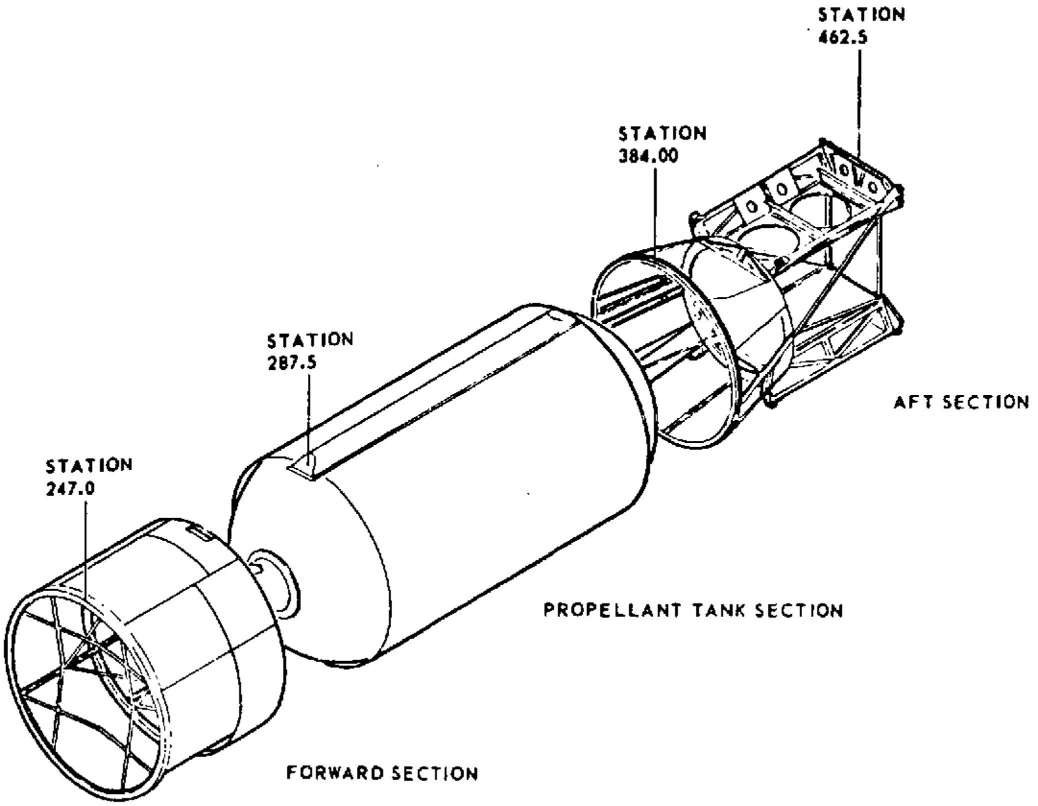


Fig. 3.2-1 Agena Spaceframe

The propellant tank section is the supporting structure between the forward and aft sections, as well as the reservoir for the main propulsion system propellants. Propellant containment components mounted on the aft bulkheads of the tanks include sumps and screens to ensure controlled propellant orientation during flight and scavenging devices to enable full utilization of propellants by minimizing residual propellants remaining in the tanks.

The aft structure consists of a truncated cone which attaches to the propellant tank at the forward end and a cantilevered rack at the aft end. The rocket engine, principal components of the cold gas attitude control system, and hydraulics system for engine steering are supported by this assembly. The open-frame aft rack design permits ready access to the engine, plumbing, wiring and components, and includes attachments for secondary payloads or payload support equipment. The aft section is enclosed by the booster adapter during flight and is attached to it by means of a ring attachment near the tank section. Rollers on the aft rack engage with rails inside the booster adapter and guide the separation of the Agena from the booster.

3.2.3 Propulsion System

The propulsion system is shown schematically in Fig. 3.2-2 and, in addition to the rocket engine, includes propellant pressurization and fill/feed/dump components.

The propulsion system uses unsymmetrical dimethylhydrazine (UDMH) for fuel and inhibited red fuming nitric acid (IRFNA) for oxidizer. Helium gas is the pressurant. The Orbital Agena uses high density acid (HDA) as the oxidizer (interchangeable).

The propellant pressurization components reduce and distribute high-pressure gas, maintaining sufficient pressure in the propellant tanks to prevent engine pump cavitation. The pressurization system is a blowdown type in which the flow of helium gas from the high-pressure storage tank to the propellant tanks is controlled by fixed orifices. The resulting pressure profile supports the pump inlet pressure requirements and ensures propellant tank common bulkhead pressure control. The pressurant tank has a capacity of approximately 1600 cubic inches (0.026 cubic m) of helium.

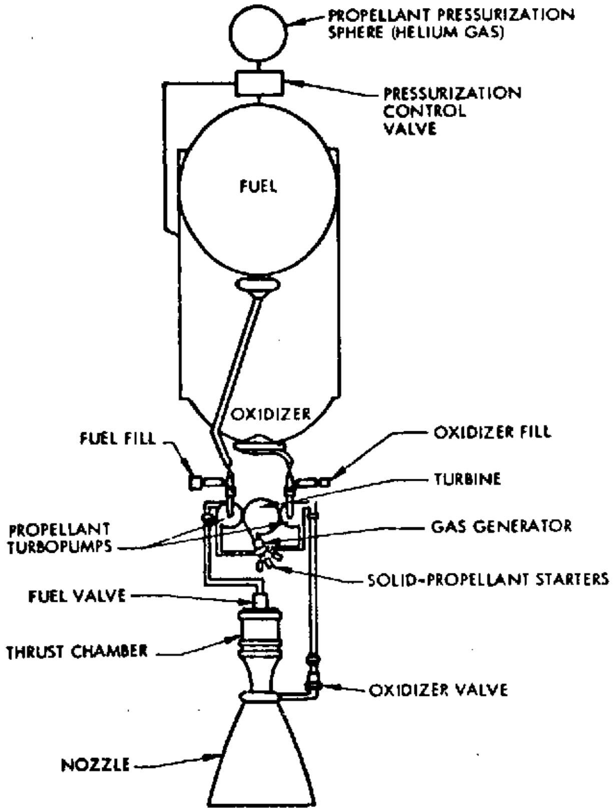


Fig. 3.2-2 Agena Propulsion System

The zero gravity environment and the varied acceleration disturbances resulting from control torques and atmospheric drag between burns can cause the propellants to relocate to the forward end of the propellant tanks. The propellant containment and scavenging screens retain necessary propellants and control their flow, supplying gas-free propellants until propellant reorientation can occur after engine ignition. A pleated screen and a velocity control plate in each sump suppress surface dip and preclude gas ingestion at the pumps as well as minimize residual propellants at depletion.

The BAC Model 8096 rocket engine is turbopump fed. The combustion chamber is regeneratively cooled by oxidizer through drilled passages in the throat and thrust chamber walls. The expansion nozzle is cooled by radiation. The engine is mounted in a gimbal ring that allows the engine thrust vector to be varied for pitch and yaw control during engine operation by means of hydraulic actuators. The pumps are geared to a single turbine, fed by a gas generator. Engine thrust (16,000 lb or 71,200 N) and mixture ratio (2.55), are controlled by cavitating flow venturis in the gas generator flow circuit. The engine oxidizer valve is spring loaded and is operated directly by the oxidizer pressure buildup or decay. The fuel valve is also spring loaded, but is actuated by a solenoid valve that shuttles when the oxidizer manifold pressure builds up. Engine start is initiated by a signal energizing the gas generator solenoid valve and igniting a solid-propellant start cartridge. Engine shutdown is initiated by closure of the gas generator and fuel solenoid valves, followed by oxidizer valve closure after pressure decay. Engine I_{sp} is 295 seconds with HDA.

Attitude Control Propulsion Systems (ACPS). The Agena vehicle incorporates one of two types of ACPS, cold gas or hot gas. The ACPS provides control of torques in all three axes during flight operation, and roll control during main engine burn.

The cold gas system consists of a pneumatic pressure regulator, two thrust valve clusters, and gas storage tanks (N_2 , Freon, or a mixture). The gas is contained in one or more 2200 cubic-inch (0.036 cubic m) spherical tanks. One supply tank is sufficient for ascent missions; additional tanks are attached as needed. Gas pressure at 3600 psia (24.8×10^6 n/m^2) is regulated to the thruster valves at either 100 psia

(6.9×10^5 n/m^2) or 5 psia (3.4×10^5 n/m^2) producing thrusts of 10 pounds (44.5 N) or 0.5 pound (2.2 N) respectively. The selected valves are pulse-width and frequency modulated in response to the controls avionics signals.

The spacecraft Agena incorporates a hot gas hydrazine ACPS. It provides more attitude control total impulse then the cold gas system. Average thrust levels are 12 pounds (53 N) in the high mode and 0.5 pound (2.2 N) in the low mode. This system is designed for long life/redundancy and is configured as shown in Fig. 3.2-3. Freon is used for propellant tank pressurization (volatile liquid concept) and propellant feed is accomplished by metal expulsion diaphragms in each tank.

3.2.4 Electrical Subsystem

Power Supplies. Energy for ascent and some orbital Agenas is supplied by internally mounted silver-zinc primary batteries. Two Type IVB batteries provide enough power for the Ascent Agena and are connected in parallel to a main power bus; one battery is

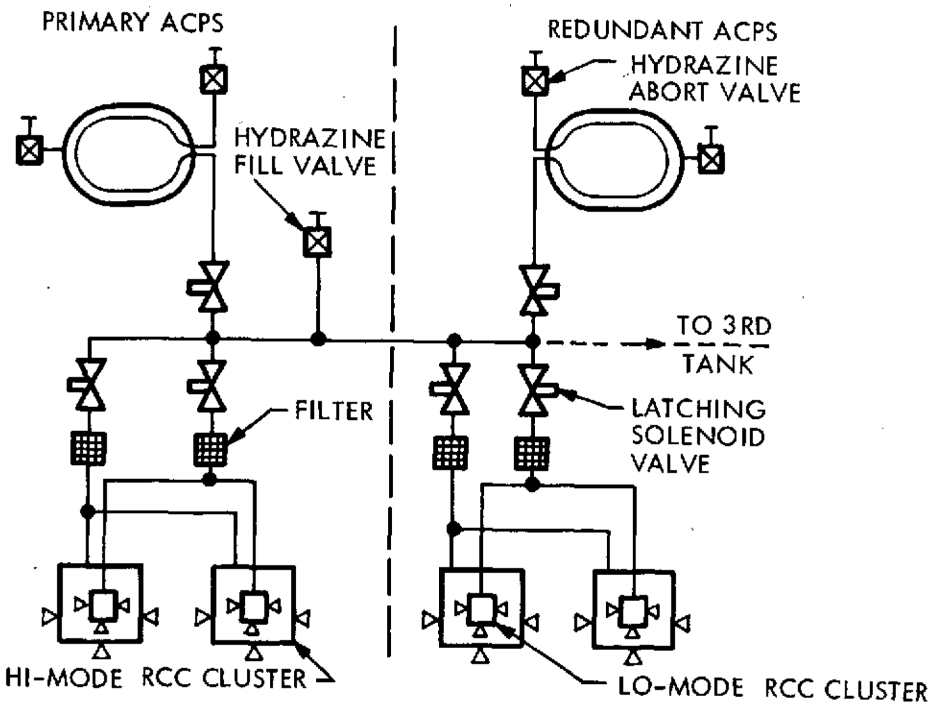


Fig. 3.2-3 Hot Gas ACPS

diode-isolated and serves as a pyrotechnic power source as well as a backup. These batteries are connected to the main distribution and pyro power distribution systems through a double-pole power control switch operated by ground control. External power supplies the vehicle loads on the launch pad when the batteries are installed and the Agena power control switch is open. Diode isolation precludes negative spikes on the main vehicle bus.

Varying capacity primary batteries (Table 3.2-1) may be selected. For larger battery capacity requirements, mounting kits that can accommodate up to three of the Type 1K or Type 30 batteries have been developed. (Type 30 batteries are also flown on the SCS).

Table 3.2-1

PRIMARY BATTERY CHARACTERISTICS

LMSC Battery	Cell	Nominal Voltage	Ampere-Hours	Mean Watt-Hours	Weight lb (kg)
Type IVB	18	27.5	16	440	17 (7.7)
Type VIA	17	26.0	45	1,170	26 (11.8)
Type IC	16	24.5	450	11,025	118 (53.3)
Type IK	16	24.5	475	11,637	128 (58)
Type 30	18	27.5	400	11,000	134 (60.8)
Type 1902	16	24.5	550 (min)	13,400	143 (65.0)

To support long-term (non-ascent) missions, solar arrays (rigid panels and extendable panels) have been flown. A flexible substrate, rollup solar array design is developed that can deliver up to 3000 watts. Arrays usually charge nickel-cadmium secondary batteries; however, on some flights arrays have been used to charge special silver-zinc primary batteries. Regulation of battery charging is provided by one of several flight-qualified charge controllers.

3.2.5 Guidance System and Flight Controls

The Ascent Agena guidance and flight control system (Fig. 3.2-4) performs flight programming functions, guidance steering, flight attitude control, and the issuance of discretes for launch vehicle system control, engine starts/stops, telemetry control, payload fairing separation, and spacecraft separation.

The guidance and flight control equipment navigates the vehicle via closed loop guidance and control from liftoff through final transfer orbit injection. An on-board guidance computer and strapdown inertial reference system provide a programmed ascent navigation capability which can sense deviations from the nominal trajectory parameters and issue compensated commands and discretes to the booster autopilot or to the Agena flight control system. The flight controls gimbal the engine for thrust vector control and operate the ACPS thruster valves during Agena flight.

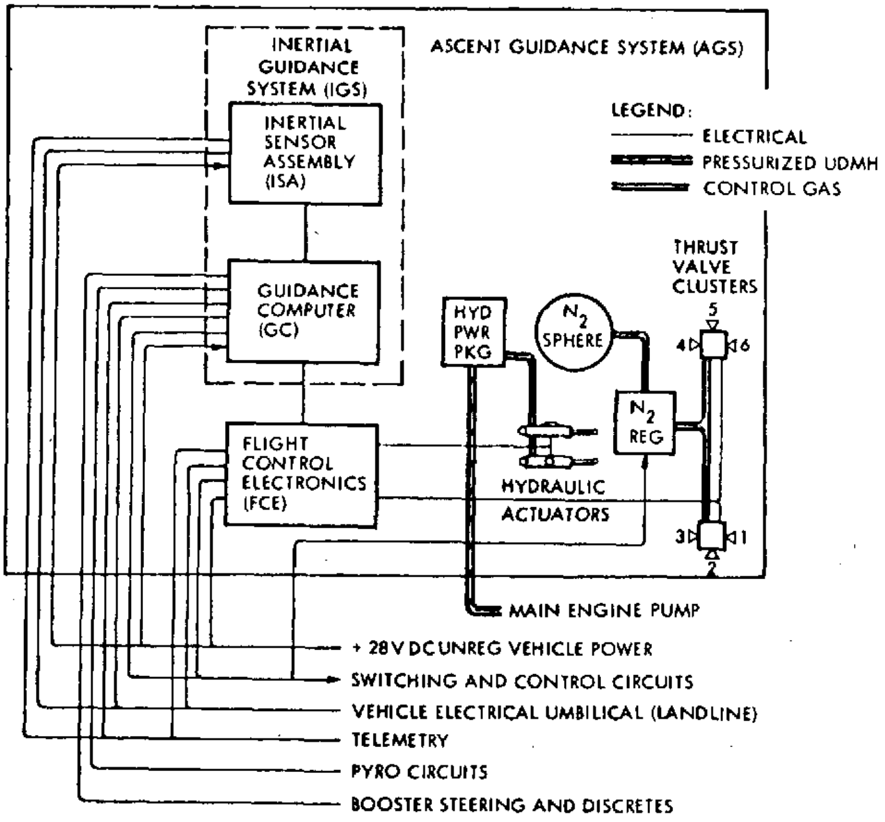


Fig. 3.2-4 Agena Ascent Guidance System

The major elements of the ascent guidance system (AGS) are the inertial sensor assembly (ISA), the guidance computer (GC), the flight control electronics (FCE), and the ACPS and hydraulic attitude controls. The first two elements make up the inertial guidance system (IGS) provided by Honeywell, Inc.

The IGS, using a strapdown inertial reference system, senses vehicle motion by means of three gyros and three accelerometers oriented to the three orthogonal vehicle axes.

After booster separation, steering signals are conditioned by the flight control electronics (Fig. 3.2-5) to operate the ACPS valves and the Agena engine hydraulic actuator servo systems. During Agena engine operation periods, attitude error correction signals control the electro-hydraulic actuators which gimbal the engine and change the thrust vector for pitch and yaw corrections. Agena roll errors are controlled by the ACPS roll thrusters.

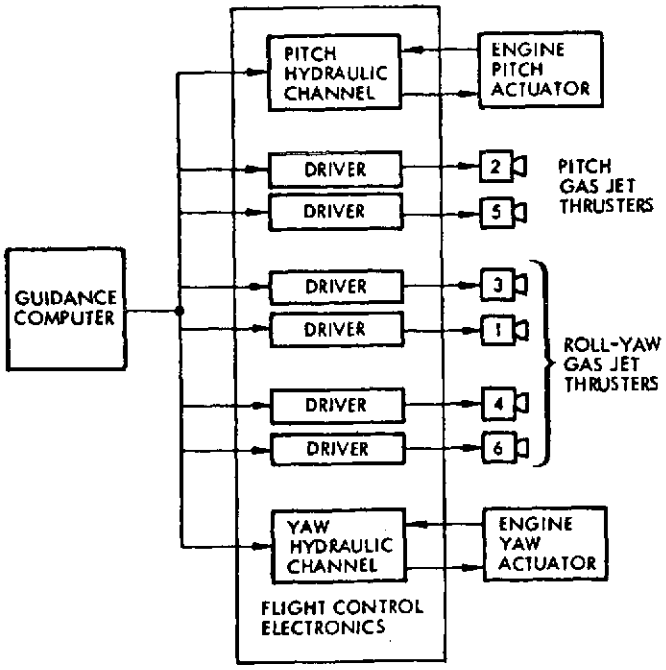


Fig. 3.2-5 Agena Flight Controls

3.2.6 Tracking and Communications

A pulse-code-modulated (PCM) telemeter accepts analog, bilevel, and direct digital inputs, converts analog signals to digital form, and formats and combines all inputs into a digital bit stream with approximately 200 channels of data. The analog signals are the electrical system current and voltage status monitors and signals from pressure and temperature transducers. Bilevel signals monitor the status of switching and control devices. Engine turbine speed and guidance computer readouts are direct digital representations. The computer readouts are cyclic samples of selected memory addresses; readout is accomplished under the control of the prelaunch-loaded program instructions.

3.2.7 Software

The Ascent Agena software program involves the prelaunch systems test and the instruction and information validation prior to computer loading for flight. The computer is loaded via punched tapes read-in through a control console in the blockhouse. Three tapes are employed: a flight program tape, a constants tape, and a target tape. The flight program is the key element as it embodies the guidance philosophy, control laws, basic computational instructions, and executive logic. It instructs the computer how to operate on input and sensed data to meet mission objectives. The constants tape has approximately 400 constants that are vehicle and equipment-dependent and are valid for a wide range of trajectories. The target tape consists of 25 mission-dependent parameters, providing operational flexibility and capability to make last-minute changes. In addition to the three flight tapes, a comprehensive testing routine has been developed which can be used in total vehicle checkouts at the launch base as well as the factory.

3.3 SUBSYSTEM EVALUATION

3.3.1 Structures Subsystem

The criteria, ground rules and assumptions upon which the structural design is based are discussed in this paragraph. The core stage design is presented, followed by description of the strap-on-tank (SOT) option. The design requirements for both core and SOT configurations are summarized and a development status of the selected hardware is provided.

3.3.1.1 Structural Design Criteria, Ground Rules, and Assumptions.

Design Criteria. Basic criteria and interpretive information governing structural design for all service conditions are taken from "Space Technology Structural Design Criteria (For Unmanned Space Systems)", ref 3-2. In addition to this referenced document, the requirements specified in "Structural Strength, Design, and Verification Program Requirements", MSFC Handbook 505, ref 3-3, and in "Reusable Agena System Requirements Document", LMSC (Unpublished), ref 3-4, were applied to this study. Where any conflict appeared between documents, ref 3-2 and 3-3 criteria had precedence. The design objectives pertinent to the vehicle structural design and the more important basic design characteristics which the structural components must exhibit and/or with which they must comply are included.

Structural, mechanical, and propulsion elements will be designed to make full use of existing LMSC flight hardware, while demonstrating capability to sustain ultimate load conditions after being subjected to nominal life conditions. Generally, both fail-safe and safe-life design philosophies apply except in cases where fail-safe design is impractical, such as pressure vessels. In those specific cases, the safe-life approach is used and is supplemented by fracture control procedures as data become available. Such fracture control procedures will conform to NASA SP-8040, "Fracture Control of Metallic Pressure Vessels", ref 3-5. These procedures will be supplemented by those presented in LMSC Engineering Memo L5-07-02-M1-1, "Fracture Mechanics Technology for Optimum Pressure Vessel Design", ref 3-6.

Structural design is based on critical flight conditions wherever possible. Designs are selected so that the burden of accommodating non-flight loads and environments is borne by the cargo bay support structure (CBSS) or by ground equipment, rather than the Agena, unless analysis shows burdening the Agena to be cost effective. The structure is not designed to withstand loads, pressures, or environments caused by systems malfunctions that would in themselves result in failure to accomplish the mission.

The load factors specified for the study and contained in ref 3-7 are presented here in Table 3.3.1-1. Vehicle loads occurring outside the cargo bay are of lesser magnitude except for engine thrust. Reference 3-4 specifies that the engine thrust for the 8096L engine is 16000 pounds ± 2.5 percent. This is significantly less than the magnitude used to design the existing Agena thrust cone structure because of the deletion of the solid propellant ignition system which causes a 20 percent ignition transient thrust load.

The maximum payload required in the mission model is 6000 pounds. Therefore 6000 pounds represents the maximum mass installed on the forward end of the Agena.

Table 3.3.1-1

PAYLOAD BAY LIMIT LOAD FACTORS

Condition*	X_o	Y_o	Z_o
Lift-off***	-1.7 ±0.6	±0.3	-0.8 -0.2
High Q Boost	-1.9	+0.2	+0.2 -0.5
Booster End Burn	-3.0 ±0.3	+0.2	-0.4
Orbiter End Burn	-3.0 ±0.3	±0.2	-0.5
Space Operations	-0.2 +0.1	±0.1	±0.1
Entry	±0.25	±0.5	+3.0 -1.0
Subsonic Maneuvering	±0.25	±0.5	+2.5 -1.0
Landing and Braking	±1.5	±1.5	+2.5
Crash**	+9.0 -1.5	±1.5	+4.5 -2.0

*Positive X, Y, Z directions equal aft, right, and up. Load factor carries the sign of the externally applied load.

**Crash load factors are ultimate and only used to design payload support fittings, all other load factors are limit. Crash load factors for the nominal payload of 65,000 pounds. The specified crash load factors shall act separately.

***These factors include dynamic transient load factors at lift-off.

Based on the statically determinant cargo bay interface attach scheme of ref 3-7, detailed dynamics analyses would be necessary to properly define vehicle and perhaps payload structural design requirements. Dynamics analyses are beyond the scope of this study. In lieu of these analyses, it was assumed that the heavier payloads (up to 6000 pounds) are laterally supported directly from the cargo bay and are not cantilevered from the Agena while in the Orbiter.

Design limit pressure valves for the HDA and MMH propellant tanks are based on the upper limit of the lock-up pressure relief-valve settings described in par. 3.3.2. The tank design values are presented here in Table 3.3.1-2. The fuel tank values are not based on propulsion requirements, but are based on providing a positive 5 psig pressure across the core tank common bulkhead at all times.

Table 3.3.1-2

PROPELLANT TANK LIMIT DESIGN PRESSURES

Type of Tank	Ascent Pressure (psia)	Orbit Pressure (psia)
Oxidizer, HDA	25*	40
Fuel, MMH	30	45

*22 psia used in propulsion analyses.

Safety considerations for the abort mode lead to a further requirement for limit design pressure. For structural design purposes it was conservatively assumed that, at initiation of propellant abort dump, maximum vehicle acceleration coexists with maximum orbit lock-up pressure.

In addition to the maximum values used for tension failure, the common bulkhead of the core tank is conservatively designed to take a negative ultimate design pressure of 5 psig.

To assess life expectancy and reusability, a preliminary pressure load spectrum was established for the oxidizer tank because it is the most critical in a stress-corrosion environment. This spectrum is presented in Fig. 3.3.1-1. A similar spectrum could be developed for the fuel tank, but, as will be shown in subsequent discussion, pressure is not critical in the final design of this tank.

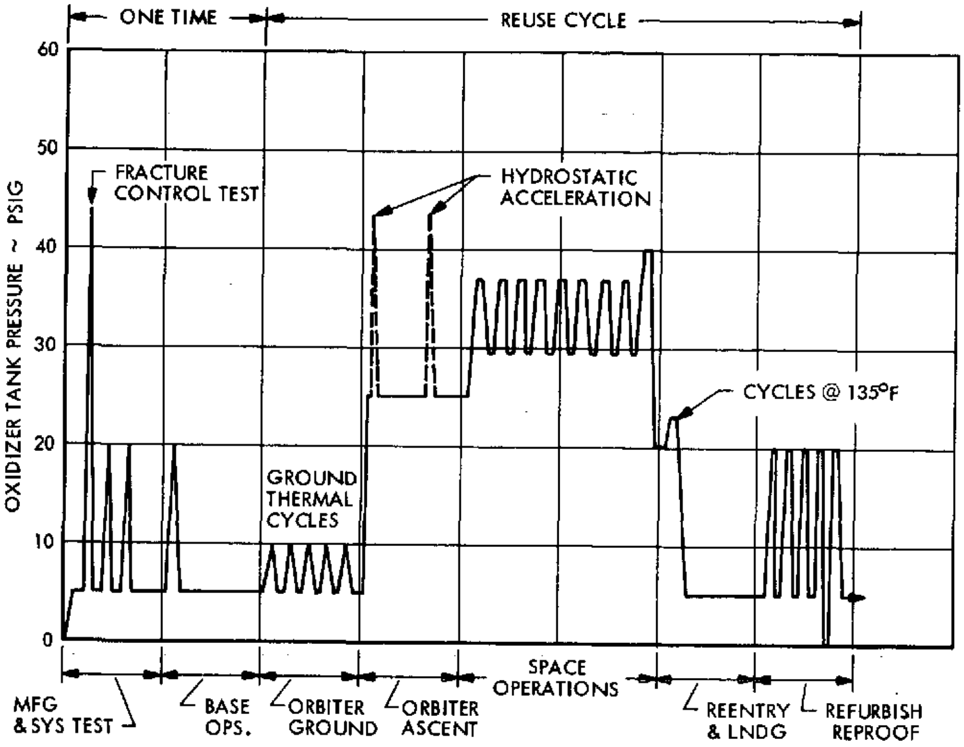


Fig. 3.3.1-1 Oxidizer Tank Pressure Load Spectrum

Factors of safety are applied only to mechanically-induced limit loads and pressures; thermally-induced limit loads, if and when they occur, are not multiplied by any factor of safety. The factors of safety used for this study are taken from ref 3-3. The more pertinent values are presented here in Table 3.3.1-3.

Table 3.3.1-3

FACTORS OF SAFETY

Component	Proof	Yield	Ultimate	
			Manned	Unmanned
General Structure	(a)	1.10	1.40	1.25
Propellant Tanks	1.05	1.10	1.40 (b)	1.25 (b)
Hydraulic & Pneumatic Tanks	1.50	(b)	2.0 (b)	

(a) Not applicable

(b) Subject to change based on development of fracture control data, employing procedure specified in NASA SP-8040 (ref 3-5).

Temperatures during space operations are controlled by passive thermal protection systems as discussed in par. 3.3.4. The propellant temperature is limited to the range of 20 deg F (266 deg K) to 80 deg F (300 deg K). Following reentry and landing, the vehicle (and tank) may reach 135 deg F (330 deg K). This value is based on the Shuttle cargo bay temperature being limited to 200 deg F (366 deg K) (ref 3-7). Therefore all vehicle structure strength is assumed to be uneffected by temperature excursions. Room temperature material strength properties are used for all preliminary analyses.

Structural Materials. Staying within the scope of the objective to make full use of existing LMSC flight hardware limited the extent to which material surveys and selections were made. For the existing hardware, no material replacement is recommended or planned except in specific cases where redesign or modification is required because of strength considerations.

The existing Agena structure excluding the tank is predominately fabricated from magnesium alloys. These alloys provide attractive weight savings for designs requiring lightly loaded structure, which was the case in the original Agena design of the forward and aft equipment sections and the engine thrust cone.

Beryllium is used in the Agena forward equipment section for structural load-carrying doors and panels. For a compression load-carrying structure subject to buckling instability, beryllium is far superior to any other homogeneous alloy system in the 0 deg to 1100 deg F range. It was for this reason that the Agena forward equipment section doors and panels were redesigned using cross-rolled sheet Beryllium. The subsequent weight reduction improved the Ascent Agena performance.

Although the existing Agena spaceframe uses a minimal quantity of aluminum, the Shuttle/Agena Upper Stage uses aluminum for all new and/or modified structure. Specifically, the 7075 alloy has been selected as the prime candidate. This alloy has been widely used in the past for many aerospace structures in the very strong -T6 Temper. The -T6 temper, however, has experienced stress corrosion cracking in some applications, mostly in heavy sections and in instances of unusual malpractice.

To avoid stress corrosion problems, and improve fracture toughness, the overaged -T73 temper has been selected. This condition does lower the minimum mechanical properties slightly, but the fracture toughness is enhanced significantly as shown in Table 3.3.1-4.

Table 3.3.1-4
ALUMINUM ALLOY 7075 FRACTURE TOUGHNESS COMPARISON

Temper	Thickness	F_{tu} (ksi)	F_{ty} (ksi)	K_c ($\text{ksi} - \sqrt{\text{in}}$)
Bare 7075-T6	.040 - 0.249	77	66	64
Bare 7075-T73	.040 - 0.249	68	56	100

The 6061-T6 aluminum alloy is currently being used in the manufacture of Agena tanks. This alloy is readily weldable and highly resistant to corrosion. It has enjoyed a wide range of applications, including cryogenic pressure vessels requiring high fracture toughness. The nominal Shuttle/Agena Upper Stage configuration utilizes the existing type of Agena 6061 aluminum main propellant tanks.

The augmented Shuttle/Agena Upper Stage achieves even greater weight efficiency by using 2219 aluminum alloy for the main propellant tanks. This alloy has seen widespread use in both the -T81 and -T87 tempers for both earth storable and cryogenic pressure vessels. The alloy manifests excellent weldability and high fracture toughness, as well as good mechanical properties. Both the nominal and augmented Agena Upper Stage configurations use 2219 alloy for the strap-on-tank.

3.3.1.2 Core Stage. The Shuttle/Agena Upper Stage (Fig. 3.3.1-2), as defined here, is the core stage vehicle without the strap-on tanks and it looks much like the existing Ascent Agena. This basic vehicle has a dual-chamber propellant tank, housing MMH fuel and HDA oxidizer. The tank compartments are sized for the optimum oxidizer / fuel mixture ratio of 2.03 for 15,000 pounds (6800 kg) of propellant, while providing

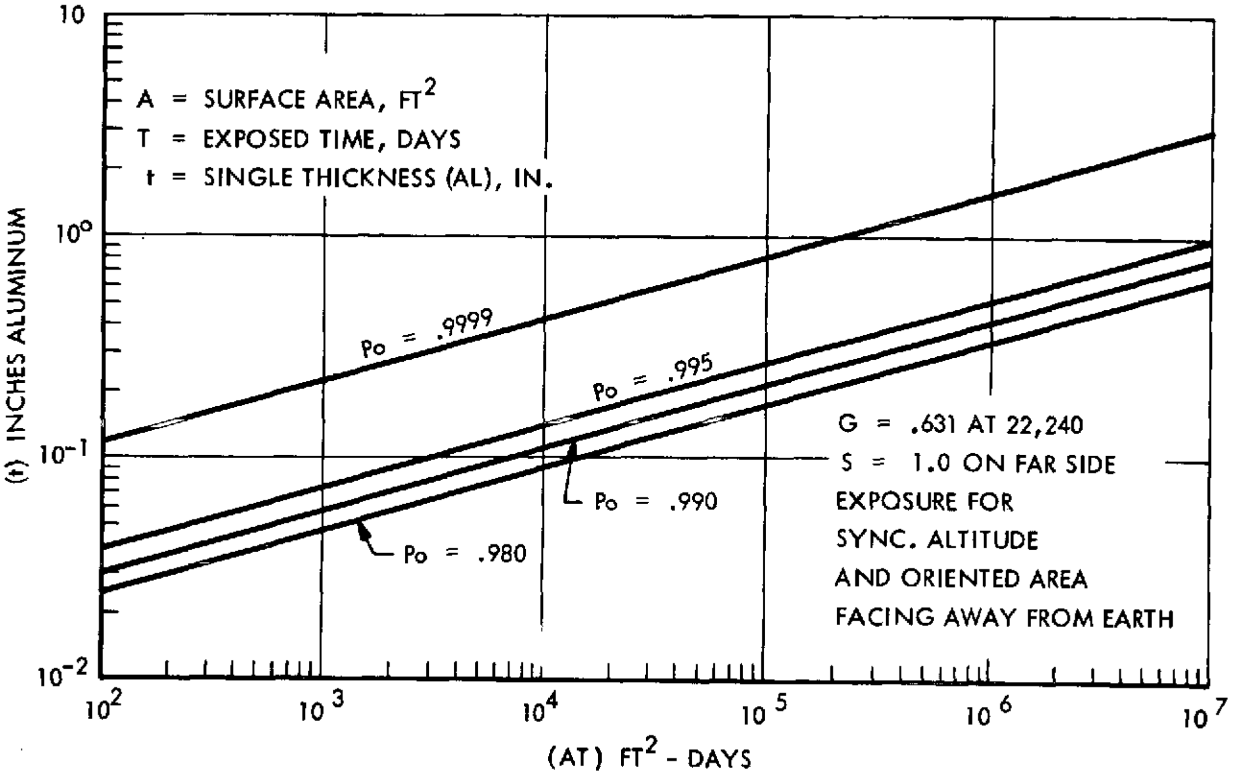


Fig. 3.3.1-2 Shuttle/Agena Upper Stage

1 percent ullage volume. The forward equipment section with its avionics equipment is basically the same as for the present Agena. The aft equipment section supported from the engine thrust cone is also the same as the present Agena. Both sections (forward and aft) are designed for field-joint attachments to the core tank skirts to facilitate core tank change-out between missions for refurbishment or replacement.

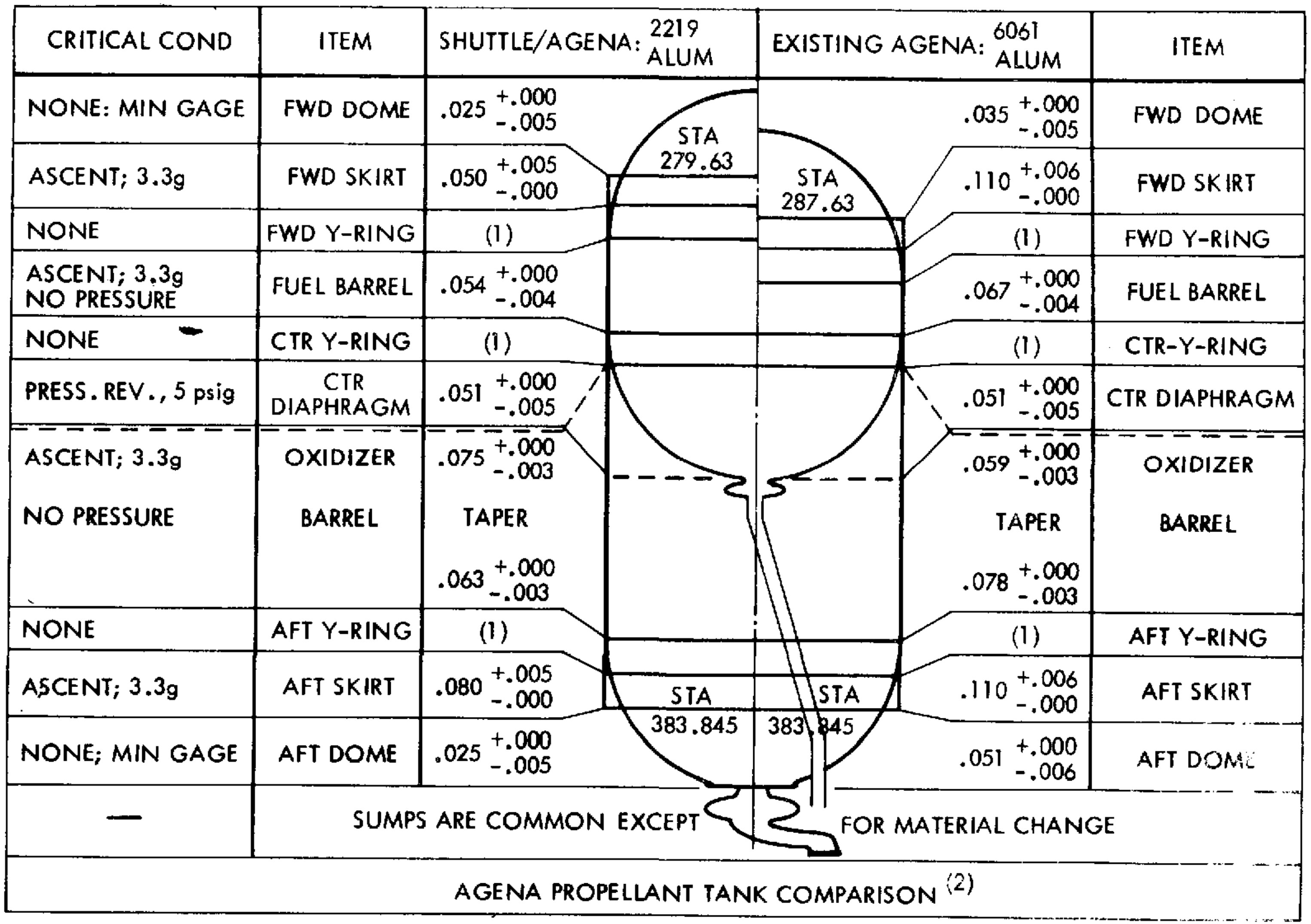
Shuttle/Agena (Core) Tank. The Agena core tank, a dual-chamber propellant tank assembly is an integral part of the vehicle space frame, and provides the supporting structure and exterior surface for the center portion of the vehicle.

The propellant tank assembly is constructed of welded aluminum sections forming a cylindrical pressure vessel with two compartments identical to the Ascent Agena except for the minor change of lengthening the fuel barrel section 8-inches to accommodate the optimum HDA/MMH mixture ratio of 2.03. The forward compartment (fuel) comprises a cylindrical section, two Y-rings, a forward skirt, and two hemispherical ends. The aft compartment (oxidizer) comprises a long cylindrical section, one Y-ring, an aft skirt, and a single hemispherical end. The aft hemispherical end of the forward compartment is a common bulkhead between the fuel and oxidizer compartments. The forward and aft skirts are short cylindrical shell elements providing integral attachment to the forward and aft sections of the core tank assembly.

The fuel sump is welded to the aft hemispherical section of the fuel compartment, and the oxidizer sump is bolted to the aft end of the oxidizer tank (See Fig. 3.3.1-2).

Two basic tank designs have been considered for the Agena Upper Stage. One design is the existing 6061-T6 tank with only two minor changes: addition of the 8-inch section to the fuel cylindrical section, and inverting of the oxidizer cylinder forward-to-aft taper to meet gage requirements. This is accomplished by simply welding this cylindrical section upside down into the tank assembly. The second design is substitution of 2219 aluminum for the 6061 alloy with the same 8-inch fuel cylinder extension and necessary gage changes. The existing 6061 tank retains the existing design, development, and fabrication capabilities. The 2219 tank affords a weight reduction and provides an increase in reuse compared to the 6061 design, while still retaining existing design and fabrication techniques. A summary comparison of these two approaches is shown in Fig. 3.3.1-3.

The existing 6061 tank as currently designed and fabricated is shown, i.e., without the 8-inch fuel extension and no inversion of the oxidizer cylinder. As noted in Fig. 3.3.1-3 safety-abort considerations determine the cylindrical pressure vessel gages rather than the maximum internal pressure requirements. It was assumed that no ullage pressure was available as a relieving load source during ascent (at maximum acceleration). Tank pressure stabilization is used only to the extent that fluid hydrostatics contribute during vehicle acceleration. The forward fuel tank dome and aft oxidizer tank dome gages are not pressure critical, either. A minimum gage for manufacturing and handling for the 2219 design was set at 0.020 inches. The aft fuel tank dome (common bulkhead) is designed conservatively for a 4 psig limit pressure reversal across the bulkhead. The 2219 bulkhead is identical in gage thickness to the existing Agena bulkhead, but stronger in this mode of failure because of the change in material mechanical properties.



CRITICAL COND	ITEM	SHUTTLE/AGENA: 2219 ALUM	EXISTING AGENA: 6061 ALUM	ITEM
NONE: MIN GAGE	FWD DOME	$.025^{+.000}_{-.005}$	$.035^{+.000}_{-.005}$	FWD DOME
ASCENT; 3.3g	FWD SKIRT	$.050^{+.005}_{-.000}$	$.110^{+.006}_{-.000}$	FWD SKIRT
NONE	FWD Y-RING	(1)	(1)	FWD Y-RING
ASCENT; 3.3g NO PRESSURE	FUEL BARREL	$.054^{+.000}_{-.004}$	$.067^{+.000}_{-.004}$	FUEL BARREL
NONE	CTR Y-RING	(1)	(1)	CTR-Y-RING
PRESS. REV., 5 psig	CTR DIAPHRAGM	$.051^{+.000}_{-.005}$	$.051^{+.000}_{-.005}$	CTR DIAPHRAGM
ASCENT; 3.3g NO PRESSURE	OXIDIZER BARREL	$.075^{+.000}_{-.003}$ TAPER $.063^{+.000}_{-.003}$	$.059^{+.000}_{-.003}$ TAPER $.078^{+.000}_{-.003}$	OXIDIZER BARREL
NONE	AFT Y-RING	(1)	(1)	AFT Y-RING
ASCENT; 3.3g	AFT SKIRT	$.080^{+.005}_{-.000}$	$.110^{+.006}_{-.000}$	AFT SKIRT
NONE; MIN GAGE	AFT DOME	$.025^{+.000}_{-.005}$	$.051^{+.000}_{-.006}$	AFT DOME
—	SUMPS ARE COMMON EXCEPT FOR MATERIAL CHANGE			

AGENA PROPELLANT TANK COMPARISON (2)

(1) REFER TO REF 9 FOR LOCAL THICKHESSES/DETAILS

(2) ALL SECTIONS SAME LENGTH EXCEPT FUEL BARREL, WHICH IS EXTENDED 8 INCHES.

Fig. 3.3.1-3 Agena Propellant Tank Comparison

The weights for the two tank configurations are: 2219-T87, 234 pounds (106 kg); 6061-T6, 286.6 pounds (130 kg).

Forward Equipment Section. The 40.5-inch (1.03 m) long forward section attaching to the forward skirt extension of the core tank contains provisions for installation of Agena equipment and thermal control provisions. It is a semimonocoque structure comprising magnesium alloy internal rings and longitudinal members covered by beryllium fixed skin and removable access doors. Within the cylindrical structure, a welded tubular aluminum truss frame assembly provides additional strength and facilitates the mounting of equipment. Except for the forward and aft rings of this assembly, the section is identical to the existing Ascent Agena forward section.

The forward ring will still provide for the payload interface, but must be changed in material and cross-section to provide the strength required for interface with the CBSS. This ring, to be made from 7075 aluminum, supports two trunnions to provide the forward transverse vertical support for the Agena (as shown in Fig. 3.3.1-2) while being transported to space in the cargo bay. The ring, supporting the trunnions, is designed for maximum operational transverse load occurring during landing. For purposes of preliminary design, it was assumed that the Orbiter lands with a core stage that is fully-fueled and supports a 6000 pound (2725 kg) payload. This configuration remains within Shuttle capability to land with a 25000 pound (11370 kg) payload. Should it be determined, as a result of further system studies, that this condition cannot occur, the allotted weight increase of 30 pounds (13.6 kg) may be decreased.

The aft ring of this section is adequate for this configuration, but must be modified to provide the required strength for the SOT option. Discussion of this change is presented in par. 3.3.1.3.

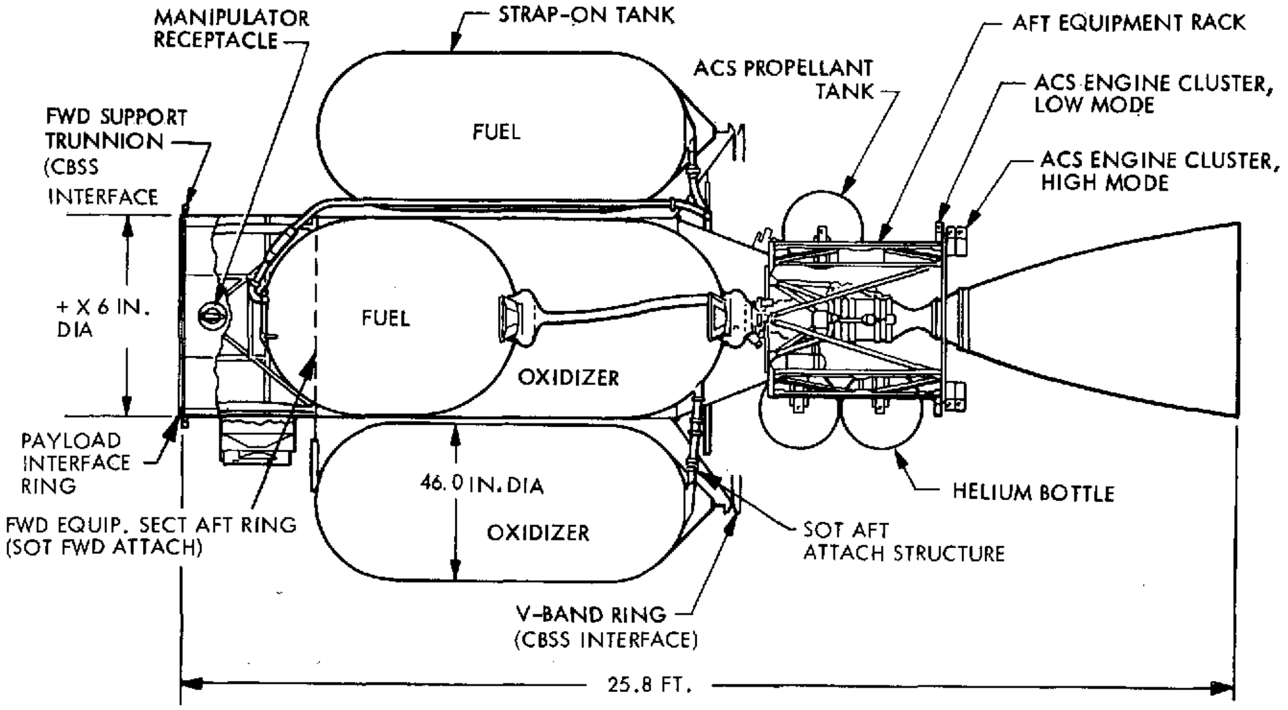
The existing Agena forward equipment section weighs 137 pounds (62.3 kg). To this value, 26 pounds (11.8 kg) are added to account for additional equipment mounting structure, and 41 pounds (18.6 kg) are added to account for the added strength required to the forward and aft rings. Although much of the 41 pounds is required only for the SOT option, it remains as scar weight to the core stage. Ten of the above 26 pounds for added equipment mounting structure are for the horizon sensor which is installed in the augmented configuration. This structure is not required for the nominal configuration.

Engine Thrust Cone. The engine thrust cone structure is an open framework, within a conical envelope, comprising magnesium alloy circular rings, longitudinal load members, and shear panels.

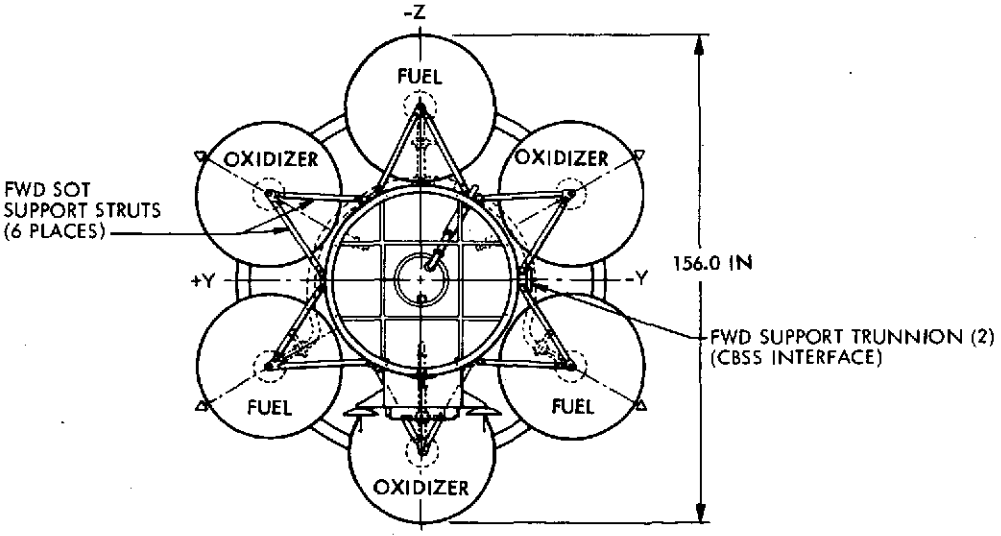
Loads to this structure are introduced from the engine mount and aft equipment rack through bolt-on fittings on the aft ring. All longitudinal loads are carried by strut members to the forward ring which attaches the cone to the aft skirt of the core tank. The redesign of this forward ring is the only design change planned for the cone structure. This ring formerly served as a separation ring, attaching the Agena to a booster adapter. The ring material, currently a magnesium forging, is to be changed to 7075-T73 Aluminum. It is to be redesigned to incorporate the interchangeability for attaching the CBSS interface V-band ring when the core stage flies without the SOT (See Fig. 3.3.1-2), or for attaching the SOT aft cone when the core stage flies with the SOT option (See Fig. 3.3.1-4). The V-band section of the ring is part of the CBSS conversion kit to convert from SOT option. The CBSS structure, mating to this ring, is discussed in par. 3.3.5.

All shear loads applied to the aft ring of the cone are considered to be carried by the conical panels, only. The structure was originally designed to cover the BAC 8096 and 8247 engine installations, both having an ultimate design thrust of 26,000 pounds (115,600 N). The current anticipated ultimate thrust is 21,000 pounds (93,300 N). The engine cone structure is capable of supporting a transverse design weight of 784 pounds (355 kg) for the maximum operational condition, the 2.5-g landing. This value is in excess of the combined weight of the engine and equipment section with all installed equipment, estimated to be 709 pounds (321 kg) including allowance for contingency.

The cone structure currently weighs 41 pounds (18.6 kg). An additional weight of 11 pounds (510 kg) is added to account for the interchangeable field joint, and 20 pounds (9.1 kg) is added to account for the V-band ring for the core stage configuration.



(SOT OPTION – END VIEW)



VIEW LOOKING AFT
INTERFACE STIFFENER AND INTERNAL
AVIONICS NOT SHOWN FOR CLARITY

Fig. 3.3.1-4 Shuttle/Agena Upper Stage – SOT Option

Aft Equipment Section. The basic aft equipment section of the Agena consists of four magnesium alloy truss frames cantilevered from the engine cone structure. The aft end of the truss frames connect to a bulkhead consisting of two segments, each spanning 80 deg (i.e., 0 deg ± 40 deg and 180 deg ± 40 deg). The truss frames and bulkhead sections are structurally augmented by aluminum alloy tubular frameworks that provide the required lateral and longitudinal structural stability. There is also one removable magnesium shear web (with two large circular cutouts) designed to support spherical bottles. The interspersing of the magnesium and aluminum elements has produced a very efficient, lightweight structure weighing 58 pounds (26.2 kg) and capable of supporting 400 pounds (181 kg) of equipment. For the case of heavy program-peculiar equipment and payloads, there exists an optional structural kit consisting of a continuous aft bulkhead and four additional shear webs, making the shape of the equipment section hexagonal in appearance. This addition makes the structure capable of supporting approximately an additional 1000 pounds (454 kg).

For the Agena Upper Stage requirements, the light weight version of the equipment section is adequate without any structural change. Some minor modifications to the web are required to mount the helium spheres.

3.3.1.3 SOT Option. The Agena Upper Stage with the strap-on-tanks and associated structure installed is defined here as the SOT option and is shown in Fig. 3.3.1-4. The core structure of this vehicle is identical to that described in par. 3.3.1.2, except for the modifications required for attachment of the SOT. With the SOT installed, the maximum propellant loading is increased from 15,000 pounds (6800 kg) to 56,000 pounds (25,400 kg). Although the combination of propellant density and mixture ratio will result in SOT fuel tanks requiring slightly less volume than the oxidizer tanks (82.71 cf versus 89.74 cf), to provide commonality, interchangeability, and lower production costs, all six tanks are designed identical in volume. As will be discussed subsequently, the required tank gages are also identical.

The SOT option comprises the addition of the six strap-on tanks, the forward and aft attach structure, and removal of the CBSS conversion kit (discussed in par. 3.3.5). The following paragraph present detailed descriptions of these structural subassemblies and the necessary modifications required to the Agena Upper Stage.

SOT Tank. The SOT tank, as shown in Fig. 3.3.1-4 is a constant thin-gage cylindrical vessel with hemispherical domes. The tank diameter of 46 inches (1.17 m) is selected because of past fabrication experience and availability of hydrospin tooling for that diameter. The tank material is 2219-T87 aluminum. The domes are to be hydrospun, machined, and then chem-milled to the final membrane thickness. The forward dome membrane thickness is .030-inches, and step-tapered to .050 -inches for edge weldment. The aft dome is chem-milled to a constant thickness of .050-inches, with no additional thickness required for weldment. The barrel section is fabricated from rolled-sheet, seam-welded, and aged before machining and chem-milling to the final membrane thickness of .030-inches, and step-tapering the edges to .050-inches for joining to the domes. No portion of the tank was designed on the basis of the maximum internal pressure. The forward dome required thickness for stress is .012-inches; the cylinder thickness, for stress, is .023-inches; and the aft dome thickness, for stress, is .012-inches. The basic membrane thickness of .030 was established to provide micrometeorite protection for a minimum period of 12-hours in space (ascent portion of the synchronous equatorial mission), with a reliability of 0.995 probability of no penetration when propellant is in the tanks.

Each of the SOTs are supported from their extremities. Pin-jointed struts attach to a small trunnion integrally welded as a thickened insert to the forward dome which incorporates an access manhole. This forward attachment is designed for lateral load support only. The critical design load was assumed to be a 2.5-g landing (with the tank full of propellant, but pressurized). A stiffened conical shell attaches tangentially to the aft-dome. An integral Y-ring juncture is provided. Both the cone structure and the aft dome are designed for the maximum acceleration condition of 3.3-g. The aft dome was thickened to .050-inches to provide adequate strength to support the tank in a vertical position, fully loaded with propellant, unpressured, and subjected to a 2-g longitudinal acceleration. Should the tank develop a leak during maximum ascent acceleration, so that only the hydrostatic and vapor pressure exist, the tank would support the load without failure (fail-safe design provision). Horizontal handling of the tank is permitted without pressurization when empty. As implied previously, vertical handling of a filled tank without pressurization is acceptable.

Each SOT, designed as discussed above, weighs 89 pounds (40.3 kg), including allowances for tolerances, discontinuities, weldments, and support structure at its extremities. (Contingency is included in the equipment list in par. 3.4).

Forward Equipment Section Modification. A design modification is required of two rings in the existing Agena forward equipment section. The forward ring design modification is required for both the basic Agena Upper Stage as well as the SOT option, because both configurations require support in the cargo bay, and interface with the CBSS.

The aft ring design modification is required, however, as the direct result of the SOT option, as shown in Fig. 3.3.1-4. Each SOT is supported at its forward extremity by two struts, which attach to fittings mounted on the aft ring. For this preliminary phase of design, it was assumed that, should it become necessary to abort, requiring the dumping of propellant prior to landing, one SOT fails to dump its propellant. This condition induces a high transverse bending moment in the ring over a 45 deg sector, during the 2.5-g landing condition. Since any one (but not all) of the six tanks is assumed to remain full, the sector loading is used to size the total ring cross-section. This design condition lead to a ring weight increase of 11 pounds.

Engine Thrust Cone Modification. A modification to the forward ring of this structural assembly is required for CBSS interface. When the vehicle flies missions requiring the SOT the V-band ring mounting to this forward ring is removed, and the SOT aft-cone structure, which supports the aft extremities of the SOT is attached. The aft-cone structure contains a mating ring at the forward point, thus combining its strength with its counterpart on the thrust cone to provide the total required strength for the change in load-path of the Agena core to the CBSS during ascent. Whereas the load during ascent is longitudinally directed thru the V-band ring in the core-only configuration, with the SOT added the load during ascent is directed outward at a 55 deg cone angle, thus introducing a compression thrust force in the plane of the ring. The 3.3-g maximum acceleration ascent condition causes the maximum loads, which size the ring. When the vehicle flies without the SOT option, part of the ring area which is associated with the SOT aft-cone structure is removed, and a scar weight of 11 pounds remains.

No other weight is added to the thrust cone when the structural conversion to the SOT option is made.

SOT Forward Attach Structure. To support the SOTs at their extremity off the Agena core vehicle, 12 pin-jointed struts are provided, forming a 6-pointed star shaped structural trussed frame around the forward equipment section and attaching to its aft ring (See Fig. 3.3.1-4, end view). These struts are designed to provide transverse pin-jointed support of the SOT. The struts are not subjected to bending or shear, but simply axial tension or compression loads with respect to the struts. All longitudinal loads on the SOT are reacted at the SOT aft-attach structure, at its aft (V-band) ring. During ascent, the longitudinal loads are reacted directly by the CBSS aft structure.

As stated previously, the most critical transverse load is assumed to occur during abort-landing, assuming one tank remains full of propellant. All struts are sized identically; i.e., the maximum compression force resulting in any one strut caused by this condition. For sizing purposes, 3.5-inch diameter magnesium alloy tubes were selected. These tubes attach to lug fittings on the forward equipment section aft ring and to the trunnions located on the forward extremity of the SOT dome. The allocated weight for this assembly including end-fittings is 36 pounds (16.3 kg).

SOT Aft-Attach Structure. To support the SOTs at their aft extremity, a conical frustum shell, fabricated from 7075 aluminum, comprises three rings and 150 zee-shaped longitudinal stringers spot-bonded to a thin conical shell.

The forward ring attaches to the forward thrust cone/core tank joint, and provides the added strength required for the load-path change for longitudinal support of the core-SOT combination during ascent.

A large ring assembly attaching to the aft end of the conical shell provides both strength and stiffness to this structure when the vehicle is not supported by the CBSS. The six SOTs attach, thru fittings, directly to this aft ring. Thus the SOT longitudinal loads are reacted by the ring and shell. This ring is sized for the Agena engine thrust accelerations. Connection to the CBSS is accomplished by a V-band extension of the ring to which the CBSS V-clamp ring mates and reacts omni-directional loads while stowed in the cargo bay, as shown in Fig. 3.3.5-1. The V-band ring also provides for vehicle alignment during retrieval operations, either in the 1-g or zero-g environment.

Although the stiffened cone shell is subjected to concentrated tension loads from the SOT occurring during the various Agena engine burns, this loading condition is not as severe as the compression loads occurring during ascent, when the cone must support the entire core weight, including payload. The maximum 3.3-g acceleration condition sized the core shell, stiffeners, and the intermediate ring which is provided to give the longitudinal stiffeners greater strength.

As a result of preliminary analyses presented in ref 3-8, the weight of this structure is estimated to be 135 pounds. This weight includes 20 pounds (9.1 kg) associated with the core stage V-band ring. The 11 pounds (5 kg) weight associated with the field joint juncture between the core tank skirt and thrust cone remains unchanged, but still contributes to the aft SOT support structure in terms of load-carrying capability.

A gross assessment of the aft SOT attach was made to determine if a change from the nominal angle of the cone frustum (55 deg) would result in decreased weight. The angle appearing to offer the best potential weight advantage is approximately 30 deg relative to the load direction. The associated length increase of the cone would be 25 inches. The longer cone design approach is assumed to be the same as for the baseline 55 deg angle (i.e., same number and type of rings, stiffeners, etc.). For this new angle, two cases were considered: SOTs relocated aft and SOTs resized. The effect on the forward SOT attach structure was included. Results of this assessment are summarized in Table 3.3.1-5.

Subject to more detailed analysis, it is concluded that the weight savings is not significant enough to warrant an angle change at this time.

Table 3.3.1-5

WEIGHT CHANGES FOR AFT SOT CONE REDESIGN(1)

	Baseline 55° Cone	30° Cone (Increase Length by 25 in.)	
		Relocate SOTs Aft	Resize SOTS (42" Dia)
SOT Aft Attach Assy (rings, shell, stiffeners)	176	158	158
SOTs (6)	534		
Relocate Aft		534	
Resize			549
Forward SOT			
Attach Assembly	36	50	32
Weight, pound (kg)	746 (338)	742 (336)	739 (335)
Δ Weight, pound (kg)	0	-4 (1.8)	-7 (3.2)

(1) Neglects Bending Loads Considerations

CBSS Attach Structure. There are two important requirements for establishing a design for Agena attachment to the CBSS. The first is to provide a physical connection in the cargo bay for reacting all loads while minimizing the weight penalty to the fly-away structure associated with these loads. The second is to provide a simple method for ingress and egress to the cargo bay, while facilitating vehicle alignment. After several considerations, the preferred CBSS concept evolved. This design is discussed in par. 3.3.5.1. To mate with this CBSS, two support trunnions at the forward support and the V-band ring at the aft support are provided.

The two forward support trunnions are required to react only transverse loads, parallel to the Orbiter Z-axis (vertical). These trunnions are rigidly connected to the forward equipment section forward ring. As stated previously, for preliminary design purposes, the critical design condition for these fittings was an assumed abort-landing, subjecting the trunnions to a 2.5-g load with the core vehicle containing propellant, and carrying the heaviest payload (an estimated combined dead weight of 23,000 pounds (10,400 kg). The design of this trunnion interface is common to both the core stage and the SOT option. There is no change to the forward section of the CBSS to accommodate either the core stage alone or with SOT added.

The V-band ring concept to react omni-directional loads is common to both core and SOT option design configurations. In the case of the core, a 60-inch diameter V-band ring is used which attaches to the engine cone/tank ring juncture and weighs 20 pounds (9 kg). For missions requiring SOT, this ring is removed, and the SOT aft attach structure has the V-band section integrated into it, but at a 110-inch diameter, for the larger CBSS mating V-clamp ring. This diameter was selected to be concentric with a circle picking up the aft attachments of the SOT. In both cases, the V-band ring facilitates vehicle positioning and alignment during installation in the cargo bay, either on the ground or in space. The SOT aft attach structure, as previously discussed, weighs 135 pounds (61 kg).

3.3.1.4 <u>Design Conditions Summary</u>. There are three basic conditions that defined the preliminary structural weights. These are (1) minimum thickness for handling and manufacturing, (2) minimum thickness for micrometeorite protection, and (3) the thickness requirement based on loads. The former two requirements established propellant tank gage limitations as previously discussed. Of all the load acceleration conditions, as defined in Table 3.3.1-1, only two were considered to be critical for structural sizing of the vehicle structure. These are as follows:

1. Orbiter end burn, at which time the Agena is subjected to 3.3-g longitudinal acceleration while stowed in the cargo bay. Maximum payload of 6000 pounds (2720 kg) is used.
2. Landing and braking, at which time the Agena is subjected to 2.5-g vertically transverse acceleration while stowed in the cargo bay. An abort case is considered whereby one SOT tank or the core tank is filled with propellant and the maximum payload of 6000 pound is used.

A third design load condition, not shown in Table 3.3.1-1, is the Agena engine ignition load after the vehicle is removed from the cargo bay in space. The maximum load condition occurs at first ignition when propellant tanks are full; this load is 0.26-g +20 percent magnification to account for dynamics.

Table 3.3.1-6 delineates the design conditions for the major structural assemblies. For the abort-landing case, the maximum payload of 6000 pound is assumed to be laterally supported to avoid dynamic amplifications to the payload which could occur if it were cantilevered off of the Agena forward equipment section.

3.3.1.5 Selected Hardware Development Status Summary. Table 3.3.1-7 presents a summary of the structures subsystem development status. The propellant management sumps and aft equipment section, both used in current Agena programs, are used as is. Equipment bracketry will be designed to support program-peculiar equipment, as required.

The forward equipment section used in current Agena programs requires only redesign of the forward and aft rings of the assembly to accommodate the CBSS support trunnions and SOT forward struts, respectively.

The connection of the engine thrust cone to the core oxidizer tank aft skirt requires a design change to incorporate interchangeability for installation of the CBSS V-band support ring and the SOT aft support structure. The engine thrust cone, itself, requires no changes.

The core tank uses the same elements now required to fabricate the existing Agena tank, with the exception of the lengthening of the fuel tank barrel section 8 inches. The tank aluminum alloy, currently 6061-T6, is being changed to 2219-T87 for the augmented configuration to provide greater strength and inherently increased safety and relaibility for reusability. Tank final thicknesses are also being changed to reflect current requirements, but raw stock sizes for forming the domes and rings remain the same for compatibility with existing production capability. Only the final machining and chem-milling operations will be modified.

The strap-on tanks, SOT forward and aft attach structure, and CBSS are new structure. The SOTs provide for increased propellant requirements and the baffles for slosh prevention on certain missions where the propellant would be off loaded. The SOT attach structure provides the necessary attachment to the core stage and

Table 3.3.1-6

DESIGN CONDITIONS SUMMARY

Structural Subsystem	Design Weight lb (kg)	Design Cond.	Alternative Design Cond.	Comments
Forward Equipment Section	203 (92)	$n_x = -3.3$	$n_z = 2.5$	No transverse load from payload. Alt. cond. is a safety-design condition.
Engine Thrust Cone	52 (236	Engine Thrust = 16,400 lb	$n_z = 2.5$	Supports 709 lb (320 kg) including its own weight.
Aft Equipment Section	58 (26.3)	Agena Max. Accel. $n_x = -5.0$	$n_z = 2.5$	Supports 340 lb (182 kg), including its own weight. Propellant almost exhausted.
Fwd SOT Suppport Structure	36 (16.3)	$n_z = 2.5$	–	Safety-design condition with one SOT full of propellant.
Aft SOT Support Structure	135 (61.3	$n_x = -3.3$	Engine Ignition $n_x = -.312$	Alternate cond. outside cargo bay.
Agena Core Tank	234 (106)	$n_x = -3.3$	$n_z = 2.5$	Comments as follows:
• Fuel Tank Fwd Skirt	–	$n_x = -3.3$	$n_z = 2.5$	Max. payload = 6000 lb (2720 kg)
• Fuel Tank Barrel	–	$n_x = -3.3$	–	Max. payload = 6000 lb, no internal pres.
• Oxidizer Tank Barrel	–	$n_x = -3.3$	–	Max. payload and fuel; no internal ullage press. Only hydrostatic head considered.
• Oxidizer Tank Aft Skirt	–	$n_x = -3.3$	–	Total axial weight considered = 22,400 lb (10,150 kg)
• Fuel Tank Dome (Fwd)	–	Not Critical	–	Min. gage for mfg = .020.
• Oxidizer Tank Dome (Aft)	–	Not critical	–	Min. gage for mfg = .020.
• Common Bulkhead	–	Neg. p = 4 psig		Assume bulkhead pressure reversal.
Strap-on Tanks	89 (40.3) (each)	$n_y = -2$ g	–	Safety-design condition for vertical handling unpressurized on aft dome only. Walls and fwd dome sized for micrometeorite protection (t = .030).

Table 3.3.1-7

STRUCTURE DEVELOPMENT STATUS

Equipment	(Agena Upper Stage)			
	Existing			New
	Supplier	Part No.	Mod Required	
Forward Equip Sec.	LMSC	1398014	Fwd and aft ring reinforcement for SOT attachment and CBSS support	
Core Tank	LMSC	1386642	Lengthen fuel sec. 8 inches Change material and tank gages for augmented configuration	
SOT (6)	LMSC		(Tooling Exists)	Yes
SOT Fwd and Aft Attachment Struct.	LMSC		–	Yes
Engine Thust Cone	LMSC	1396330	Fwd attach ring for field joint and CBSS support	
Aft Equip Section	LMSC	1395050	Use as is	
Prop Mgt Sumps	LMSC	1380550	Use as is	
Baffle	LMSC			Yes
CBSS	LMSC			Yes

provides support to the CBSS. The CBSS, with its special V-clamp ring assembly for support of the SOT option is necessary to bridge the interface eccentricities with the cargo bay and minimize the fly-away weight. This structure is provided with a conversion kit which permits the CBSS to support the core stage separately when the SOTs are not required. The V-clamp ring assembly concept is preserved with the conversion. This V-clamp assembly also acts as a guide for Agena retrieval into the CBSS either in space or during ground sequences.

If auxiliary supports are not available for this payload while in the Orbiter, the added bending moments on the Agena would require additional strength in some of the Agena structure. A preliminary assessment of the impact of accommodating the bending has been made, and a conservative weight of 143.1 pounds (65.0 kg) would be required for the failure case of zero pressure in the core tanks. Dynamic effects have not been analyzed. The affected assemblies are as follows:

Core tank skirts	0.7 lb	(0.3 kg)
Core fuel tank	7.0 lb	(3.2 kg)
Core Ox tank	51.9 lb	(23.5 kg)
SOT Aft Attach Structure	15.7 lb	(7.1 kg)
Core Forward Rack	5.3 lb	(2.4 kg)
Total	80.6 lb	(36.5 kg)

The values for the core tank relate to the existing 6061-T6 design which has allowable strength in the domes greater than that required for Agena Upper Stage application. Therefore the Δ weight shown for the core tank can be significantly decreased by gage reduction to required thicknesses. The weight of the CBSS and its core kit include effects of bending loads.

3.3.2 Propulsion Systems

3.3.2.1 General Description. The propulsion system for the Shuttle/Agena Upper Stage uses the Bell Aerosystems Company (BAC) 8096L rocket engine and monomethyl hydrazine (MMH) and high density acid (HDA) as the fuel and oxidizer respectively. The existing Agena thrust vector control (TVC) system can be used with the 8096L engine.

The current Agena pyro-controlled orifice-fed helium pressurization system is replaced by a regulated system. The system also incorporates tank relief valves and a safety control circuit to maintain fuel tank pressure greater than oxidizer tank pressure. The helium is stored at high pressure and ambient temperatures.

A propellant management system featuring sumps utilizing capillary retention and refill is incorporated in the core propellant tanks and ensures gas free propellants to the rocket engine. These devices are currently in development for a specific type of Agena vehicle and are modified by removing the acquisition sponge. The strap-on tanks (SOT) have small sumps and gas arrestors to permit the propellant to drain completely from each tank. The engine feed, fill, and vent system is slightly modified from that on the present Agena and the transfer lines from the SOT are manifolded and routed to the core tank so that the propellant drains from all SOTs simultaneously into the core tanks.

The hydrazine reaction control system (RCS) uses components presently flying on LMSC-built space vehicles. The system uses a set of high (8-18 pounds thrust) and a set of low (0.3 to 0.6 pounds thrust) mode thrusters. Another set of high mode thrusters is used for back up. The propellant tank is identical to one used on current vehicles.

3.3.2.2 Engine. The engine selected for the Shuttle/Agena Upper Stage is the BAC 8096L, a modified version of the 8096 engine used on the current Agena vehicles. The BAC 8096L uses HDA/MMH + silicone oil (SO) as the propellants. It is pump fed, using a gas generator, turbine, and gear box to drive the pump. A multi-start system similar to that developed for the Gemini Agena BAC 8247 engine is incorporated. As pressure in the pumps builds up, propellant flows to the gas generator to maintain steady-state operation. The thrust chamber is regeneratively cooled by HDA and the columbium nozzle extension is radiatively cooled. The engine is shown in Fig. 3.3.2-1 with an indication of the few modifications to go from the existing 8096 to the 8096L. A schematic of the engine is shown in Fig. 3.3.2-2.

Engine and Propellant Selection. The selection of the BAC 8096L engine and the particular propellant combination was made for a combination of reasons. In keeping with the groundrule that as much existing Agena equipment as possible would be used, and that other components and subsystems would be modified as little as possible, the Agena engine derivatives were selected. Studies showed that the engine derivatives that used HDA/MMH or N_2O_4/MMH provided the greatest performance, with the system that uses N_2O_4/MMH slightly better by about 3 percent. Analyses indicated that vehicles with either HDA or N_2O_4 captured the same number of missions.

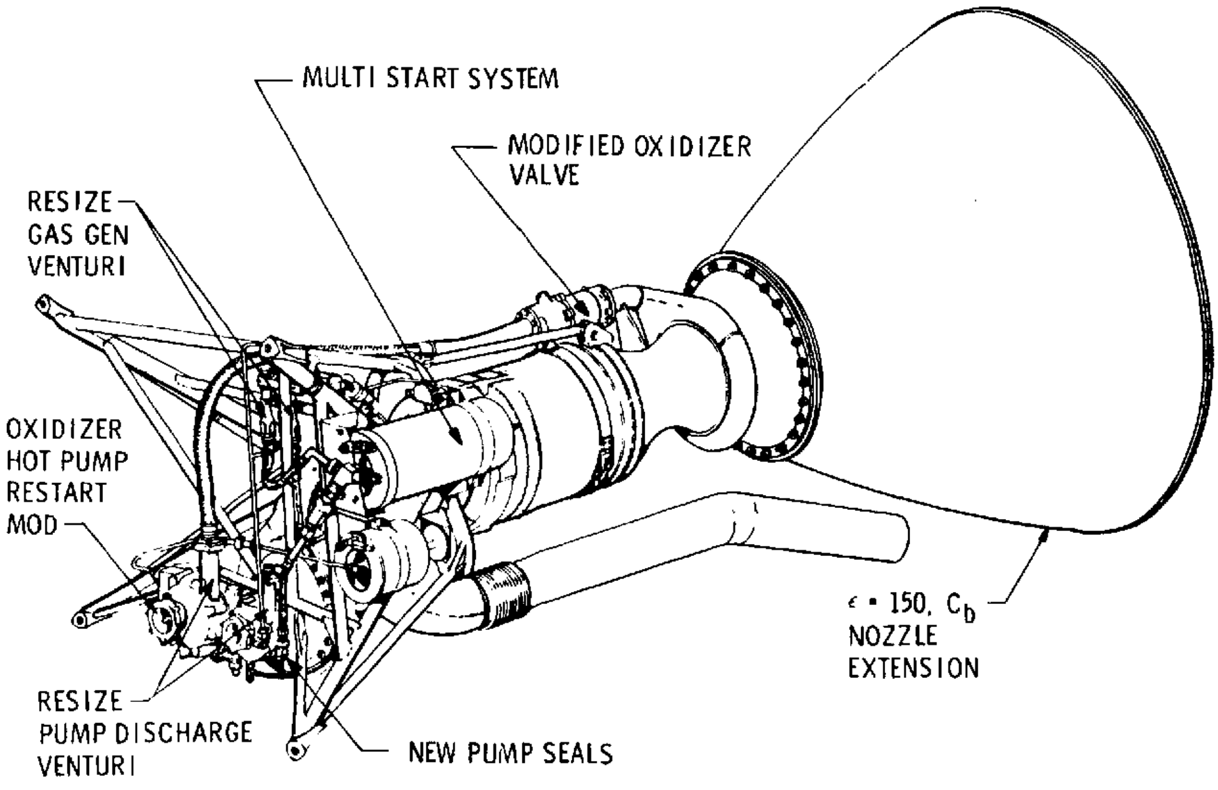


Fig. 3.3.2-1 8096L Agena Engine Modifications

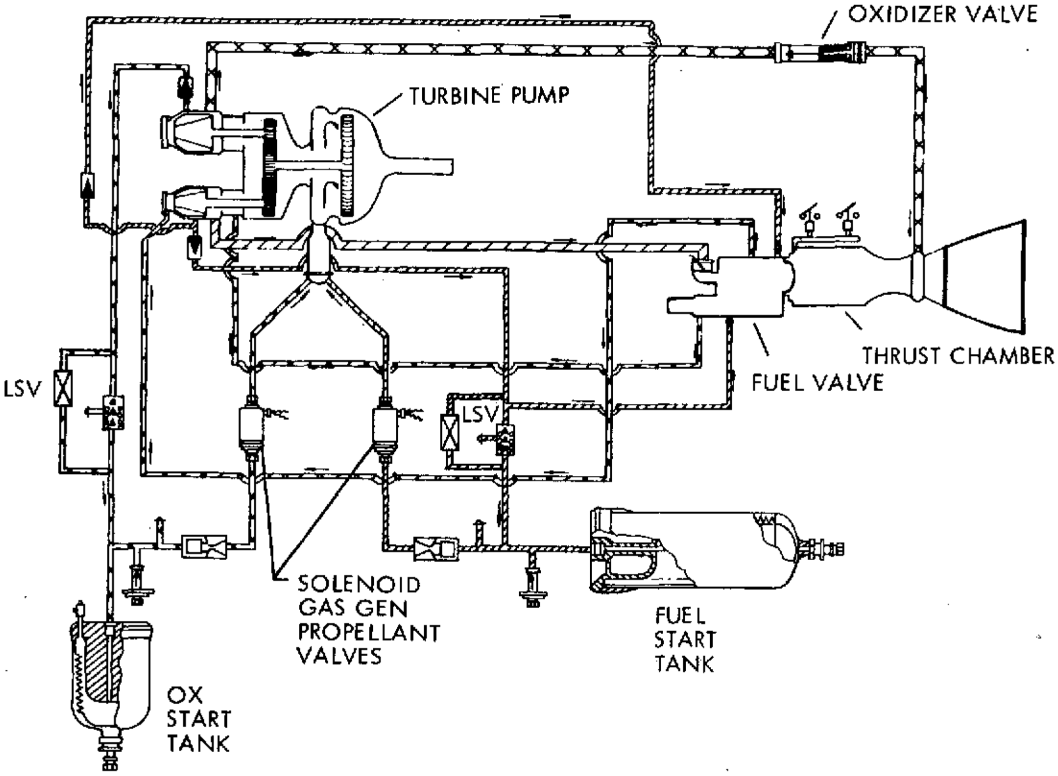


Fig. 3.3.2-2 Agena Engine Multistart System

Furthermore, cost analyses indicated that the development of the HDA/MMH engine would be less than the N_2O_4/MMH engine primarily because the HDA is already being used in Agena flight vehicles and significant Government-sponsored and in-house development has been accomplished. Thus the selection of the 8096L engine with the HDA/MMH propellant represents a good compromise among performance, cost, and development risk.

Performance. A comparison of the performance and operating parameters of the existing Agena engine with the 8096L and the 8096B is shown in Table 3.3.2-1. The large improvement in specific impulse of the 8096L and 8096B as compared to the 8096 is made possible by the incorporation of a baffled injector and use of higher energy propellants. The specific impulse as computed and modified by test data by BAC is shown in Table 3.3.2-1. The breakdown of performance is shown in Table 3.3.2-2 and parametric data of weight, length, and specific impulse is shown in Fig. 3.3.2-3. Additional engine characteristics data are shown in Table 3.3.2-3.

Table 3.3.2-1

AGENA ENGINE PERFORMANCE CHARACTERISTICS

		Current Baseline 8096	8096L	8096B
Propellants		HDA/UDMH	HDA/MMH + SO*	NTO/MMH + SO
Thrust, lbf vac (Newton) ±2.45%		16,000 (71,100)	16,000 (71,100)	16,000 (71,100)
Area Ratio		45:1	100:1/150:1	100:1/150:1
Chamber Pressure, PSIA, (N/M^2)		505 (3.49×10^6)	484 (3.34×10^6)	486 (3.34×10^6)
VAC Specific Impulse (Sec) ±0.61%		295	321/324	327/330
Mixture Ratio (Ox/F) ±0.8%		2.69	2.03	1.78
Pump Inlet Pressure PSIA (N/M^2) (Minimum at 60°F)	OX	12 (0.83×10^6)	16.5 (1.13×10^6)	23 (1.58×10^6)
	Fuel	12 (0.83×10^6)	12.7 (0.88×10^6)	12 (0.83×10^6)
Pump Inlet Temperature °F (°K)		20 – 80 (267-300)	20 – 80 (267-300)	20 – 80 (267-300)
Max Single Burn (Sec)		240 (Spec)	1200	1200
Total Starts		3	10 To 100	200
Min Time Between Burns (Sec)		15	15	15
Time to 90% Thrust (Sec)		1.13 ±0.1	1.0	0.90 ±0.1
Preflow Weight, lb, (kg)	OX	9.5 (4.3)	9.5 (4.3)	6.7 (3.0)
	Fuel	0.7 (0.32)	0.8 (0.36)	1.2 (0.55)
Post Flow Weight, lb, (kg)	OX	23.8 (10.8)	14.0 (6.3)	14.0 (6.3)
	Fuel	0.9 (0.4)	1.0 (0.45)	1.0 (0.45)
Shutdown Impulse, lb-sec, (N-Sec)		2330 ±388 (Fast) (10400) ±1730	3100 ±365 (13800) ±1630	2900 ±365 (13000) ±1630

*SO = Silicone Oil

Table 3.3.2-2

BELL 8096 ENGINE PERFORMANCE DERIVATION

	8096	8096 L	8096 B	
Injector	Production	Optimized	Optimized	
Propellants	HDA/UDMH+SO	HDA/UDMH + SO	N_2O_4/MMH + SO	
Area Ratio	45:1	100/150	100	133
THEORETICAL				
Mixture Ratio		2.33	2.15	2.15
ODK Peak I_{sp}		335.2	345.4	345.7
THRUST CHAMBER				
Core O/F	3.54	2.81	2.14	2.14
Barrier O/F	1.37	1.50	0.70	0.90
Barrier Flow %	17.2	13.0	13.0	13.0
Overall T.C. O/F	2.94	2.1	1.9	1.90
T.C. I_{sp} (Includes) Bl. 3D, Two Zone)	302.3	328.0	333.4	334.1
TEST CORRELATION				
c* Two Zone, Calc.	5250.0			
c* Test	5210.0			
ΔI_{sp} (From c*)	2.4	~1.5	~1.5	~1.5
Net TC I_{sp}	299.9	326.5	331.9	332.6
ENGINE				
Engine O/F	2.69	2.03	1.75	1.78
TPA I_{sp} Loss, Secs	5.0	5.0	5.0	5.0
Net Engine, I_{sp}	294.9	321.5/324	326.9	327.6
Flight I_{sp}	295.0			
TC DRILL ANGLE DEG	34	34	34	40
% Bell (Nozzle Ext)	85	100	100	90

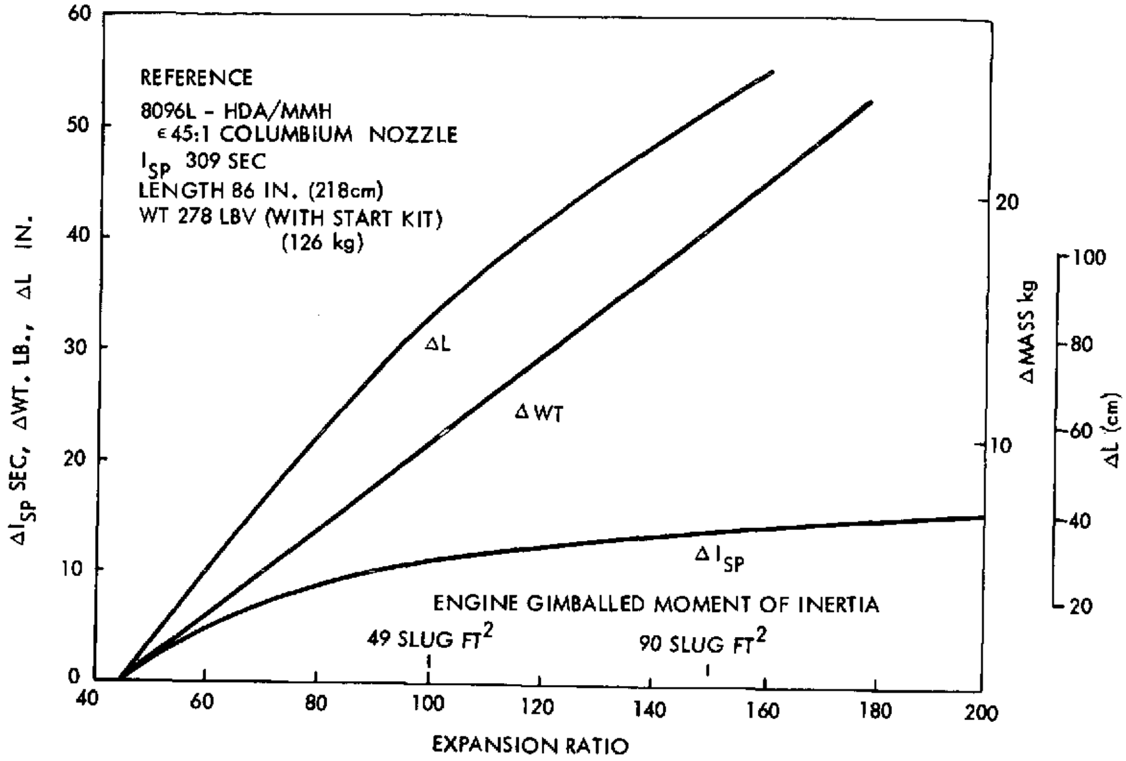


Fig. 3.3.2-3 8096L Engine Performance Sensitivities

Engine Modification and Improvements. HDA/MMH were selected as the best propellant combination for the Agena Upper Stage. Since the current Agena used either IRFNA/ UDMH or the HDA/UDMH-SO, an engine improvement program was undertaken by LMSC and BAC to demonstrate the ability of the 8096 to use HDA/MMH with only minor modifications. It was found in the HDA program that the oxidizer could continue to be used in the regenerative cooling jacket if 1 percent silicone fluid (SO) was added to the UDMH fuel. The silicone fluid deposits a silicone dioxide coating on the chamber wall and reduces nozzle heat flux (Q/A) significantly. This reduction in Q/A results in the HDA having sufficient cooling capacity so the cooling concept of the engine did not have to be changed.

Government sponsored investigation of the physical and solubility characteristics of silicone oil led to the selection of hexamethyldisilazone (HMZ) as the additive to MMH. Cooling verification (water-cooled hot fire) tests were run and significant reductions in Q/A occurred. On the basis of these test results, 1.5 percent HMZ was selected

Table 3.3.2-3

AGENA ENGINE CHARACTERISTICS

	Current Baseline 8096	8096L	8096B	Reasons For Change
Envelope (in.) 100:1 ϵ 150:1 ϵ	83.2 x 32.5D	120 L x 48D	120 L x 48D	
Weight (lb)	296 Dry (Start Cartridges)	300 Dry 318 (150:1)	290 Dry	Includes 100: 1 Nozzle and Start Tanks
Engine Mount	Truss Assembly	Existing 8096	Existing 8096	
Pump Installation	Forward Position	Existing 8096	Existing 8096	
Gimbal - Angle (Deg)	±2.5	±3.0 Cap To ±5.0	±3.0	
Engine Orientation (TPA Position Looking Fwd)	3 O'Clock	6 O'Clock	6 O'Clock	• Prevent Oil Leakage
TC Barrel		Same Length	Same Length	• Use Existing Actuator
Coolant Passage	–	–	Decrease Diameter	• Flow Velocity Increase
Injector/Ignition	• Flat-Face Injector • Pilot Fuel Flow	5 Legged Baffle Pilot Flow	• 5-Legged Baffle • Pilot Fuel Flow	• Increased Performance
Start System	Solid Propellant Cartridges	Start Tank System Dry at Launch and Landing	Start Tank System - (1) Dry at Launch and Landing	• Mission Flexibility • Safety
Propellant Utilization	Passive	Passive	Passive	
Pump Seals	N_2 Lip Seal	Improve Design	Improved Design, Min B/O Torque Vs. Lipseal Press	• Minimize Leakage • Increase Reliability
Fuel Valve	–	Existing 8096	Existing 8096	
Oxidizer Valve	–	Torque Motor	Torque Motor	• Reduce S/D Losses
Burst Discs	Yes	Yes	Yes	
Exhaust Duct	Round Exit Plane	Redesign	Redesign (TBD)	• Gas Impingement
Hot Pump Restart	–	Min Mod Design	Redesign for HPR	Anod and Bearing Change
Reusability - Mount - TPA - TCA - NE - Seals		Limited Demo Test - Reuse Determined After Each Flight	26 Reuse Demo Test Goal	
Safety		Piv Relocation	Piv Relocation for Dry Engine in Cargo Bay	• Safety in Cargo Bay

(1) Suction Start Required for 1st Burn

as the additive. In addition, analyses were conducted to determine the effect of increased coolant velocity and the results indicate that a propellant temperature of 90 deg F a coolant margin of 50 percent will exist, thus confirming the capability of the BAC 8096L to operate on the selected propellants.

To meet the requirement for a dynamically stable injector that will damp overpressures induced by suitably sized bombs located in the most sensitive position within 40 msec to within ± 5 psi of steady state pressure, the 8096 injector has been redesigned to incorporate a five-legged baffle. The baffle design is based on BAC experience. Injector level testing is in progress and adequate performance and reliability have been demonstrated. A current customer has contracted to have a baffled injector incorporated in the 8096 engine (HDA-UDMH + SO propellants).

The 8096 turbine pump assembly can be used with minor changes. A comparison of pump requirements between the present IRFNA/UDMH propellants and the HDA/MMH is shown in Table 3.3.2-4. The total horsepower requirements are similar. Pump

Table 3.3.2-4

TURBINE PUMP ASSEMBLY COMPARISON

	IRFNA/ UDMH	HDA/ MMH+SO	
Head Rise, Ft			
Ox Pump	1340	1340	Same Impeller Diameter and Rotative Speed
Fuel Pump	2150	2150	
Capacity, GPM			
Ox Pump	180	146	Resize Pump Discharge Venturi
Fuel Pump	139	135	
Brake HP			
Ox Pump	212	178	Shaft and Bearing Margins - O. K.
Fuel Pump	159	169	
Total	371	347	
Turbine			
Flowrate, Lb/Sec	1.6	1.3	Resize Gas Generator Venturi
Temperature, °K	1050	1105	Material Margin - O. K.

discharge venturis and gas generator venturis will require resizing, but the major components, i.e., turbine, gears and pumps can be used as is. The oxidizer pump will require modification to a stainless steel bearing support and the pump housing will require anodizing to meet hot pump start requirements. The hot gas-driven turbine leads to heat soak-back from the turbine manifold into the pumps after shutdown. On the current 8096 engine the pump temperature peaks at approximately 220 deg F about 60 minutes after shutdown.

An analysis of the six types of missions specified for the study showed that situations exist where engine restart is required at times when the pump is still hot. This is shown in Table 3.3.2-5. The boxed figures indicate the hot pump restart (HPR) conditions. At these condtions, sufficient heat is available to the HDA when it impinges on the pump to cause evaporation and eventually boiling. Methods of preventing boilout were evaluated and passive thermal control means were favored. A summary of the peak temperatures (with margin included) and corresponding required oxidizer pressures are shown in Table 3.3.2-6. The 11-mil anodized pump housing and

Table 3.3.2-5

HOT PUMP RESTART REQUIREMENTS

Type of Mission	I Syn Eq		II High Energy (ETR)		III Planetary		IV Hi Inc (Circ)		VA Hi Inc (Ellipt)		VB Hi Energy (WTR)	
	Burn Time (sec)	Hrs to Restart	Burn Time (sec)	Hrs to Restart	Burn Time (sec)	Hrs to Restart	Burn Time (sec)	Hrs to Restart	Burn Time (sec)	Hrs to Restart	Burn Time (sec)	Hrs to Restart
	393	2.9	336	2.8	462	4.6	8.9	0.8	35	2.1	321	2.8
Mission	245	5.3	259	8.8	287	0.2	8.1	1.0	9.2	1.3	247	5.8
Burn	235	1-25	129	15.0	100	9.5	4.4	0.8	3.0	74.1	123	6.0
Schedule	104	5.3	11.2	5.3	4.5	17.3	4.3	–	2.5	1.2	103	5.5
	43	2.9	10.7	4.3	93	–			14.5	3.6	46	2.7
	31	–	103	5.5					11.0	–	28	–
			46	2.7								
			28	–								

Table 3.3.2-6

OXIDIZER HOT PUMP RESTART DESIGN REQUIREMENTS
(1200 Seconds Burn Duration)

Oxidizer	Bearing Support and Housing Design	Pump Peak Temp ($^{\circ}$F) ($^{\circ}$K)	Tank Pressure(1) 50°F(2)	Psia, (N/M^2) 80°F(2)
IRFNA	Existing Aluminum No Coating	240 (390)	17 (1.17 x 10^5)	23 (1.88 x 10^5)
HDA	Stainless Steel 11 MIL Anodized Housing	209 (372)	25 (1.72 x 10^5)	32 (2.2 x 10^5)
NTO	Stainless Steel 11 MIL Anodized Housing	214 (375)	53 (3.65 x 10^5)	58 (42) (3) (3.99 x 10^5) (2.9 x 10^5)

(1) Based on static criteria

(2) Propellant temperature

(3) Expected value with pump spin up and valve command opening

stainless steel bearing support methods of reducting the pump temperature and heat transfer to the oxidizer so that acceptable pressures and temperatures can be achieved. The tests and data are based on conditions where the pump is static. During normal operation the pump would be in the process of spinning up and less boiling occurs. In addition, the tests were conducted simulating a closed oxidizer valve downstream of the pump. This prevents flow-through during the start process and aggravates the boilout problem. As opposed to the existing spring-loaded valve with a torque-powered oxidizer valve in the 8096L engine, the oxidizer flows through the pump sooner and less boiling occurs. When these dynamic conditions are considered, the 32 psia pump inlet pressure used in the study can probably be reduced. Thus the heat soak-back and oxidizer boil-out phenomenon can be handled, and little development risk is involved.

A comparative evaluation of available start system options was conducted to establish the best system to select for the engine. Options considered were:

- Suction Start (main tank head start)
- Rechargeable start tanks (with and without dump capability)
- Solid propellant cartridges (with and without suction start capability)
- EMPA start system (electric motor pump assembly)

The results presented in Table 3.3.2-7 show suction start and start tanks rank about equal, with EMPA also about equal if an integrated secondary propulsion system (ISPS) is incorporated. The start tank system was selected to minimize development risk related to hot pump restart.

Table 3.3.2-7

START SYSTEM SELECTION (LOW SCORE PREFERENCE)

	Suction Start	Start Tanks	Solid Charge Only	Solid	EMPA (w/ISPS)
Weight	1	6	4	4	2
Cost – R	1	6	4	5	2
NR	6	5	1	7	3
D/Q Status	5	1	1	4	3
Start Trans	5	1	1	4	3
Mission Flex	1	1	10	2	1
HPR Impact	6	1	1	1	3
Safety	1	2	3	3	2
Reliability	1	2	2	2	3
Reusability	1	2	4	3	2
Maintainability	1	2	3	3	4
Total Score	29	29	34	38	28

Eliminated
By Mission
Requirements (> 3 starts)

R = Recurring NR = Nonrecurring D/Q = Design/Qual

For safety purposes the start system is configured to launch and return with tanks empty. This requires that the first burn utilize suction start, which is acceptable with cold pumps. Hot pump restart impact on suction start should be investigated during development and if capability is proven, the start tanks can be deleted with weight reduction benefits.

The multi-start kit consists of oxidizer and fuel start tanks, check valves, fill valves, solenoid gas generator propellant valves, and appropriate interconnect lines and controls. The system shown schematically in Fig. 3.3.2-2 uses pressurized bellows tanks to supply propellant to the gas generator during the start period. As pump speed increases, pump pressure increases and automatically opens the check valves when it is greater than start tank pressure which has been decaying (blowing down) as propellants are expelled. As the pump reaches rated speed, the start tanks are automatically refilled, compressing the pressurant to the nominal 1000 psia (6.9×10^6 N/M^2). The first start is by suction (main tank) pressure and the start tanks are filled during the first start transient. After the last burn the propellant in the start tanks is discharged via the latching solenoid valve (LSV) to the overboard dump. Because the bellows have multi-cycle capability (50,000), the start system has a large restart capability margin as well as inherently high reuse capability.

3.3.2.3 Main Engine Thrust Vector Control. The main engine incorporates a square pattern gimbal capability. Hydraulic power for the gimbal servoactuators will be supplied by the existing flight qualified Agena hydraulic power package (HPP). High pressure fuel, bled from the engine fuel pump, powers a gear type motor which drives the hydraulic pump. The hydraulic system supplies hydraulic fluid at approximately 3000 psia (20.7×10^6 N/M^2) to the pitch and yaw servoactuators.

Studies were conducted to determine if the present HPP can supply the power required for the 100:1 and 150:1 nozzle extension on the 8096L (present 8096 has a 45:1 nozzle). The response rate of the engine gimbal will be slower with the large nozzles, but an assessment verified that the gimbal rate can be maintained fast enough to assure vehicle control. The gimbal rate response time constant is J/B, where J is the engine gimballed inertia and B is the damping term. The inertias are 36, 49 and 90 ft-lb-sec^2 for the 45:1, 100:1, and 150:1 nozzle extensions, respectively. The value of B is approximately 650 ft-lb-sec for the existing controls electronics and hydraulic pump/servoactuator combination. This value includes effects of thrust misalignment, dynamic friction and related restraints. Therefore, the response time will be 55, 75, and 140 msec, respectively. This longer time response was assessed relative to nozzle gimbal capability with the existing TVC during both steady state and engine start transient conditions. The start transient represents the worst case. To ensure that the gyro reference is not lost, the gimbal rate capability must be high enough to prevent saturating the gyros (primary criteria). In this case the gyros are rate limited. The minimum value of gimbal rate can be found by setting the engine gimbal at its maximum setting, setting the vehicle rate equal to the gyro rate limit, and using the lowest moment of inertia. Under these conditions the minimum gimbal rate is 3 to 5 deg/sec. This is well within the existing gimbal rate of 15 deg/sec.

The maximum engine gimbal angle without making modifications to the aft rack, and using the currently used servoactuators, is 2.8 degrees. By using the existing servoactuators and by making minor modifications to the aft rack, a gimbal angle of 6.5 degree (square pattern) can be achieved. A gimbal angle of 2.8 degrees will track a CG off-set of 4 to 5 inches for a full vehicle and about 8-10 inches for a partially empty vehicle, depending on payload and its longitudinal CG location. The maximum expected CG offset under realistic orbit conditions and associated thermal-heating is about 1.5 inches for a 10 deg F temperature differential in the strap-on tanks and about 3.6 inches for a 30 deg F temperature differential. The temperature differential will be less than 10 deg F for insulated SOTs and less than 30 deg F on noninsulated SOTs.

Thus the CG offset is always within the 2.8 degree gimbal capability which produces the minimum required gimbal rate of 3 to 5 deg/sec which is in turn less than the capability of the existing rate of 15 deg/sec. Therefore the existing hydraulic power package and servoactuators can be used.

C-2

3.3.2.4 Pressurization/Feed/Fill/Drain.

System Description and Operation. The pressurization/feed/fill drain system for the Shuttle/Agena Upper Stage is shown schematically in Fig. 3.3.2-4. The blowdown helium pressurization system presently used for the Agena has been changed to a regulated pressurization system primarily to meet the variable requirements. The normal propellant feed system on the Agena has been retained between the core tank and the engine. The lines that transfer the propellant from the strap-on tanks are in effect manifolded at the aft end of the tank cluster. The oxidizer transfer lines lead directly into the oxidizer core tank and the core thus acts as the manifold. The fuel lines are manifolded together in a ring and a stand pipe transfers the fuel from the ring to the top of the fuel tank. The Agena fill and drain system is modified by incorporating parallel redundant shut off valves and an open disconnect as compared to only a closing disconnect. This change is required to meet the abort dump and other safety requirements.

Normal Pressurization and Feed System Operation. The primary propulsion system pressurization is supplied by two helium tanks located on the aft rack and controlled by separate regulators for the HDA and MMH. After the Agena is placed in orbit the parallel redundant isolation valves are opened and the gas flows through the regulators to pressurize the strap-on tanks (SOT). The core tank is isolated from the pressurant supply at this time.

Pressure relief is provided by redundant vent valves. These valves are operated by signals from a pressure controller which receives pressure data from triple transducers in the propellant tanks. If pressure increases occur in the SOT, following propellant depletion and isolation from the core tank, the pressurization line isolation valves are opened and if necessary, the valves in the transfer lines are also opened to permit venting.

To initiate engine start the propellant isolation valves (PIV) are opened and the start signal is given to the engine. As propellant flows from the core tank it is replaced by propellant flowing from the strap-on tanks to the core tank. The propellant flows simultaneously from each strap-on tank so that they empty at the same time. During

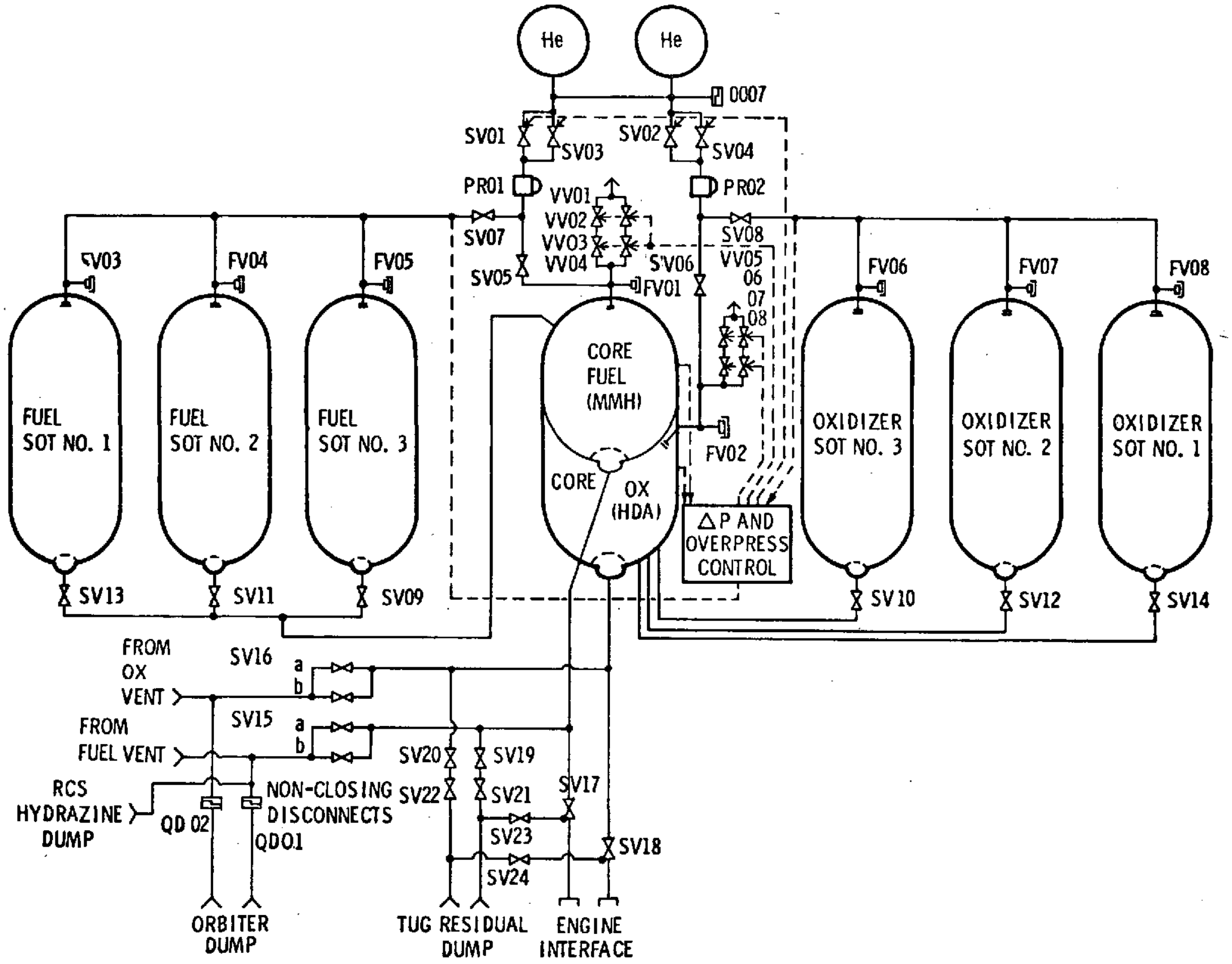


Fig. 3.3.2-4 Pressurization/Feed/Fill/Drain Schematic

coast periods the valves in the transfer lines between the SOTs and the core tank are closed. This maintains propellants in the lines and ensures that the propellant retention/feed heads are always wet. There is a small chance that the propellant might migrate from one tank to another through the small pressurization lines because of thermal gradients between the tanks. However after engine start the propellant levels will settle due to engine thrust and propellant usage. When the SOTs are emply, the valves in the transfer lines are closed and remain closed during subsequent engine operations. Also, after the SOTs are empty the valves in the SOT pressurization lines are closed and the valves in the core pressurization line are opened. All propellant for subsequent burns is supplied from the core tank.

During each engine operation the PIVs are opened at start and closed at shutdown. A vent in the PIV permits propellants trapped in the engine between the PIVs and the engine valves to vent to space.

The residuals in the core tank are dumped on orbit through series redundant dump valves and lines routed along the turbine exhaust duct. First HDA and then MMH is dumped. After pressure decays, the residual dump valves are closed and the pressurization isolation valves are opened. The MMH pressurant supply valves are opened first to ensure a positive pressure across the common bulkhead.

The Agena is retrieved into the cargo bay and the vent and dump disconnects are reconnected. * Tank pressure control is automatic, or by command override from the mission specialist station.

A sequence of events for the main propulsion system is provided in Table 3.3.2-8. An abort dump sequence is presented in par. 3.6.2.

Engine and Tank Pressure and Helium Requirement. Values of pressures required at the pump inlets for the 8096L engine are shown in Fig. 3.3.2-5.

The values selected are 32 psia (0.22×10^6 N/M^2) for HDA and 17 psia (0.117×10^6 N/M^2) for the fuel at a propellant temperature of 80 deg F (300 deg K).

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*The Agena electrical umbilical is also reconnected.

Table 3.3.2-8

MAIN PROPULSION SYSTEM – SEQUENCE OF EVENTS

– Normal Operation –

Prelaunch (In Orbiter)

Condition: All propellants and helium have been loaded and tanks are pressurized to 22 psia (ox) and 31 psia (fuel).

1. Open all transfer line valves – SV13, SV11, SV09, SV10, SV12, SV14, and pressurization isolation valves SV07, SV08.

Launch, Ascent, and Orbit/Injections – Prepare to Deploy

1. Disconnect QD02, QD01.

Deploy Agena – Orbit Operations

Condition: After the separation distance between the Orbiter and the Agena is sufficient and after the vehicle is stabilized and oriented, main propulsion system is initiated.

1. Open SV01-03, SV02-04. Regulators PR01 and PR02 control pressure. SOTs are pressurized to a nominal 31 psia (ox) and 36 psia (fuel). (Due to regulator lockup pressure increment the actual nominal lockup pressure is 35 psia (ox) and 40 psia fuel). Open SV23 and 24 (PIV valve vent line shut of valves)
2. Open PIVs – SV17 and SV18
3. Initiate engine operation – Preflow to 90% thrust – 10.2 lb
4. Engine operation for 689 seconds
5. Engine shutdown – helium valves SV01-03, SV02-04, engine valves and SV17 and SV18
6. Post flow and engine trapped propellant vent – 42.3 lb (SOTs are now 84% empty)

Table 3.3.2-8 (Cont)

7. Close SV13, SV11, SV09, SV10, SV12, SV14
8. Coast 5.27 hours
9. Open SV01-03, SV02-04, SV13, SV11, SV09, SV10, SV12, and SV14
10. Open PIVs – SV17 and SV18
11. Initiate engine operation preflow 10.2 lb
12. Engine operation for about 131 seconds
13. Close SV13, SV11, SV09, SV10, SV12, and SV14 as the propellant is expelled from the SOTs.
14. Close SV07, SV08. Open SV05, SV06 (Core tanks are now isolated and all propellant for subsequent burns will be withdrawn from the core tank. SOTs are at nominal regulator pressure; 31 psia ox, psia fuel.) Continue engine operation for about 108 sec.
15. Engine shutdown – close engine valves and SV17 and SV18
16. Post flow and engine trapped propellant vent 42.3 lb. (SOTs are now empty and core tank is about 40% empty)
17. Coast 11.5 hours
18. Open PIVs SV17 and SV18
19. Initiate engine operation – preflow 10.2 lb
20. Engine operation for 106 sec
21. Engine shutdown – close engine valves and SV17 and SV18
22. Post flow and engine trapped propellant vent 42.3 lb (Core is now 75 percent empty)
23. Coast 5.27 hours
24. Open PIVs – SV17 and SV18
25. Initiate engine operation – preflow 10.2 lb
26. Engine operation for 44 seconds
27. Engine shutdown – close engine valves and SV17 and SV18

Table 3.3.2-8 (Cont)

28. Post flow and engine trapped propellant vent – 42.3 lb (Core is now 90 percent empty)

29. Coast 2.8 hours

30. Open PIVs – SV17 and SV18

31. Initiate engine operation – preflow 10.2 lb

32. Engine operation 30 sec

33. Engine shutdown – close engine valves and SV17 and SV18

34. Post flow and engine trapped propellant vent 42.3 lb. Open latching solenoid valves on engine and discharge high pressure propellant back through pumps and overboard vent

35. Close helium isolation valves SV01-03, SV02-04

36. Now in the vicinity of the Orbiter. Coast 1.5 to 2 hours or more.

37. During coast initiate residual dump – open SV20 and SV22 – oxidizer residuals dump is initiated.

38. At approximately 100 sec after oxidizer residual dump valves are opened, open fuel residual dump valves SV19 and SV21 (The fuel and oxidizer residual dump valves are series redundant to prevent a single point leak into the Orbiter.)

39. After approximately 20 sec after oxidizer vent valves are opened gaseous flow begins

40. After approximately 20 sec after the fuel vent valves are opened gaseous flow begins

41. At approximately 100 sec after initiation of oxidizer vent the oxidizer and fuel tank pressures are approximately 2 psia. Fuel tank pressure is decaying more rapidly than oxidizer tank pressure.

42. Close fuel residuals dump valves SV19 and SV21

43. About 20 sec later, close oxidizer tank residuals dump valves – SV20, SV22

44. Close engine vent valves SV23 – SV24

45. Open SV07. Equalize pressure in SOT and core fuel tanks (total pressure 26 psia)

Table 3.3.2-8 (Cont)

46. Open SV08 equalize pressure in SOT and core oxidizer tanks (total pressure 23 psia)
47. Propulsion system can now be deactivated
48. Retrieve Agena

Agena in Orbiter

1. Reconnect QD01, QD02
2. Reconnect electrical umbilical.
3. For normal operation no other valves need to be opened or closed until the vehicle is in the refurbishment center.

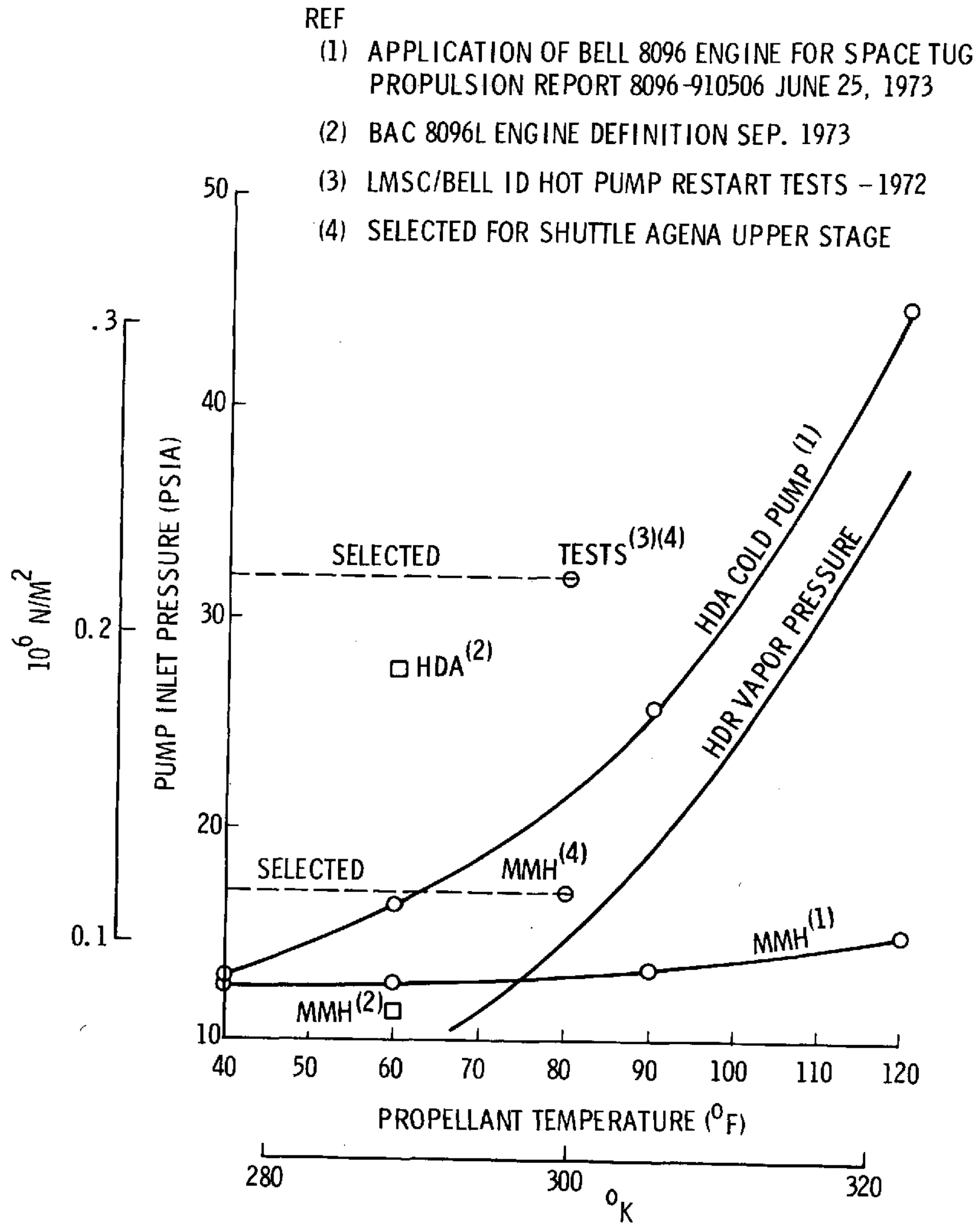


Fig. 3.3.2-5 Engine Pressure Requirements

The 32 psia (0.22 x 10^6 N/M^2) is established on the basis of hot pump restart tests. The 17 psia (0.177 x 10^6 N/M^2) is established based on a conservative value of 4 psia greater than that required for cold pump start in order to ensure that sufficient suppression pressure is available, and is less than the value of fuel pressure required when atmospheric pressure and/or common bulkhead pressure increment requirements are considered.

The tank pressure requirements for the Shuttle/Agena are included in Table 3.3.2-9. In the oxidizer tank the condition that establishes the design pressure is the pump inlet pressure for engine start during periods when the pump is hot (hot pump restart, HPR). When regulator tolerance and lock up delta pressure is considered, the nominal regulator setting of 31 psia (0.214 x 10^6 N/M^2) and a tank design pressure of 40 psia (0.276 x 10^6 N/M^2) results. The condition that establishes the fuel tank pressure is the ground rules to maintain a 5 psi (0.034 x 10^6 N/M^2) higher pressure in the fuel tank than in the oxidizer tank. When tolerances are considered the resultant nominal fuel tank regulator is set at 36 psia (0.248 x 10^6 N/M^2) tank design pressure is 45 psia (0.31 x 10^6 N/M^2).

Helium pressurant requirements were determined for the primary propulsion system based on complete expulsion of the propellant load at the nominal operating pressures of 31 psia (0.214 x 10^6 N/M^2) for the oxidizer and 36 psia (0.248 x 10^6 N/M^2) for the fuel (Table 3.3.2-8). Tank prepressurization values were 22 psia (0.152 x 10^6 N/M^2) for the oxidizer and 31 psia (0.21 x 10^6 N/M^2) for the fuel. An equilibrium temperature of 60 deg F (280°K) was assumed at launch.

Since the SOTs are drained early in the mission, a conservative adiabatic expulsion with the propellant at 60 deg F (280°K) was assumed. Propellant depletion in the core was based on a final propellant temperature of 40 deg F (278°K) which yields maximum core helium requirements. An adiabatic blowdown of the pressurant storage spheres resulted in a final gas temperature in the spheres of approximately 410 deg R (228 deg K).

The total helium required to accomplish the expulsion is 15.8 pounds (7.15 kg). At a storage pressure of 3600 psia (24.8 x 10^6 N/M^2) a volume of 6.96 ft^3 (0.197 m^3) is

Table 3.3.2-9

PRESSURE REQUIREMENTS SUMMARY

Core Tank Plus Strap-On-Tank Kit	HDA	MMH
	PSIA (N/M^2)	PSIA (N/M^2)
Min. Pump Inlet (HPR)$^{(1)}$ 80°F	32 (0.22 x 10^6)	17 (0.117 x 10^6)
Pump Inlet (Cold) 80°F	22 (0.15 x 10^6)	13 (0.089 x 10^6)
Accel Head Reg. (HPR)	1	NIL
ΔP SS	3.0	3.0
ΔP Screens	3.0	3.0
Start Press (HPR)	33	17
Press SS	28	19
Press line P	1	1
Reg Tolerance	±2	±2
Reg Lockup P	+4	+4
Nom Reg Set Prim$^{(2)}$	31 (0.214 x 10^6)	36$^{(3)}$ (0.248 x 10^6)
Nom Reg Set Sec	–	–
Max Tank Press (Op)	37 (0.254 x 10^6)	42 (0.289 x 10^6)
Thermal Press Deviat	1	–
Margin		1
Vent Valve Tol	2	2
Burst Dis Tol	–	–
Total Tank Press	40 (0.27 x 10^6)	45 (0.31 x 10^6)
Tank Press at Launch	22 (0.151 x 10^6)	31 (0.213 x 10^6)

(1) HPR = Hot pump Restart

(2) At full flow rate

(3) 5 psi greater than oxidizer

required. Storage weights were computed based on high strength materials (200 ksi ultimate) and an added 35 percent to account for weld lands and bosses. Total pressure vessel weight was determined to be 137 pounds (62 kg).

Core Tank and Agena Sump. The feed/fill/drain system of the core tanks has been maintained as close to the Agena configuration as possible. The fuel line extends through the oxidizer tank from the common bulkhead to a point adjacent to oxidizer tank and outlet. Both oxidizer and fuel tanks incorporate sumps that are currently used on the Agena. A drawing of the oxidizer sump is shown in Fig. 3.3.2-6. The fuel sump is similar except the outlet is symetrically located at the bottom of the tank instead of off-set to the side and the sump is welded in to the bottom of the common bulkhead. The sponge or propellant acquisition assembly shown in the figure is not required and a screen will be used instead. In the future, if an integrated secondary propulsion system is required for maneuvering, the sponge can easily be added as an option.

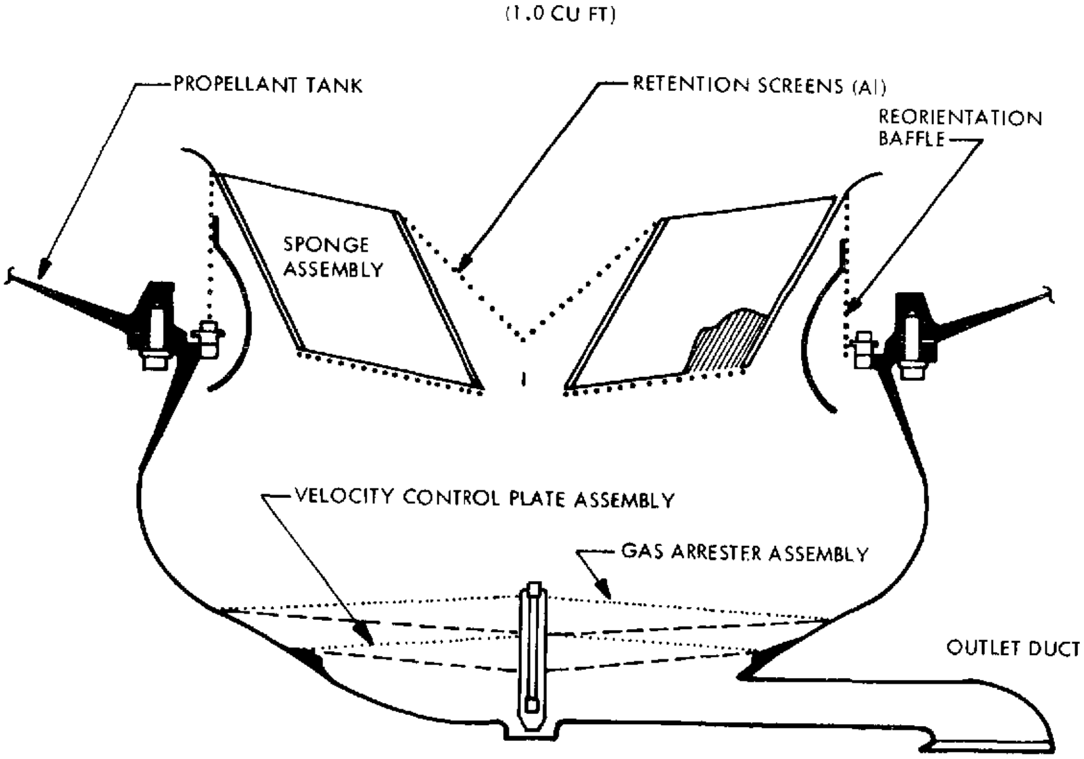


Fig. 3.3.2-6 Propellant Management Sump

The bellows and propellant isolation valves connect to the outlet ducts and then to the engine at the pump interface. Because of the action of the sumps, screens, gas arresters, and velocity control plates, the core tanks drain almost completely.

The SOT line and sump arrangement is depicted in the schematic shown in Fig. 3.3.2-4. Each transfer line on the oxidizer tanks is routed directly from the strap-on tank to the core tank. Arranging the oxidizer lines in this manner creates the shortest line, permit the smallest residuals possible, and minimizes the number of stages on the gas arrester. The fuel tank lines are manifolded together at the aft of the vehicle and a single standpipe is extended from the manifold to the top of the fuel tank. Arranging the fuel lines in this manner minimizes the number of stages on the gas arrester and provides a near-minimum residual.

A gas arrester is placed in a small sump at the bottom of the SOT as shown in Fig. 3.3.2-7. It is designed to stop the flow of liquid when the gas reaches the screens. When this happens the flow rate out of the other two tanks increases so that the total pressure drop between the empty tank and the core tank is the same as the pressure

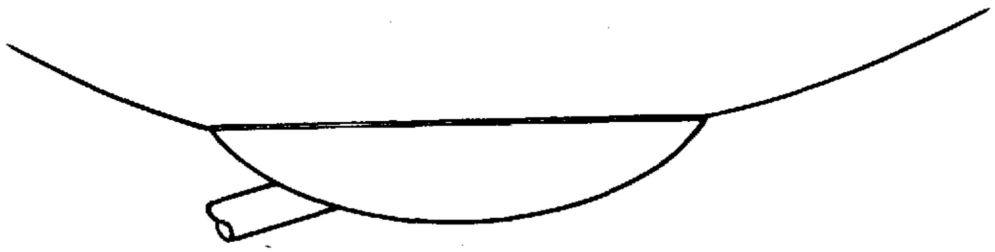


Fig. 3.3.2-7 Strap-on Tank Sump and Gas Arrestor

drop between the still flowing tanks and the core. When a second tank is depleted the flow from that tank tends to stop; however, the screens are designed to hold against a flow rate of 16.5 lb/sec and when the flow rate tends to increase to 33 lb/sec gas breaks through the screen in the tank that was second to deplete. Liquid continues to flow from the third tank because the screens in the depleted tanks still provide a pressure drop until they dry out completely.

When significant amounts of gas flow by a capacitance type sensor in the line the isolation valve is closed. Gas then flows in another line, then that isolation valve closes, and finally when gas flows in the last line and that isolation valve closes the pressurization is switched to the core tank. Both the fuel and oxidizer tanks are drained in this manner. Downstream of the shut off valves the oxidizer runs directly into the core tank and no residuals are left. On the fuel side, the lines are manifolded together downstream of the shut off valves. This manifold stays nearly full of fuel. From this manifold a standpipe routes to the top of the core tank. This line nearly empties because the bubble rise rate relative to the liquid is much smaller than the liquid velocity relative to the standpipe at the time the bubbles enter the system.

The total line weight for this manifolded configuration is shown in Table 3.3.2-10.

The liquid residual weights are shown in Table 3.3.2-11.

Non-impulse and Residual Propellants. The pre- and post-flow propellants shown in Table 3.3.2-12 are based on Agena analysis, ground test, and flight histories, and are scaled in proportion to the propellant density to convert from existing HDA/UDMH to the HDA/MMH combination.

During the start sequence 10.3 pounds (4.66 kg) of oxidizer and fuel are lost from main power relay (MPR) activation through thrust chamber ignition (TCI) to 90 percent chamber pressure (P_c).

During shut down, 28.5 pounds (12.9 kg) of propellant is lost from shutdown (SD) signal through the engine fuel and oxidizer valves to full closures and from the oxidizer cooling passages. When the PIVs are closed after engine shutdown 13.8 pounds

Table 3.3.2-10

STRAP-ON-TANK TRANSFER LINE WEIGHT

Oxidizer	LB	
Sump	1.98	
Gas Arrester (11 in. dia 5 stages)	0.80	
Line 2 in. O.D. x 0.065 wall x 6 in. al	0.24	
Line 2 in. O.D. x 0.035 wall x 10 in. al	0.22	
Line 2 in. O.D. x 0.028 wall x 8 in. cres	0.39	
Line 2 in. O.D. x 0.065 wall x 3 in. al	0.12	
Flex Line 2 in. O.D. x 6 in. active length	1.04	
Flanges on Flex and Cres Lines – 2	0.30	
Flanges on al Lines – 5	0.25	
V Band Clamps – 4	0.40	
Capacitance Depletion Sensor	0.50	
Total	6.24	
Total for three (3)	18.72	(8.46 kg)
Fuel	**LB**	
Sump ΔWeight to Tank 1.95 x 3	5.94	
Gas Arrester 0.8 x 3	2.40	
Line 2 in. O.D. x 0.065 x 6 in. al x 3	0.72	
Line 2 in. O.D. x 0.035 x 10 in. al x 3	0.66	
Line 2 in. O.D. x 0.035 x 80 in. al	1.73	
Line 2 in. O.D. x 0.035 x 6 in. al	0.13	
Line 2 in. O.D. x 0.035 x 60 in. al	1.30	
Line 3 in. O.D. x 0.035 x 140 in. al	4.56	
Line 3 in. O.D. x 0.065 x 8 in. al	0.48	
Flex 2 in. O.D. x 6 in. active length – 2	2.08	
Flanges on Flex Lines – 4	0.45	
Flanges on al Lines – 16	0.80	
Tees	0.41	
V band Clamps	1.00	
Capacitance Depletion Sensor – 3	1.50	
Total all fuel lines	24.16	(11.0 kg)
TOTAL SOT TRANSFER LINE WEIGHT	42.88	(19.4 kg)

Table 3.3.2-11

STRAP-ON TANK LIQUID RESIDUALS

Oxidizer	LB
Valve is closed after gas is pulled through the arrester	
Sump 1/4 full	2.34
Line to shutoff valve 1/2 full	1.46
Line downstream of valve drains into core tank	
Total Oxidizer per tank	3.80
Total for three (3) tanks	11.40 (5.18 kg)
Fuel	
Valve is closed after gas is pulled through the arrester.	
Sump 1/4 full x 3	3.81
Line 1/2 full x 3	2.48
Manifold at bottom of tank	14.00
The standpipe is nearly cleared because the bubble rise velocity relative to the fluid is much smaller than the fluid velocity relative to the pipe	5.00
	25.29 (11.0 kg)
Total liquids trapped in SOT transfer lines	36.69 (16.8 kg)

(6.25 kg) of propellant that is trapped between these valves and the engine valves is vented overboard automatically through a port in each PIV.

The current Agena uses a spring actuated oxidizer valve that can be closed rapidly by a pneumatic override if desired. For the 8096L engine a motor driven valve will be incorporated to reduce post flow and aid hot pump start.

The current Agena vehicles do not use an active propellant-utilization system. Through controlled and accurate propellant loading, extensive experience on engine mixture ratio deviations, and the depletion residuals in each tank, a 12 pound fuel bias has been determined as being adequate. For the Shuttle/Agena + SOT, the bias becomes larger, but is adequately covered when a flight performance reserve (FPR) of 1.7 percent is used. When an FPR of 1.0 percent is used, a fuel bias of 50 pounds is added to the 133 pounds shown in Table 3.3.2-12.

The total non-impulse propellant losses for a six-burn mission (example only) results from six starts (preflows) and five shutdowns. The vented propellant in the engine and lines (13.8 pounds) is included as part of the shutdown losses. The losses during the last shutdown are included as part of the liquid residuals aboard at the time of engine thrust cessation.

The residuals in the SOT are based on trapping a portion of liquid propellant in the feed lines as described in Table 3.3.2-11 and the associated propellant vapor and He gas in the ullage.

The arrangement of the selected feed, fill, and drain system, described earlier, permits the propellants to be drained only while there is a longitudinal force on the vehicle (axial/vertical dump). The abort modes and dump times are discussed in par. 3.6.2 (Safety).

Fluid System Component Weights. The fluid system component weights for the propellant and pressurization system shown in Fig. 3.3.2-4 are listed in Table 3.3.2-13.

3.3.2.5 Reaction Control System (RCS). The Shuttle/Agena requires three-axis stabilization during the entire orbital mission. The impulse requirements for stabilization were established based on a combination of discrete events plus limit cycling during coast periods. In most instances, the requirements were based on past Agena orbital experience and the mass characteristics of the Shuttle/Agena. A Summary of these requirements for the 38-hour syn eq mission is presented in Table 3.3.2-14. Conservatism is included to accommodate uncertainties in vehicle properties and mission parameters. The propellant quantity necessary to meet the impulse requirements will depend on the thruster characteristics and the pulse modulation factors selected. A loading of 54 pounds (24.4 kg) was selected for the syn eq mission shown. This provides a contingency of about 20 pounds (9.1 kg).

Table 3.3.2-12

NON-IMPULSE AND RESIDUAL PROPELLANT

	Existing 8096 HDA OX	 UDMH F	8096L HDA OX	 MMH F
START				
MPR To Thrust Chamber IGN (Preflow)	9.1	0.5	9.1	0.6
TCI To 90 Percent PC	0.4	0.2	0.4	0.2
	10.1 LB (4.6 kg)		10.2 LB (4.6 kg)	
SHUTDOWN				
SD Signal to Fuel Valve Close	1.5	0.6	1.5	0.7
FV Close To Ox Valve Close (Post-Flow)	9.8(1)	0	14.0(2)	0
Cooling Passages	12.0	0.3	12.0	0.3
Vented Between Burns	9.3	4.1	9.3	4.5
TOTAL	37.6 LB (17.0 kg)		42.3 LB (19.2 kg)	
RESIDUALS (CORE TANK)				
Fuel Bias	0	12.0	0	0
Fill Line	1.6	0.8	1.6	0.9
Sump/Tank, PIVs, Feed Line, Incl Vapor	17.2	5.4	17.2	6.0
TOTAL	37.0 LB (16.7 kg)		25.8 LB (11.7 kg)	
	Residuals		Vapor	Liquid
LOSSES				
Start 10 x 5 = 50	Core		12	38(3)
Shut Down 42 x 4 = 168	SOT		46	37
218 LB			133 LB	

(1) Pneumatic Fast Shutdown

(2) Torque Motor Valve

(3) Includes 12 lb For Oxidizer Postflow For Last Shutdown

Table 3.3.2-13

PROPULSION SYSTEM COMPONENT WEIGHT BREAKDOWN

System/Component	Schematic Ref. (Fig. 4)	Unit Wt. (lb)	No. Req'd	Total Wt (lb)	Manufacture	Part No.
Pressurization and Pressure Relief						
He Tank	He	68.5	2	137.0	LMSC/Airite	–
He Fill Valve	QD07	0.3	1	0.3	LMSC	1381302
He ISO Valve	SV01-04	3.5	4	14.0	P-H/Valcor	Mod. V27700-49
He Regulator	PRO1, 02	3.0	2	6.0	P-H/Fairchild	Mod. 5660148
He SO Valve	SV05-SV08	2.3	4	9.2	P-H/Valcor	–
Command Vent (Fuel)	VV01-VV04	2.4	4	9.6	P-H/Valcor	–
Command Vent (Ox.)	VV05-VV08	2.4	4	9.6	P-H/Valcor	–
Lines and Ftgs		2.5	1	16.5	LMSC	–
Total				202.2 (91.4 kg)		
Prop. Feed, Fill, Dump						
Fill Vent Valve	FV01-FV08	1.2	8	9.6	LMSC	8106086
SOT SO Valve	SV09-SV14	5.5	6	33.0	Dyn SC1/Whittaker	1463144
Emerg. Dump Valve	SV15, 16	5.5	4	22.0	Dyn SC1/Whittaker	1463144
Prop. ISO Valve	SV17,18	5.5	2	11.0	Dyn SC1/Whittaker	1453144
Residual Dump Valve	SV19-22	2.5	4	10.0	P-H/Valcor	–
Feedline Vent Valve	SV23,24	2.5	2	5.0	P-H/Valcor	–
Fill Line Disc.	QD01, 02	2.0	2	4.0	P-H	Mod 1062532
SOT Transfer	Oxidizer	18.7	–	18.7	LMSC	–
Lines, Ftgs, PRD	Fuel	21.5	–	24.2	LMSC	–
Core, Feed Fill Drain	Ox. & Fuel	13.3	–	13.3	LMSC	–
Total				151.4 (68.6 kg)		
System Total				353.6 (160 kg)		

Table 3.3.2-14
SHUTTLE/AGENA RCS IMPULSE EXPENDITURE

(SYN-EQ MISSION) (6 BURNS – 38 ACTIVE HOURS)

Disturbance Source	Time or No. of Occur.	Impulse Expenditure Scaling			Agena Impulse Requirements (Lb-Sec)
		Existing Agena Range (Data From >100 Flights)	Shuttle/Agena Requirement Calculated	Shuttle/Agena Requirement Used	
1. Vehicle Maneuvers	24 Times	218 $\frac{\text{Lb-Sec}}{\text{Maneuver}}$ (1st Burn Ignition) 57 $\frac{\text{Lb-Sec}}{\text{Maneuver}}$ (Final Burn Out)	200 $\frac{\text{Lb-Sec}}{\text{Maneuver}}$ (1st Burn Ignition) 23 $\frac{\text{Lb-Sec}}{\text{Maneuver}}$ (Final Burn Out)	110 $\frac{\text{Lb-Sec}}{\text{Maneuver}}$ (Avg)	2,640
2. Turbine Wind-Up/Down	5 Times	40 $\frac{\text{Lb-Sec}}{\text{Burn}}$ (Max. Observed)	40 $\frac{\text{Lb-Sec}}{\text{Burn}}$	40 $\frac{\text{Lb-Sec}}{\text{Burn}}$	200
3. Turbine Exhaust	18.9 Min	47 $\frac{\text{Lb-Sec}}{\text{Min. of Burn}}$ (Max. Observed) 20 $\frac{\text{Lb-Sec}}{\text{Min. of Burn}}$ (Avg)	60 $\frac{\text{Lb-Sec}}{\text{Min. of Burn}}$	80 $\frac{\text{Lb-Sec}}{\text{Min. of Burn}}$	1,510
4. Propellant Vent	5 Times	32 $\frac{\text{Lb-Sec}}{\text{Burn}}$ (Max. Observed)	40 $\frac{\text{Lb-Sec}}{\text{Burn}}$	60 $\frac{\text{Lb-Sec}}{\text{Burn}}$	300
5. Residual Propellant Dump	Once	–	(213 Lb Liquid and Vapor) 455 Lb-Sec	(300 Lb Liquid & Vapor) 640 Lb-Sec	640
6. Deadband Switch (Coarse to Fine)	5 Times	50 $\frac{\text{Lb-Sec}}{\text{Switch}}$ (Max. Observed)	50 $\frac{\text{Lb-Sec}}{\text{Switch}}$	100 $\frac{\text{Lb-Sec}}{\text{Switch}}$	500
7. Aero Torques and Limit Cycle	29 Hours	8.5 $\frac{\text{Lb-Sec}}{\text{Hr}}$ (Max. Observed)	6 $\frac{\text{Lb-Sec}}{\text{Hr}}$	18 $\frac{\text{Lb-Sec}}{\text{Hr}}$	522
8. Reserve RCS					2,074
TOTAL					8,386 Lb-Sec (37,300 N-Sec)

Shuttle/Agena RCS Description. The RCS selected for the Shuttle/Agena upper stage is a hydrazine system using the thrusters and fluid systems components from the current spacecraft Agena and the nitrogen pressurized blowdown propellant tank from the LMSC satellite control section (SCS) vehicle RCS. Maximum blowdown is 2 to 1 with a full propellant load of 102 pounds (46 kg). Initial pressurization will be 300 psia (2.06×10^6 N/M^2). The system is shown schematically in Fig. 3.3.2-8. To provide added control capability, a backup stabilization system (BUSS) has been incorporated which will provide stabilization and maneuvering capability in the event of a main system failure. The propulsion components of BUSS are integrated with the RCS and logic provided to permit the BUSS thrusters to be used during normal RCS in the event a reaction engine module (REM) fails. Operating in this mode the normally closed isolation valve (SV04) will be opened and the high mode RCS valve SV01 closed. Propellant for BUSS operation will be stored in a small propellant tank based on a design by Pressure Systems, Inc. (PSI) built for Aeros (Part No. PSI-80156-1). The tank is 9-1/2 inch diameter (24 cm) and holds 7-1/2 pounds (3.4 kg) of hydrazine at a 2 to 1 blowdown. The tank will be similar in all respects except size to the main tank, also built by PSI.

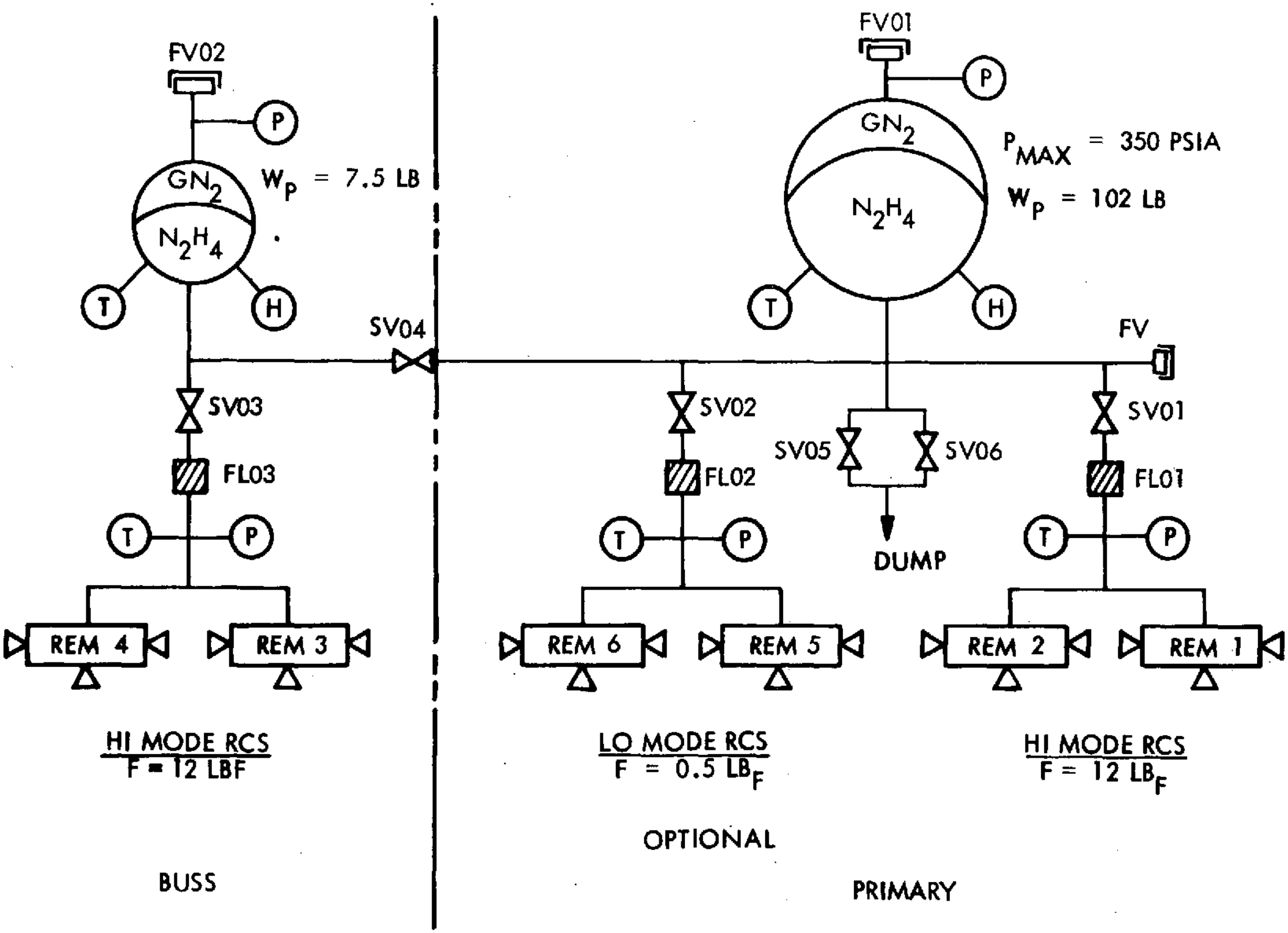


Fig. 3.3.2-8 RCS Fluid System Schematic

For normal operation with the augmented configuration the high mode thrusters are used only during main engine burns. During coast interval when vehicle distrubances are small, the low mode units are active. For malfunction operation the high mode system can perform the low mode function, but will consume more propellant. By using high mode REMs in the BUSS, redundant thruster capability is provided for the high mode RCS for the entire orbit operations phase.

Electrical heaters are provided on the propellant tanks to maintain the hydrazine above minimum temperature. Heaters are also provided in the REMs to provide temperature control for the thruster valves and catalyst beds.

RCS propellant requirements as a function of total impulse are presented in Fig. 3.3.2-9. For the nominal mission the propellant tank will be offloaded nearly 50 percent. The extra capacity can be used to provide additional RCS performance, or to feed a secondary propulsion system if required for certain missions.

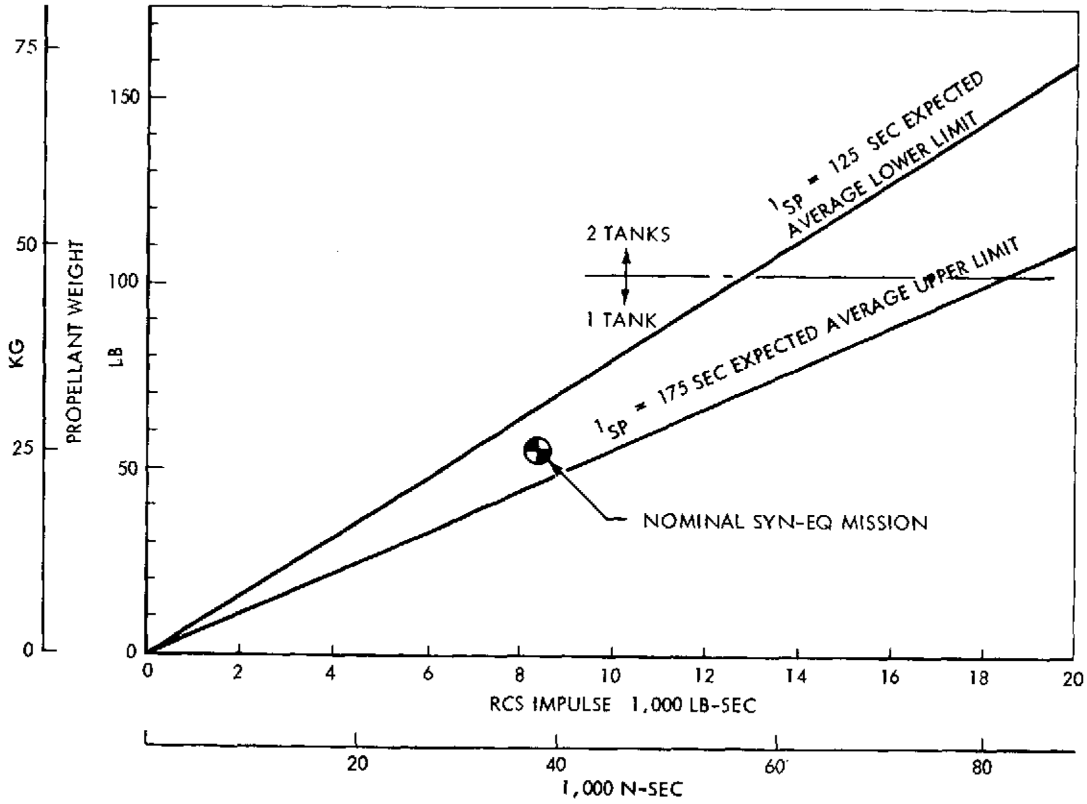


Fig. 3.3.2-9 RCS Propellant Weight

Reusability. All fluid system components except the reaction control thrusters meet the requirements for reusability based on their current qualification. The only apparent limitation is the current three-year calendar life which can be extended to meet the four to five year requirement without modification.

The hydrazine thrusters have a five-year calendar life. Performance life is sufficient in terms of total impulse and total cycles to permit 20 mission use for the high mode thrusters and eight missions for the low mode. However, a modification to the injector/diffuser and catalyst retention design will be necessary to meet the requirements for multiple launches with ascent environments where vibration will be encountered.

RCS Configuration With High Mode Thrusters Only. When low mode thrusters are deleted the minimum vehicle rates will increase. However, the RCS system weight can be reduced by about 9 pound (4.1 kg). The high mode thruster provides the stabilization function and consequentially the limit cycle impulse increases by about 500 pound-sec (2220 N-sec).

Cold Gas Vs Hot Gas RCS Comparison. Before choosing the hot gas RCS system a performance comparison was made with a cold gas system. The results are shown in Fig. 3.3.2-10 and show that total system weight for the nominal syn eq mission is about 110 pound (50 kg) for hot gas vs about 280 pound (127 kg) for cold gas.

3.3.2.6 Propulsion Development Status. Status of the proposed propulsion concept is provided in Table 3.3.2-15. Although several changes have been incorporated into the propulsion fluid flow and control assemblies, the system design is based on use of existing components without modification with four exceptions: (1) the helium supply tanks, in which new tanks fabricated from high strength titanium (200 KSI ultimate) selected to reduce weight; (2) regulators, in which the Apollo regulator design will be modified to meet the Shuttle/Agena pressurization requirements; (3) the hydrazine thrusters in which the current Hamilton Standard units will be modified to incorporate design improvements which will increase their reusability. In addition to the aluminized catalyst screens, case weldment design mods, which would facilitate catalyst bed repacking, may also be incorporated for cost effectiveness. The fourth

Table 3.3.2-15

PROPULSION DEVELOPMENT STATUS

Equipment	Existing		
	Supplier	Part No.	Change
Pressurization			
He Tanks (2)	LMSC/Airite		New
Regulators	P-H/Fairchild	Sim to 5660148	Pressure Change (Mod)
Shut Off Valves	P-H/Valcor	Sim to V27700-49	–
Disconnects	LMSC/Cons Cont	8106086	
Feed/Fill/Drain			
PIVs	Dyn Sci-Whittaker	1463144	–
Bellows	Metal Bellows Inc.	1462532	–
Shut Off Valves	P-H/Valcor	Sim to V27700-49	–
Disconnects	P-H	1062532	–
Propellant Mgmt Sumps	LMSC	1380550	–
TVC			
Servo Actuators	MOOG	1461902	–
Hydraulic Power Pack	Lear	1461104	–
RCS			
Hydrazine Tank	PSI	8100024	–
Thrusters	Ham Stand	1462635 and 1452636	Aluminide Screens
Valves	P-H	8100098	–
Engine	Bell Aerosystems	8096L (Sim to 8096)	
Pump Cav Diffusers		Existing	Resize
Ox Pump		Modified	Substitute steel bearing support. Add anodized housing
Gas Generator		Existing	Resize venturiis
Thrust Chamber		Modified	Resize Baffled Injector
Nozzle		New	Incorporate high E Columbium extension
Valves & Controls		New	Substitute Torque motor ox valve in TCA
Start System		Modified	Substitute multistart rechargeable start tanks and use suction start

component to be modified is the 8096 engine. The rechargeable start tank system previously qualified for the Model 8247 Gemini target vehicles will be used with a shortened fuel tank. The main ox valve will be changed to a torque motor valve to decrease shutdown postflow loss and provide backup to hot pump restart. The baffled injector currently being developed under AF contract will be modified to incorporate the higher performance fuel (MMH). A higher area ratio Columbium nozzle. will be used to further increase I_{sp} and reduce dry weight. Gas generator control ventures will be resized to maintain the thrust at 16K. Pump diffusers will be resized for compatibility with the HDA/MMH mixture ratio of 2.03. The ox pump will incorporate a steel bearing support and anodized housing to provide reliable restart with hot pumps and HDA oxidizer.

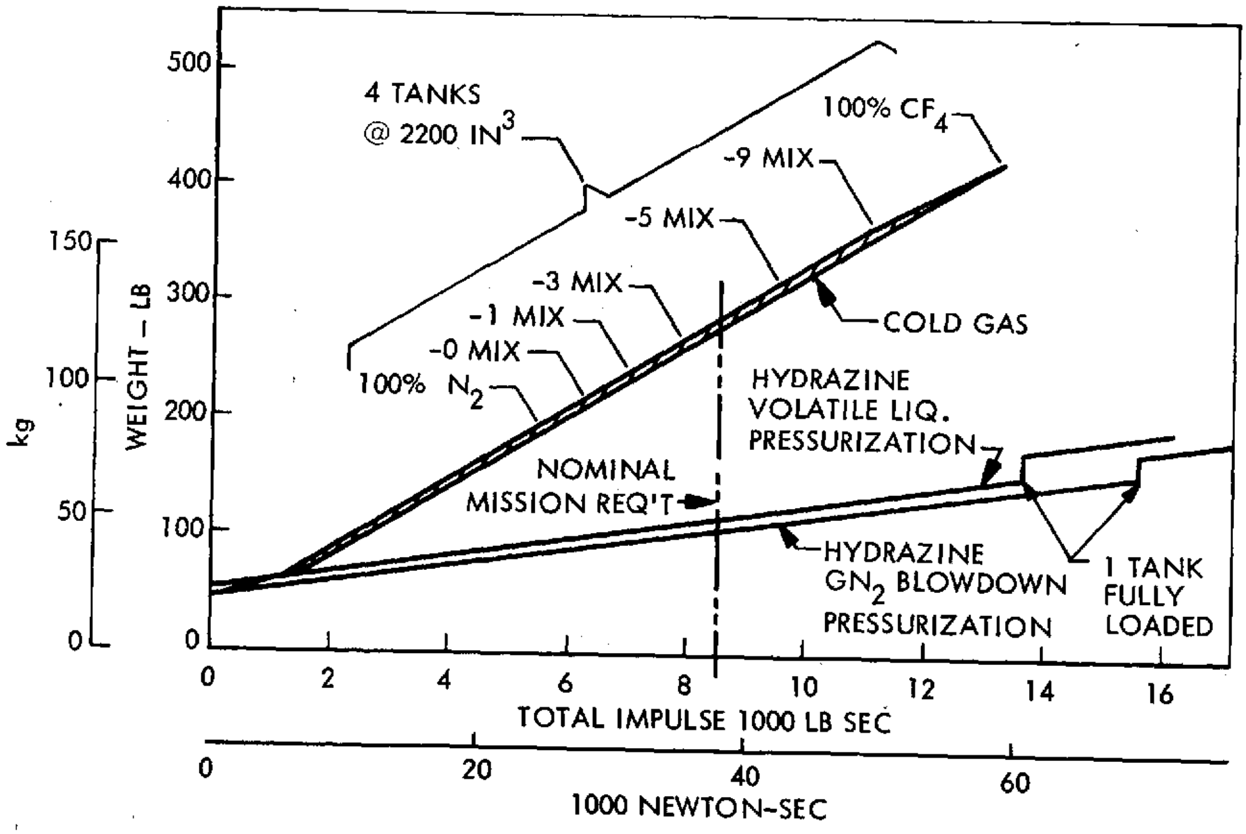


Fig. 3.3.2-10 Reaction Control System Comparison

3.3.3 Avionics Subsystem

The avionics subsystem consists of the guidance, navigation and control (GN&C) assembly, the data management and instrumentation (DM&I) assembly, the communication and control (C&C) assembly and the electrical power supply and distribution (EPS&D) assembly. Avionics equipment is also required in the Orbiter for Agena support.

The only major functional and operational differences between the Shuttle/Agena Upper Stage avionics and the existing Agena avionics are that for the Shuttle/Agena, (1) the DM&I assembly is identified as a separate system, (2) in-flight attitude and ground generated navigational updates are required, and (3) the safety and operational data and command interfaces are provided hardwired to the Orbiter when the Agena is in the cargo bay. Table 3.3.3-1 shows avionics subsystem functions new to the existing Agena.

Although a separate DM&I assembly is a new concept for Agena vehicles, the functions of processing GN&C and other data in a digital computer, storing data in mass storage devices, and providing on-board checkout and on-board failure detection are not entirely new to Agena applications. The present Ascent Agena GN&C system uses a strapped-down inertial guidance system similar to that proposed for the Shuttle/Agena and has an 8000 word digital computer to provide GN&C computations. Tape recorders have been used on many Agena and non-Agena LMSC applications. On-board checkout of existing Agena systems is limited mainly to GN&C (torqueing of gyros, providing step inputs to hydraulic servo loop, etc.) and to providing a flight simulated series of events (power-on, off) to the various vehicle systems. Validation of system responses and outputs is performed by the ground-based support equipment. On-board failure detection is limited on existing Agena vehicles to use of analog and discrete devices (e.g., detection of failed attitude control channel through excessive time duration of thruster activity).

The existing S-band communication systems used on Agena and other LMSC-developed vehicles with range and range-rate tracking capabilities are compatible with the Air Force Satellite Control Facility (AFSCF) and the associated ground stations. A

Table 3.3.3-1

AVIONICS SUBSYSTEM FUNCTIONS

SUBSYSTEM LEVEL	● Subsystem/Assembly Integration ● Subsystem/Subsystem and Other Systems Integration		
Guidance, Navigation and Control (GN&C)	Data Management and Instrumentation (DM&I)	Communication and Control (C&C)	Electrical Power Supply & Distribution (EPS&D)
● Powered Guidance, Steering and Control ● Powered and Cruise Navigation Using On Board Attitude Update and Ground Generated Nav Update ● Attitude Reference, Control and Stabilization	● Hardwired Data and Command Interface With Orbiter During Mated Conditions ● Data Processing in DM&I Computer (Primarily GN&C Mission Computations) ● Data Storage for Trend Analysis and Diagnostics ● On-Board Checkout(1) ● On-Board Fault Detection(1)	● Instrumentation Data Formatting and Transmission ● Command and Control Data Receiving and Decoding ● Stored Program Management ● RF Provisions for Agena Tracking by Ground and Orbiter	● Energy Source ● Power Management ● Power Conditioning and Distribution

(1) Limited in scope

▭ Bordered functions are new to existing Agena transponder compatible with the NASA STDN system would be used in lieu of the AF SGLS transponder for NASA missions.

The study resulted in two final avionics configuration designated by LMSC as the Augmented and Nominal avionics configurations. Table 3.3.3-2 presents a comparison of the Augmented and Nominal configurations.

Basically the Nominal avionics configuration eliminates some of the redundancy incorporated in the Augmented configuration (Fig. 3.3.3-1) and changes the powered down mode of operation from an earth centered approach to an inertially oriented approach.

The difference between the Augmented and the Nominal avionics are summarized in Table 3.3.3-3. With the Augmented avionics, single failures in the redundant sections can be tolerated. These same single point failures in a single string configuration could result in loss of a mission. Therefore, trend data analysis and other techniques requiring additional data are of more significance to the Nominal configuration. The tape recorder shown for the Nominal configuration is used primarily to supplement data transmitted in real time from the Agena. This data would be used to help determine the flight worthiness of the Agena systems and equipment for the next flight.

The particular application of this additional data, computerized trend analysis techniques to reduce the possibility of a failure during the next flight, must be further evaluated.

3.3.3.1 Requirements and Groundrules. The requirements and groundrules which had the greatest impact on the selection of avionics concepts and configurations were the following:

a. Avionics subsystem designed to baseline 38-hour syn eq mission with payload deployment and return to Orbiter orbit. Configuration to meet other guide missions with little or no impact on selected configuration.

b. Existing hardware and systems to be used whenever practical.

c. Autonomous navigation considered a goal and not a requirement unless autonomous navigation provides the only means for meeting other requirements (e.g., no ground station available when update is required.)

Table 3.3.3-2

COMPARISON BETWEEN AUGMENTED AND NOMINAL AVIONICS CONFIGURATIONS

Equipment	Augmented Configuration					Nominal Configuration				
	Part No.	Supplier	Qty	Total Wt (lb)	Power Watts	Part No.	Supplier	Qty	Total Wt (lb)	Power Watts
GN&C										
1. Inertial Measurement Unit	1460976	Honeywell	2	76	120 at 100°F	1460976 or Delta DIGS	Honeywell Ham Std.	1	38 or 32	120 at 100°F 70 at 100°F
2. Control Electronics Assembly	Similar to 8103450	LMSC	1	30	33	Same as Augmented	LMSC	1	30	33
3. Horizon Sensor Assembly	MOD IVA	Quantic	1	45	38					
4. Star Tracker Assembly	Skylab ATM	Bendix	1	71	24	SAS-C	Ball Bros.	2	30	10
DM&I										
1. Computer	DF224 (16 K)	Rockwell	1 Dual	76	81	DF224 (24K	Rockwell	1 Single	60	100
2. Computer Interface Unit	Similar to 8152145	LMSC	1	25	30	Same as Augmented	LMSC	1	25	30
3. Tape Recorder						Type 35	Oodetics	1	16	18 Rec 24 Play
C&C										
1a. Transponder (DoD)	Similar to RFPD 333945	Motorola	2	44	50 (4 on standby)	Same as Augmented	LMSC	2	44	50 (1 on standby)
1b. Transponder (NASA)	Similar to ERTS	Motorola	2	44	50	Same as Augmented	Motorola	2	44	50
2. Command Data Processor	Similar to 2P22630	LMSC	2	32	22	Same as Augmented	LMSC	2	32	22
3. Power Amplifier						Series PA	Microwave Pwr Devices	2	3	68
4. Power Divider (3 dB Hybrid)	INA0566-3	Anaren	2	0.4		Same as Augmented	Anaren	2	0.4	
5. Directional Antenna	2P56051	LMSC	2	2						
6. Omni Antenna	8100131	LMSC	4	3.2		Same as Augmented	LMSC	4	3.2	
7. Secure Encryptor and Decryptor	KGX28, KGR29	LMSC	4 2 ea	24		Same as Augmented	LMSC	4 2 ea	24	
8. RF Switch –	1462071	Transco	2	0.6						
EPS&D										
1. Batteries	Type 1902 Type IVB	Eagle-Picher Eagle-Picher	1 3	143 51		Type 30 Type IV B	Eagle-Picher Eagle-Picher	1 2	134 34	
2. Power Dist. Assembly	Similar to 1398613	LMSC	1	10	2	Same as Augmented	LMSC	1	10	2
3. Aft Instrumentation and Control Assembly	Similar to 1369660	LMSC	1	6	8	Same as Augmented	LMSC	1	6	8
4. Harnesses	New	LMSC	40	47		New	LMSC	38	47	
BUSS										
1. Rate Gyro						1461681	Nortronics	3	6	21
2. Magnetometer						1461662	Schonstedt	1	3	1
3. BUSS Electronics						8100397	LMSC	1	8	10
4. Logic and Distribution Assembly						Similar to 8106380	LMSC	1	11	2
SUPPORT AVIONICS										
1. Agena Service Console	New	LMSC	1	183		Same as Augmented	LMSC	1	183	559 Max
2. Cradle Harness	New	LMSC	1	37		Same as Augmented	LMSC	1	37	–

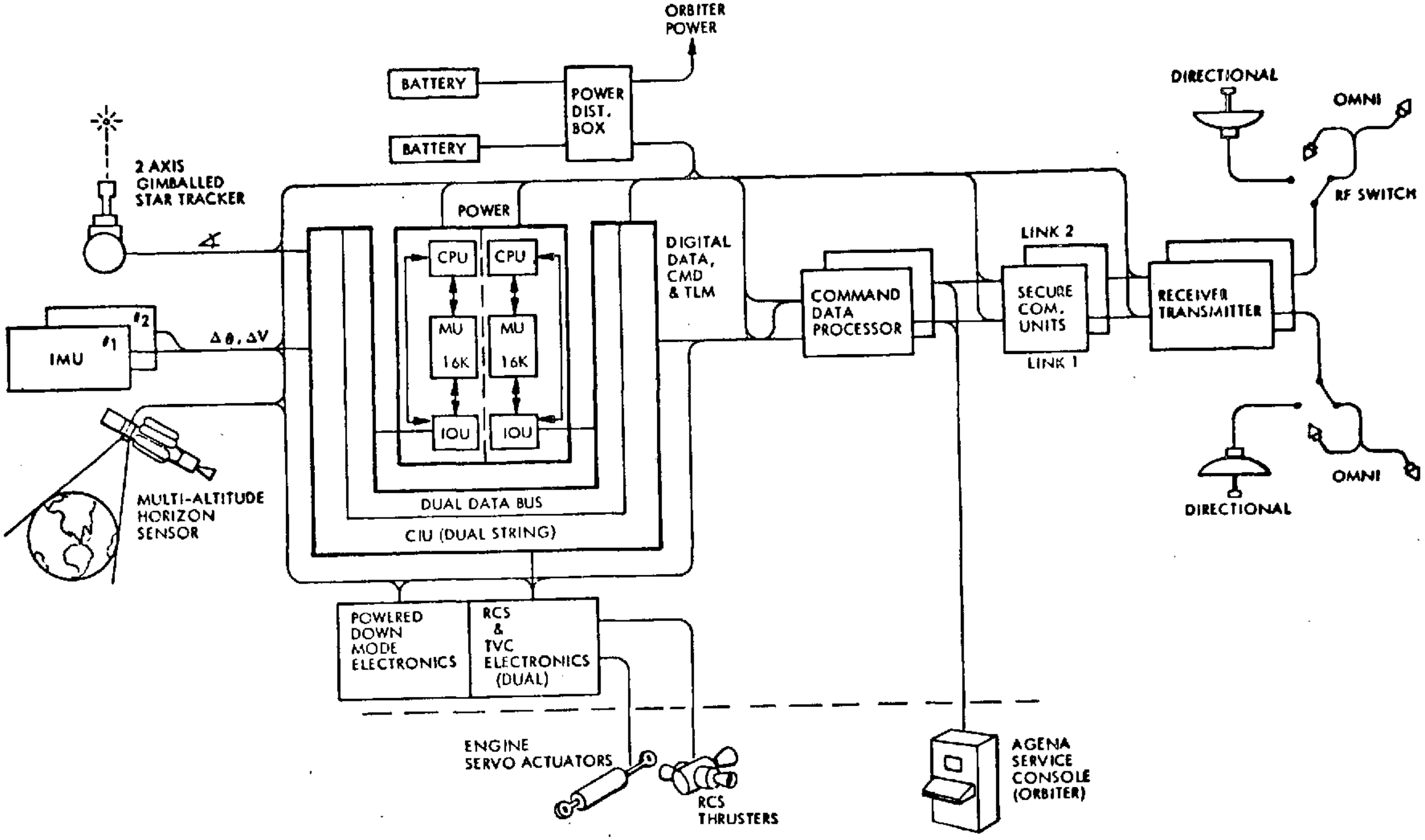


Fig. 3.3.3-1 Augmented Avionics Configuration

Table 3.3.3-3

AVIONICS – DIFFERENCES BETWEEN AUGMENTED AND NOMINAL CONFIGURATIONS

Equipment	Augmented Configuration					Nominal Configuration				
	Part No.	Supplier	Qty	Total Wt (lb)	Power Watts	Part No.	Supplier	Qty	Total Wt (lb)	Power Watts
GN&C										
1. Inertial Measurement Unit	LMSC 1460976	Honeywell	2	76	120 at 100°F	1460976 or Delta DIGS	Honeywell or Ham Std.	1	38 or 32	120 at 100°F 70 at 100°F
2. Star Tracker Assembly	Skylab ATM	Bendix	1	71	24	SAS-C	Ball Bros.	2	30	10
3. Horizon Sensor Assembly	Mod IVA	Quantic	1	45	38					
DM&I										
1. Computer	DF224 (16K)	Rockwell	Dual String	76	81	DF224 (24K)	Rockwell	Single String	60	100
2. Taper Recorder						Type 35	Oedetics	1	16	18 Rec 24 Play
C&C										
1. Power Amplifer						PA Series	Microwave Pwr Devices	2	3	68
2. Directional Antenna	2P56051	LMSC	2	4						
EPS&D										
1. Battery	Type 1902 Type IVB	Eagle-Picher Eagle-Picher	1 3	143 51		Type 30 Type IVB	Eagle-Picher Eagle-Picher	1 2	134 34	
BUSS										
1. Rate Gyro						1461681	Nortronics	3	6	21
2. Magnetometer						1461662	Schonstedt	1	3	1
3. BUSS Electronics						8100397	LMSC	1	8	10
4. BUSS Distr and Logic Box						8106380	LMSC	1	11	2
TOTAL				466 (211 kg)					343 (155 kg)	

d. Navigation update received from the Orbiter through hardline while within the cargo bay and from the Orbiter or ground station through RF link while deployed:

● Position	–	3 nm (5.5 km)	RSS, 3-sigma
● Velocity	–	5.6 FPS (1.76M/sec)	RSS, 3-sigma
● Time	–	1 part in 10^{10}	

e. Navigation update will be available for an accumulated period of at least one half hour over a span not to exceed one and one half hours prior to each engine burn.

f. Return to Orbiter orbit will be within:

- 15 nm (27.8 km) max at 0 radians inclination
- 0.15° (2.62×10^{-3} radians) max at 0 nm
- Downrange angle to be less than 1.1° (1.92×10^{-2} radians) at 160 nm (296 km) altitude

g. Capability provided to relay immediately to the Orbiter crew indications of emergency conditions when the Agena is either attached to or in the vicinity of the Orbiter.

h. All safety-critical command and control circuitry to be fail operational, fail safe as a minimum.

i. As a goal, no single failure on the Agena to present a hazard to the flight or ground crew.

j. The Orbiter crew has command override capability of the Agena inside or in the vicinity of the Orbiter.

k. Changeover from NASA to DoD missions to have minimum impact to the avionics. The C&C system compatible with both NASA STDN and AFSCF systems (including tracking) through the use of easily replaceable kits.

l. Communication with the Orbiter through the S-band system used for communication by the Agena with the ground stations.

m. Orbiter power of 30 VDC nominal provided for Agena operation when mated. Load capability of up to 100 watts average, 1500 watts peak provided during peak Orbiter operations. Higher load capability available during quiescent Orbiter operations.

3.3.3.2 Guidance Navigation and Control (GN&C). The augmented GN&C assembly consists of 2 strapped-down inertial measurement units (IMU), a 2-axis gimballed star tracker assembly (STA), a multi-altitude horizon sensor assembly (HSA) and a control electronics assembly (CEA). Figure 3.3.3-2 shows the GN&C system and its operational interfaces. The GN&C system, operating with the data management and instrumentation (DM&I) computer, provides on-board attitude update of the IMU reference using the STA. It computes the required engine burn parameters using ground

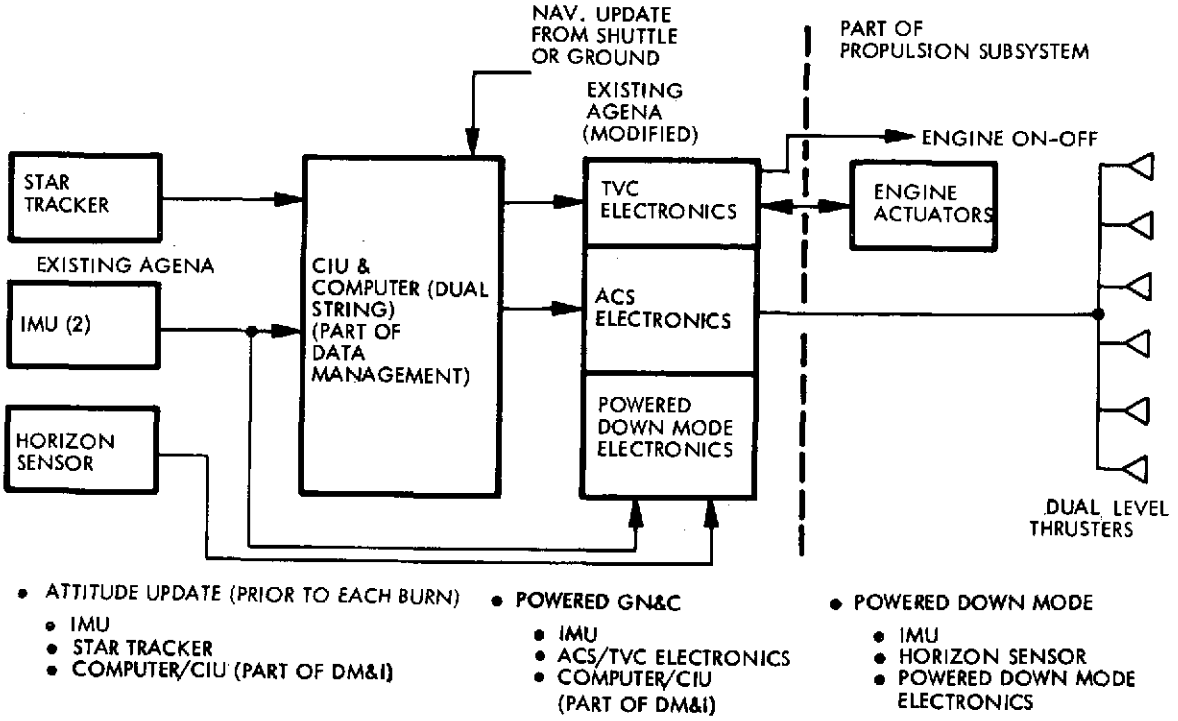


Fig. 3.3.3-2 GN&C Configuration

tracking navigation data and provides powered guidance, navigation, and vehicle control during engine burn, using the reaction control thrusters and the engine gimbal actuators. It executes maneuvers required to reorient the vehicle and provides 3-axis attitude control and vehicle stabilization during non-burn phases using the reaction control thrusters.

The GN&C system operates in 3 basic modes. These are (1) attitude and navigation update, (2) powered (engine burn), and (3) powered down modes.

Attitude Update. Attitude updates are necessary because gyro drifts introduce uncertainties in the alignment of the gyro reference axes to the navigational reference frame over prolonged periods.

The attitude update sequence is begun by the selection of 2 or more stars by Mission Control. The estimated angles between the first star and the IMU reference axes are computed on the ground and the STA telescope is gimballed by a command loaded into the on-board computer through the RF link. Because the Augmented avionics GN&C configuration provides for vehicle attitude control to the local earth vertical using the HSA during the period preceding attitude update initiation, the knowledge of actual vehicle attitude at update initiation will be better than 0.2 deg. The STA telescope has a scanned field of view of 1 deg square and an instantaneous field of view of 10 arc-minutes square. Within a few seconds of a star coming into the 1 deg field of view, the tracker automatically locks the instantaneous field at the star position. The gimbals, which are driven by the DC torquers, then drive the optical axis in line with the star line. A 14-bit resolver provides star line-of-sight angle data to within 30 arc-seconds accuracy. These data are then read into the computer and stored. Determination of the second star angle then proceeds. With these star angle data, the computer determines the orientation of the 3 orthogonal IMU axes to the inertial frame within 30 to 60 arc-seconds accuracy.

In the Nominal configuration, use of the star trackers for both attitude reference and for attitude control simplifies the system from a hardware standpoint. However, without a positive, easy-to-identify object such as the sun or earth to provide one point of reference, the initial acquisition of stars, star pattern recognition, and star identification could have major impact on operational and software complexity and computer memory sizing. This area requires further evaluation.

Navigation Update. Navigation (position and velocity) updates are periodically received from ground stations prior to engine ignition. The ground tracking stations transmit signals to the vehicle from which the coded pseudo-random noise signal is extracted, summed with the subcarrier oscillator signal and retransmitted to the ground. The time delay (after accounting for internal computational delays) is used to determine slant range. Range rate data are obtained by the doppler effect or by incremental change in position over a given period of time.

Range and range-rate data obtained from the remote stations are transmitted to the mission control center. These data, together with an accurate timing reference, are processed through a recursive filter to compute vehicle position and velocity relative to the inertial frame. The state vector information is transmitted to the vehicle through the remote station RF link and is stored in the computer. An accurate onboard timing reference (stability over 120 days better than ±10 parts per million) is used to keep track of time from that corresponding to the latest update position and velocity.

The attitude and navigation update data are used, together with preprogrammed targeting inputs, instrument compensation data, and the local gravity model, by the computer to determine burn parameters.

Powered GN&C. During engine burn, the IMU detects vehicle angular rate and linear acceleration. The outputs of the IMU, which are incremental body angles ($\Delta\theta$) and incremental linear velocity (ΔV), are accumulated in incrementing counters in the computer interface unit (CIU). Every 20 milliseconds, these data are transferred into the computer and the incrementing counter is reset to zero. Current estimated position and velocity are determined from these data by the computer and compared with that required to achieve the desired terminal state vector. Radial guidance is achieved by pitch steering to adjust the radial component of the thrust pointing vector as a function of time-to-go, radius-to-go, and radius rate-to-go. Out-of-plane guidance is achieved by yaw steering to adjust the angular moment component of the thrust vector so that the vehicle inertial vector is in the plane normal to the desired angular momentum vector.

The pitch and yaw steering commands from the computer are sent to the engine gimbal hydraulic servo amplifiers in the CEA to provide thrust vector control. The vehicle is only rate-controlled in the roll axis with the rate signals being derived from the IMU incremental roll attitude signals.

Powered Down Control. During all quiescent phases of the mission where navigation or guidance is not required, the computer power is turned off and the vehicle is controlled by the IMU (rate) and the HSA (attitude). Figure 3.3.3-3 shows the electronics required for this mode of operation and how the signals are used to provide vehicle control. The IMU pulsed outputs are converted to analog signals through a frequency

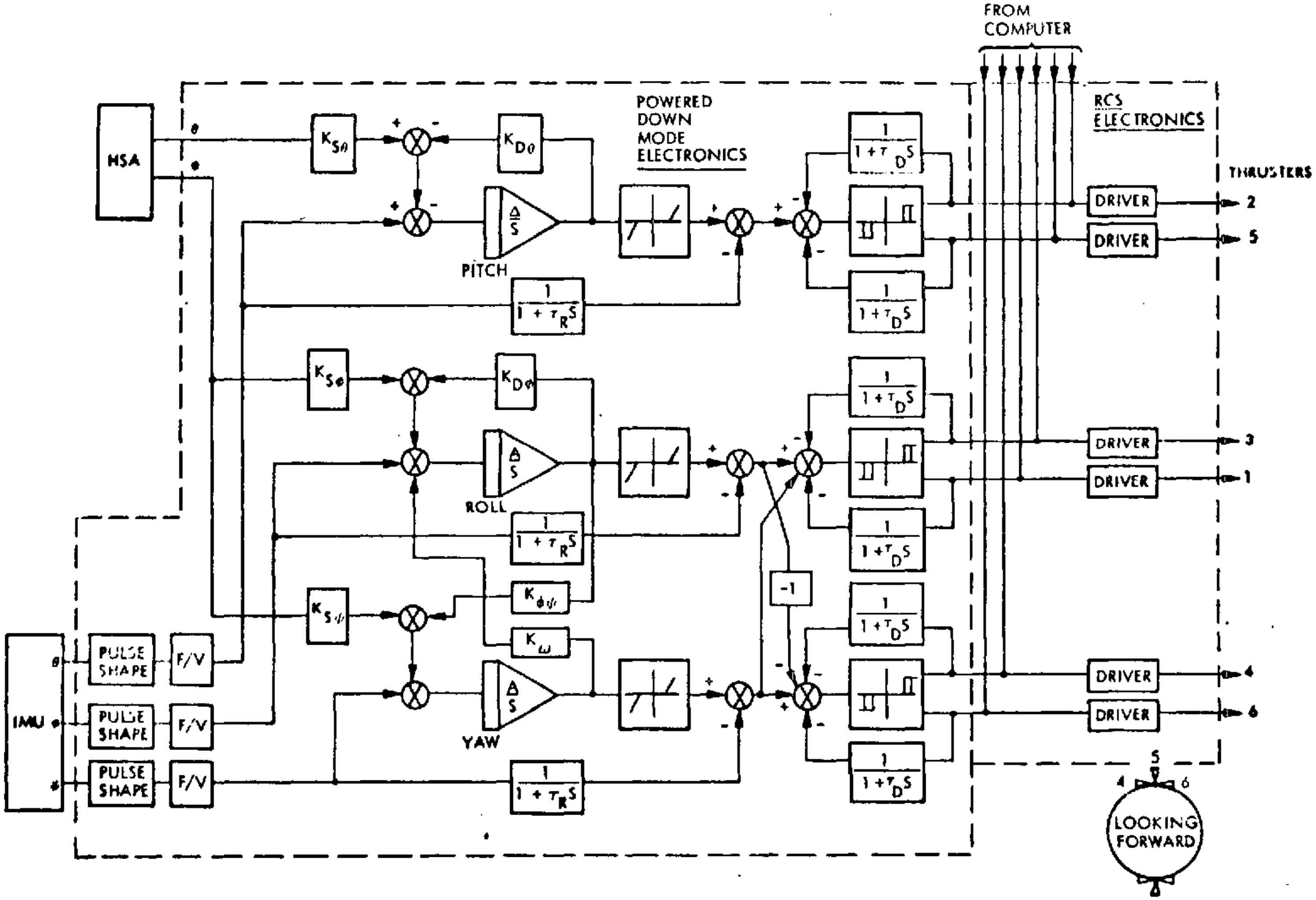


Fig. 3.3.3-3 Powered Down Mode

to voltage (F/V) converter. This circuit is a simple passive filter which reduces the fixed shape pulses coming out of the pulse shaper to a dc level proportional to the frequency of the pulses. The rate signal is then processed through two paths, (1) an analog integrator to derive attitude and (2) a straight-through path (filtered) to provide rate damping. The HSA signal is also processed through the integrators in the pitch and roll control channels to correct the gyro derived attitude signals for drift errors. The integrator also provides required filtering of the HSA signals. The attitude outputs of the integrators are fed back to difference with the HSA signals to allow operation on error level signals rather than on the full HSA outputs.

The output of the roll control channel integrator is fed to the yaw integrator together with the roll HSA output to provide yaw attitude reference through the gyrocompassing technique (for a vehicle controlled to the earth-referenced local horizontal, yaw offset couples in as a roll rate error). A geocentric rate feed back from the yaw control channel integrator output to the input of the roll control channel integrator input (K_W) may be necessary. This still remains to be determined.

The outputs of the integrators are summed with the rate outputs in each of the 3 channels to provide the full controlling error signal. These error signals are then fed into the respective pulse modulators. The output pulses are current amplified by the drivers and are used to control the reaction control thrusters.

Because of the inherent cross coupling effect between the roll and yaw reaction control thrusters, (refer to thruster locations shown in Fig. 3.3.3-3) the control signals must also be cross-coupled. This signal coupling is shown in Fig. 3.3.3-3 between the roll and yaw control channels before the pulse modulators.

Back-up Stabilization System (BUSS). For the Nominal configuration the back-up stabilization system will provide the redundancy required to meet Orbit crew safety requirements when operating in the vicinity of the Orbiter. This system provides backup attitude control capability only for the retrieval operation. If the critical control failure occurs prior to the Agena returning to rendezvous orbit the BUSS system would not be effective for completion of the mission.

Key Issues. The major issues developed during the study period and addressed were (1) accuracy of GN&C system, (2) trade off between GN&C accuracy vs mid-course corrections using a secondary propulsion system (SPS) for corrective ΔV, (3) methods of providing powered down mode of operation, and (4) thruster sizing, dual vs single level thrusters and attitude control propellant consumption level. The powered down mode of operations was discussed earlier in the paragraph and another key issue involving GN&C, failure detection and redundancy switching, is presented in the data management and instrumentation (DM&I) paragraph.

Synchronous Orbit Injection Error Analysis. Although placement accuracy objectives are specified in a downrange/crossrange/vertical coordinate system, the placement dispersions are displayed in terms of orbit-related parameters because:

- The behavior and propagation of orbit-related errors are for the most part invariant or well-defined as functions of time and hence are easily defined at distinct locations in the orbit (burn insertion, payload insertion, nodal crossings, etc.).
- The inter-relationship of orbit parameters with mission objectives and on-orbit correction maneuvers are more clearly recognizable and defined.
- The influence of correlation inherent to orthogonal representations of errors in state are eliminated.

The representation of errors in an orbit element frame eliminates many of the ambiguities induced by state vector coordinates and at the same time lends a clearer insight into the physical significance of errors and subsequent corrective maneuvers. The pertinent errors resulting from a 2-burn ascent operation are summarized in Tables 3.3.3-4 and 3.3.3-5 for the transfer and circularization burns, respectively. Ground track derived state vector data of 0.5 nm (0.93 km) and 1.0 ft/sec (0.3 m/sec) used for the analysis represent current capability demonstrated by the Satellite Control Facility network. These data are used prior to each burn for navigation update. Attitude update data (derived using the on-board star tracker) of 0.02 deg, 3-sigma accuracy was also used.

Table 3.3.3-4

ASCENT TRANSFER ORBIT ERRORS DUE TO SYNCHRONOUS TRANSFER BURN (B1)

Error Source	Error Source Magnitude, 3-Sigma	Transfer Orbit Errors, 3 Sigma Apogee Altitude, Nm (km)	Apogee Nodal Longitude, Deg	Apogee Time, Sec	Inclination, Deg
B1 Position Update	0.5 nm (0.93 km)	26 (48.8)	0.12	29	0.0
B1 Velocity Update	1.0 Ft/s (0.3 m/s)	10.0 (18.5)	0.05	11	0.002
B1 Attitude Update	0.02°	20 (37.0)	0.10	21	0.004
B1 Tail-off Impulse	0.6 Ft/s (0.18 m/s)	6 (11.1)	0.03	7	0.0
B1 GN&C Errors	3-Sigma(1)	47 (87.0)	0.24	51	0.008
Total (RSS)		58 (108.6)	0.29	64	0.009

---

(1) GN&C error sources are listed in ref 3-8. B1 = Burn 1.

Of the transfer orbit errors specified in Table 3.3.3-4, the dispersions in time of apogee and inclination are effectively eliminated by the positioning of burn two and the state vector update prior to burn two, respectively. However, because the circularization burn is performed at apogee and at the equatorial crossing, guidance corrections will be ineffective in eliminating either position error (altitude and longitude). Hence these two errors are projected as contributors to final orbit accuracies shown in Table 3.3.3-5.

Return Orbit Injection Error Analysis. As a result of analyses of guidance, navigation, and control errors and errors in navigation and attitude updates at synchronous altitude, the following errors are predicted at the end of transfer orbit:

Error Source	Δ Perigee Alt-nm (km)	Δi (deg)	Δt_{perig} (sec)	Δ Period (min)
Position Update uncertainty – 0.5 nm (0.93 km) 3σ	0.2 (0.37)	0	0.7	0.24
Velocity Update uncertainty – 1.0 ft/s (0.3 m/s), 3σ	1.7 (3.15)	0.01	2.6	0.60
Attitude Update uncertainty – 0.02°, 3σ	4.1 (7.60)	0.02	5.7	8.50
GN&C/Tailoff	4.0 (7.42)	0.01	5.0	1.50
RSS	6.0 (11.1)	0.025	8.0	8.64

Table 3.3.3-5

FINAL SYN ORBIT ERRORS DUE TO CIRCULARIZATION BURN (B2)

Error Source	Error Source Magnitude 3-Sigma	Apogee Altitude NM (KM)	Perigee Altitude NM (KM)	Inclination Deg	Placement Longitude Deg	Longitude Drift Rate, Deg/Rev	Period, Min.
B2 Position Update	0.5 nm (0.93 km)	1.0 (1.9)	1.1 (2.0)	0.001	0.002	0.024	0.10
B2 Velocity Update	1.0 ft/s (0.3 m/s)	8.7 (16.1)	2.1 (3.9)	0.005	0.001	0.108	0.43
B2 Attitude Update	0.02 Deg	5.3 (9.8)	4.6 (8.5)	0.011	0.001	0.087	0.35
B2 Tailoff Impulse	1.0 ft/s (0.3 m/s)	9.1 (16.9)	0	0.002	0	0.097	0.52
B2 GN&C Errors(1)	3 Sigma	6.8 (12.6)	3.3 (12.6)	0.008	0.001	0.102	0.37
B1 Induced Errors(2)	3 Sigma	58 (108.6)	–	–	0.29	0.692	2.76
Total (RSS)		60 (112.2)	6.1 (11.3)	0.015	0.29	0.720	2.89

(1) GN&C Error Sources Are Listed in Ref. 3-8.

(2) Apogee Altitude and Placement Longitude Errors Are Directly From Table 3.3.3-4
Longitude Drift Rate and Period Errors are Derived From Apogee Altitude Error of 58 nm (108.6 km)

B2 = Burn 2

State vector/attitude updates prior to the phasing burn will permit the phasing burn to account for a major portion of the transfer burn-induced errors with the exception of altitude at perigee (phasing burn location). Some additional altitude error could result from phasing targeting (phasing burn ignition), but designing guidance errors to be small compared to the ground derived position update uncertainty of 1.0 nm (0.93 km) will not be a problem based on past LMSC and industry experience. The following errors apply to the phasing orbit.

	ΔPerigee Alt-nm(km)	Δi (deg)	ΔPeriod (min)
From Transfer Orbit	6.1 (11.0)	*	*
Phasing Orbit-Induced	1.0 (1.85)**	0.004	0.22
RSS	6.1 (11.3)	0.004	0.22

---

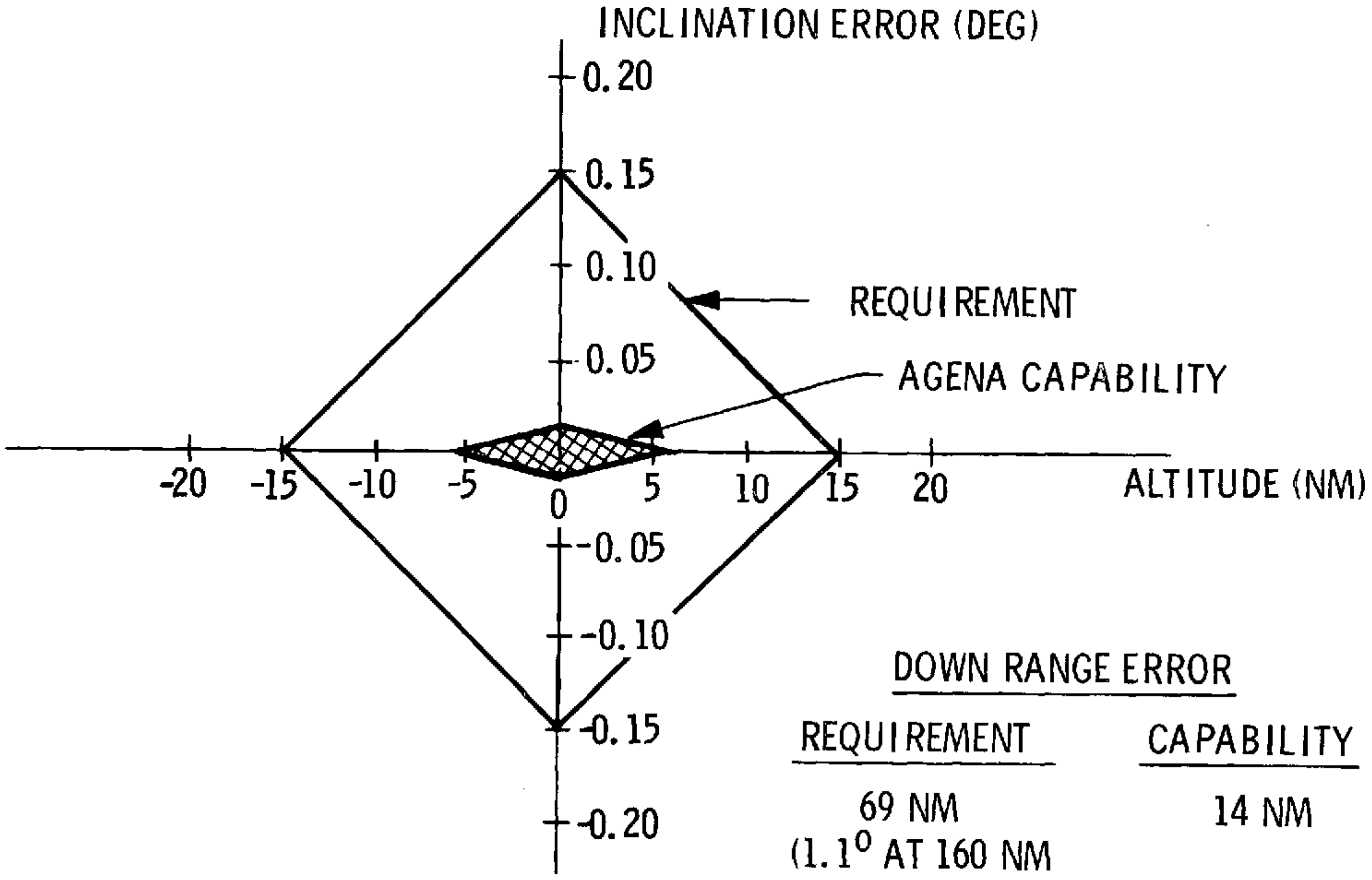
*Corrected through phasing burn
**Update error

The final circularization burn will also reduce phasing orbit errors with the exception of the vertical position error at perigee. The guidance/ground algorithm for determining final burn state vector will be adjusted to minimize the guidance induced errors (sensor errors, computational errors, etc.). This adjustment will result in a slightly increased downrange error, but at least 75 percent of the equivalent downrange (period) error of the phasing orbit can be eliminated through the final burn adjustments. The following errors would exist in the final rendezvous orbit:

1. ΔInclination 0.004°
2. Vertical position $\sqrt{6.1^2 + 1^2} = 6.2$ nm (11.5 km)
3. Downrange position $25\% \times 0.22 \text{ min} \times 50 \frac{\text{sec}}{\text{mm}} = 3.3 \text{ sec} \times \frac{4.2 \text{ nm}}{\text{sec}}$
$= 14$ nm (26 km)

These errors are depicted in Fig. 3.3.3-4 along with the requirements. These results show that the stated requirements can be met without having to provide a Δvelocity (midcourse adjust) capability through a secondary propulsion system (SPS).

(3 BURN RETURN FROM SYN. EQ ORBIT)



DOWN RANGE ERROR

REQUIREMENT	CAPABILITY
69 NM (1.1° AT 160 NM ALTITUDE)	14 NM

Fig. 3.3.3-4 Injection Accuracies

GN&C Accuracy vs Mid-course Corrections. The capability of the Agena GN&C system for accurate placement of a payload and return to Orbiter rendezvous orbit was discussed previously in this paragraph.

An evaluation was made of the mid-course corrections required if a horizon sensor is used for attitude update instead of the accurate star tracker. Attitude accuracy values used were 0.2 deg in all axes for low earth orbits and 0.2 deg in pitch and roll and 1 deg in yaw at synchronous orbit using gyrocompassing for yaw reference. The ΔV required for the return leg of a 5-burn synchronous orbit mission is 92 ft/s (28 m/s) to correct for the inclination error induced by the 1 deg yaw attitude error during transfer burn and 75 ft/s (23 m/s) to correct for the perigee altitude error due again to the 1 deg yaw altitude error.

A comparison of star tracker and secondary propulsion system (SPS) weights for the 167 ft/s (51 m/s) ΔV corrections made during these phases of the mission is shown below.

- Star tracker (Bendix ATM) – 71 lb (32.2 kg)
- SPS (hydrazine, blow-down)
  - Dry weight – 30 lb (13.6 kg)
  - 92 ft/s change made near syn apogee – 92 lb (41.8 kg)
  - 75 ft/s change made at phasing orbit apogee – 51 lb (23.2 kg)

Total SPS weight – 173 lb (78.6 kg)

Because of the difference in weight of more than 100 lb (45.4 kg) between the star tracker and the secondary propulsion system, the decision was made to improve GN&C accuracy through the use of an accurate star tracker attitude update.

Thruster Sizing, Dual vs Single Level Thrusters and Attitude Control Impulse Requirements. The detailed analyses of these areas are provided in ref 3-8. The results are summarized in Tables 3.3.3-6 and 3.3.3-7.

Table 3.3.3-6

SUMMARY OF RCS THRUSTER SIZING ANALYSES

1. Thruster Sizing	Ability to control turbine exhaust torques up to 10 ft-lb (13.6 N-m) Use 20 ft-lb (27.2 N-m)	Thruster force (2 thrusters) $= \frac{20 \text{ ft-lb } (27.1 \text{ N-m})}{2.17 \text{ ft } (0.66 \text{ m})}$ $= 9.2$ lb (40.8 N) One thruster force $= 4.4$ lb (19.5 N)
2. Dual vs Single Level Thrusters	Ability to meet minimum rate of 0.1°/sec (Use 0.01°/Sec)	$F_{max} = \frac{I\omega_{min}}{2r\Delta t}$ F = thruster force I = vehicle inertia ω = min rate = 0.01°/sec r = thruster lever arm t = thruster minimum bit time $= 20 \times 10^{-3}$ sec. $\frac{r}{I} = 1.4 \times 10^{-3}$ (ave) $F_{max} = \frac{0.01}{2 \times 1.4 \times 10^{-3} \times 20 \times 10^{-3} \times 57.3}$ $= 3$ lb (13.4 N) Therefore from 1 and 2 above, Select High mode = 10 lb (44.5N) (available) Low Mode = 0.5 lb (2.2 N) (available)

3.3.3.3 Data Management and Instrumentation (DM&I). The DM&I assembly consists of the digital computer, the computer interface unit, the computer software and the Agena system instrumentation. The Agena Service Panel discussed in par. 3.3.5.2 is also the responsibility of the DM&I system as are all interface functions between the avionics and other subsystems or systems. Figure 3.3.3-5 shows the DM&I hardware configuration.

Table 3.3.3-7

AGENA ACS IMPULSE EXPENDITURE

(38 Hrs Syn-Eq Mission)

(SYN-EQ MISSION) (5 BURNS – 38 ACTIVE HOURS)

Disturbance Source	Time or No. of Occur.	Impulse Expenditure Scaling			Agena Impulse Requirements (Lb-Sec)
		Existing Agena Range (Data From >100 Flights)	Shuttle/Agena Requirement Calculated	Used	
1. Vehicle Maneuvers	24 Times	218 $\frac{\text{Lb-Sec}}{\text{Maneuver}}$ (1st Burn Ignition) 57 $\frac{\text{Lb-Sec}}{\text{Maneuver}}$ (Final Burn Out)	200 $\frac{\text{Lb-Sec}}{\text{Maneuver}}$ (1st Burn Ignition) 23 $\frac{\text{Lb-Sec}}{\text{Maneuver}}$ (Final Burn Out)	110 $\frac{\text{Lb-Sec}}{\text{Maneuver}}$ (Avg)	2,640
2. Turbine Wind-Up/Down	5 Times	40 $\frac{\text{Lb-Sec}}{\text{Burn}}$ (Max. Observed)	40 $\frac{\text{Lb-Sec}}{\text{Burn}}$	40 $\frac{\text{Lb-Sec}}{\text{Burn}}$	200
3. Turbine Exhaust	18.9 Min	47 $\frac{\text{Lb-Sec}}{\text{Min. of Burn}}$ (Max. Observed) 20 $\frac{\text{Lb-Sec}}{\text{Min. of Burn}}$ (Avg)	60 $\frac{\text{Lb-Sec}}{\text{Min. of Burn}}$	80 $\frac{\text{Lb-Sec}}{\text{Min. of Burn}}$	1,510
4. Propellant Vent	6 Times	32 $\frac{\text{Lb-Sec}}{\text{Burn}}$ (Max. Observed)	40 $\frac{\text{Lb-Sec}}{\text{Burn}}$	60 $\frac{\text{Lb-Sec}}{\text{Burn}}$	300
5. Residual Propellant Dump	Once	–	(213 Lb Liquid and Vapor) 455 Lb-Sec	(300 Lb Liquid & Vapor) 640 Lb-Sec	640
6. Deadband Switch (Coarse to Fine)	5 Times	50 $\frac{\text{Lb-Sec}}{\text{Switch}}$ (Max. Observed)	50 $\frac{\text{Lb-Sec}}{\text{Switch}}$	100 $\frac{\text{Lb-Sec}}{\text{Switch}}$	500
7. Aero Torques and Limit Cycle	29 Hours	8.5 $\frac{\text{Lb-Sec}}{\text{Hr}}$ (Max. Observed)	6 $\frac{\text{Lb-Sec}}{\text{Hr}}$	18 $\frac{\text{Lb-Sec}}{\text{Hr}}$	522
8. Reserve RCS					2,074
TOTAL					8,386 Lb-Sec (37,300 N-Sec)

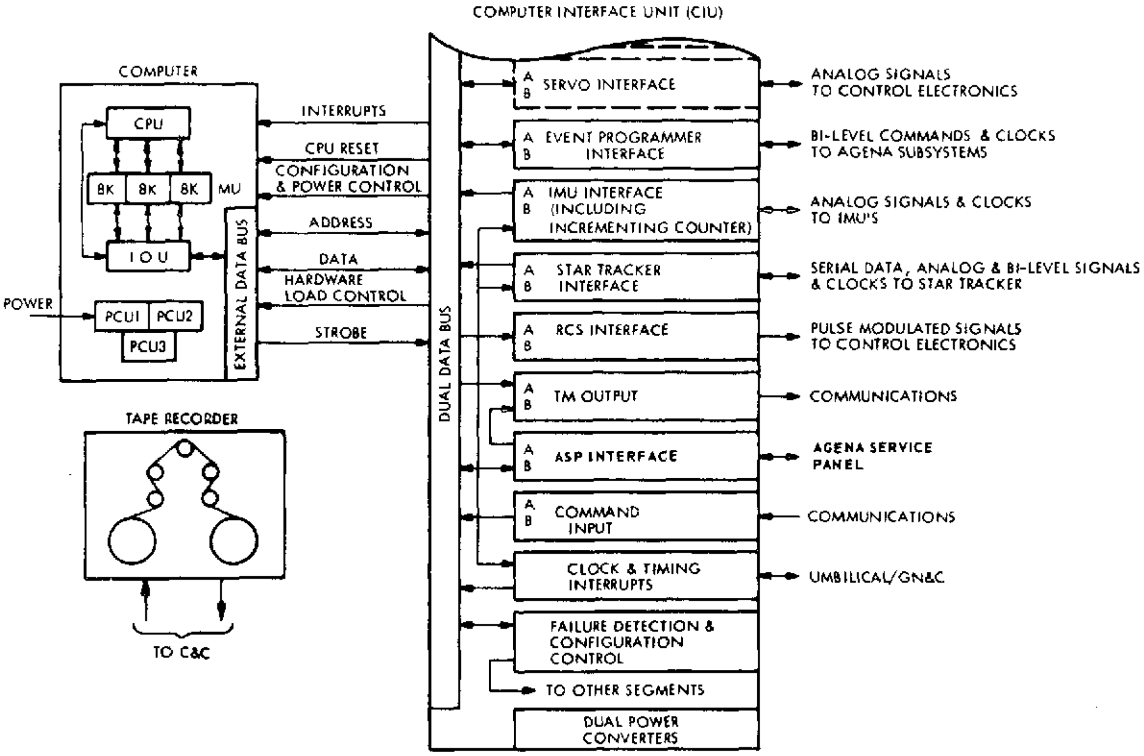


Fig. 3.3.3-5 DM&I Configuration

Computer Hardware Description. The dual string version of the DF224 computer consists of 2 identical, separate sections. Each section comprises a central processor unit (CPU), an input-output unit (IOU), three 8000 word memory units (MU), two power supply units (PCU), and a dual internal data bus. The recommended nominal agena upper stage uses a single string version of the computer.

Computer Characteristics. The autonetics DF224 digital computer is a high speed machine using advanced but proven technology. It is being developed for a current space mission and is scheduled for qualification and flight test in the near future.

- Memory size of 8000 words expandable by 8000 increments (Agena version is 16K)
- Non-destructive memory (power off capability)
- Basic computer expansion capability
    - 1 to 3 (CPU)
    - 1 to 3 (IOU)
    - 1 to 6 MU (expandable to 24)
    - 2 to 7 (PCU)

Subassemblies are modular. Width and height of computer family are standard, added capability is taken care of by expansion in one direction. Both bipolar (IOU) and MOS/LSI (CPU) technology are used.

The CPU is a general purpose, sophisticated processor formed by a group of P-channel MOS/LSI building blocks. The CPU structure includes an arithmetic section and a program control section.

The CPU control section controls the status and operation of the CPU arithmetic section, MU, and the IOU. Control signals and addresses are generated and sent to the MU and IOU. Monitor signals from these units and the interrupts are decoded in the control section. Twenty-four independent program interrupt channels are provided with each interrupt having its own dedicated memory address. The control section registers are the P register, the timing register, a 16-bit program counter (P), the arithmetic status register and the operand bank register.

The CPU arithmetic section performs the arithmetic, word manipulation, and logic operations of the computer.

The MU are composed of 8192 25-bit words each (24-bits data, 1-bit parity). The logic mechanization of the MU includes data and address registers, priority and control functions, timing, parity, write protect and decoding functions.

Each MU contains four registers: the address register, the MU bank address register, the data register, and the memory protect register. The 13-bit address register is used to hold the memory address (location 0000-8192) for the MU and can be loaded from any of the address buses. The bus to be used is determined by the priority logic.

The MU logic also includes a 3-bit comparator for MU bank address recognition. The three most significant bits of the address word (bit 15, 14, and 13) are compared to the bank address register. The code on the lines identifies the address for that particular MU.

The IOU handles all data between the computer and external devices or subsystems. The IOU performs two functions. First, it electronically isolates the CPU and MU from changes in input/output signal conditions. It performs the signal conditioning necessary for the electrical interface between the computer and external systems. Second, it isolates the CPU and MU's from changes in input/output functional requirements by providing a standard interface.

The IOU consists of an Internal Data Bus (IDB) interface, an External Data Bus (EDB) interface and a format control section made up of an address register, a buffer register, a word counter and control logic.

The IDB and EDB are dual for redundancy purposes on this version. For multiprocessor version, these redundant buses (3 IDB,2 EDB) are used in reconfiguration.

The internal data bus is made up with 16 address lines, 24 data lines, and 24 control/monitor/clock lines.

The internal data bus handles 24-bit words at the computer logic rate. This is equivalent to a transfer rate of 1.25 million words per second.

The address lines allow the CPU to address up to 65,536 words in memory. The data lines are used to carry data in both directions over the bus as parallel 24-bit words.

The control lines provide the following functions: 1-cycle steal, 3-memory busy, 2-MU commands (read, write), 3-IOU commands (IOU mode control), 1-memory parity error interrupt, 1-write protect violation interrupt, 1-memory protect disable, 4-STE mode control signals, 1-memory inhibit, 6-clock signals, and 1-CPU Reset.

Computer Interface Unit. A computer interface unit (CIU) (Fig. 3.3.3-5) is employed between the DF224 computer and other vehicle equipment. The CIU design uses a single enclosure with circuit card modules for each separate interface function. Existing I/O designs appear to be applicable to greater than fifty percent of the identified requirements.

Referring to Fig. 3.3.3-5, redundant functions are provided for interfacing with redundant equipment (e.g., IMU).

The CIU is connected to the computer through a high speed data bus. The desired reliability, the peak computation load, and the amount of data to be stored will affect the final CIU configuration.

The functions of the CIU are to provide signal and data conversion (digital to analog, analog to digital, parallel to serial digital, serial to parallel digital, etc.) between the computer and other Agena equipment, provide failure detection and switching for the IMU and computer outputs, provide clock and timing interupts to the computer, and provide command and telemetry conditioning.

Existing CIU modules (with Shuttle/Agena Upper Stage nomenclatures) that will be used with minor modifications are described as follows:

- Computer I/F. Provides a parallel interface between an external computer and the internal data bus of the CIU. The data bus is 24 bits to the computer and 12 bits from the computer.
- Command Input. Accepts serial command data in a 1, 0, S form (typical of SGLS) and formats in parallel form for transfer to the computer or for use internal to the CIU. Makes checks on format, word length and parity.
- Configuration Control. Accepts command words from the command input module for reconfiguring systems with redundancy.
- Timing. Provides all internal timing signals for the CIU and synchronous interrupts to the computer.
- ASP I/F. Provides the interface between the internal data bus and external remote decoder-multiplexers (RDM) used with the Agena Service Panel (ASP). Routes 8-bit serial TM requests and command words to the ASP and receives 8-bit TM words from the ASP.

- TSP. A multipurpose module providing a common internal data bus interface with the PCM telemetry output, star tracker input and other functions.
  - Telemetry. Multiplexes data in 8-bit bytes from the RDM I/F, the internal data bus (computer words), and an external device for outputting a 16 kbps PCM bit stream.
  - Star Tracker. Accepts azimuth and elevation angle data and time tags. This data is formatted for reading by the computer.
- CUS I/F. A multipurpose module providing interface with 12 reaction control thruster drivers and 2 servo amplifiers.
  - Thruster drivers. Provides pulse-period, pulse width modulated signals to each of 12 thruster drivers for attitude control and stabilization.
  - Servo Amplifier. Provides an analog signal to each of 2 servo amplifiers for powered GN&C steering
- IMU I/F. Accepts fixed value pulses of up to 1800 pulses per second rate from each of 3 gyro channels and 3 accelerometer channels. Accumulates each of the 6 data inputs in reset counters which are read out each 20 millisecond by the computer.

Software. An initial examination of the Shuttle/Agena Upper Stage software requirements indicates that many of these will be similar to those currently used on the Lockheed Ascent Agena. Any of the existing Agena guidance system (AGS) programs that are applicable will require recoding because of the use of a different computer from that used for the AGS.

Typical flight programs that will be necessary for the Shuttle/Agena Upper Stage include the following:

- In-Flight Executive. Controls the major cycle guidance flow, minor cycle (flight controls, steering, compensation) flow, interrupt processing, computer self check and redundancy switching.
- Navigation. Computes current vehicle inertial position and velocity using navigation update data, compensated IMU data, and computed gravity vector in recursive difference equations.
- Guidance. Solves for the desired thrust-pointing unit vector by exercising the radial, out-of-plane and downrange guidance algorithms. Using current estimates of position and velocity furnished by the navigation module, the guidance algorithms are used to estimate terminal position and velocity, compare them to the targeted terminal conditions and compute and relay appropriate error signals to the steering subroutine.
- Steering. Converts the instantaneous difference between the desired and actual vehicle pointing vectors into a correction signal.
- Powered Flight Controls. Processes the steering signals to command engine pitch and yaw actuators to achieve the desired vehicle attitudes.
- Attitude Control. Computes pulse width and repetition rate of pulsed signals required by reaction control thrusters. IMU rate output signals are used to close the control loop about the vehicle dynamics.
- Navigation Update. Accepts ground tracking generated state vector data and stores data with timing tab.
- Attitude Update. Accepts and implements star tracker gimbal commands to orient optical axes to estimated line of sight of two or more selected stars. Uses gimbal azimuth and elevation angle readouts to compute IMU reference axes attitude relative to G&N inertial reference frame.
- Strapdown Algorithm. Converts IMU sensed body acceleration and rates into inertial reference frame through the use of a computed body to inertial direction cosine matrix and an inertial velocity change vector.
- Instrument Compensation. Corrects the inertial reference established by the strapdown algorithm to account for deterministic instrumentation errors.

- Gravity. Computes the value of local gravitational acceleration using position and oblate earth gravity model.
- Event Sequencing. Computes predicted time of discretes and changes the values of event-dependent flags affecting the execution of appropriate guidance subroutines.
- On-board Checkout. Provides off-line test sequence and stimuli for IMU, computer, attitude control channel, hydraulic servo loop, C&C and EPS&D systems. (Data evaluation and diagnostic not performed on-board).
- Utility and Constant Storage. Provides program loading, normalization, square root, dot and cross product, sine/cosine functions, star map, gravity model and other constants.

Instrumentation. The Shuttle/Agena Upper Stage requires over 400 instrumentation points. Comparison with existing Agena and other similar programs indicate that this is a reasonable level for the quantity of equipment and types of functions to be monitored.

Table 3.3.3-8 summarizes the instrumentation points required. Points are listed by Agena subsystems and by functional types. A detailed listing of these monitor points with accuracies required, signal levels, ranges and sampling rate is presented in ref 3-8.

The instrumentation points were placed in three categories as follows:

- Category I. These data involve crew or vehicle safety, the highest priority for acquisition, and display. Safety data will be provided through dedicated hardline both directly from the sensor to the display and through PCM during mated operation and through PCM RF link after deployment. The data will be in engineering units where appropriate. An estimated 62 signals fall into this category.
- Category II. These data permit real time vehicle/subsystem performance evaluation. Data may result in use of equipment redundancy, altering mission objectives, tasks, etc., primarily related to accomplishment of mission. These data will be provided hardlined to the orbiter during mated operations, and through the RF data link to both the orbiter and ground stations after deployment. These data include safety data and are estimated to consist of 342 signals.
- Category III. These data, if needed, are associated with the reusable nature of the tug. Incipient failure recognition based upon trend data analysis permits Agena equipment replacement during Orbiter refurbishment on the ground rather than risk flight failure. Also, failure diagnosis using the

Table 3.3.3-8
AGENA INSTRUMENTATION

Telemetry Points By Subsystem				
Subsystem	Analog	Bilevel	Digital	Total
• Structures	15	1		16
• Propulsion	59	53		112
• Avionics				
• GN&C	39	37	57	133
• DM&I	18	2	4	24
• C&C	16	70	18	104
• EPS&D	13	2		15
• Total Vehicle	160	165	79	404
• Cradle (Orbiter)	7	59		

Telemetry Points By Function									
Function	Structure	Propulsion	GN&C	DM&I	C&C	EPS&D	Total Vehicle	Cradle	(1) Non-Integral To Equipment
• Control Signals			49		22		71		
• Current						5	5		
• Data/CMD Verif			25	4	18		47		
• Event Verification			26		48		74		
• Leak Detector							0	6	
• Level/Intensity		1			2		3		
• Limit/Position	1	43	4			2	50	53	
• Liquid Level		8					8		8
• Pressure		25					25		25
• Speed/Velocity		1	6				7		
• Strain	6						6	6	6
• Temperature	9	32	13	2	14	5	75		51
• Voltage		3	12	18			33	1	
Total	16	113	135	24	104	12	404	66	90

(1) These are included in vehicle total of 404.

malfunction data should reduce time required for flight and ground failure isolation to the level required for repair. Trend, malfunction and failure analysis data will be stored either on the Agena Service Panel recorder tape located in the Orbiter or ground station tapes or both. Data falling in this category will, in most cases, be the same data belonging to the other 2 categories.

Safety Data. The Agena safety data will be provided redundantly to the Orbiter crew. During Shuttle/Agena mated operations, in addition to Agena PCM data hardwired to the Orbiter, safety critical data will be dedicated hardwired directly from the Agena sensors to the Orbiter interface (and to an appropriate display). This permits Orbiter monitoring of critical Agena parameters with the Agena telemetry system off or failed. The redundant signals will generally originate in a common sensor, but for critical parameters, redundant sensors will be provided. The dedicated hardwired data provides continuous monitoring of Agena status as compared to the sampled nature of PCM telemetry systems. Following deployment, only the PCM (RF link) data will be available. Safety data will be sampled at a high enough rate to prevent dangerous out-of-limit state changes from going unnoticed.

Cargo bay safety data will be dedicated hard-wired to the Orbiter crew console displays during Agena storage in the cargo bay.

Safety data can be further categorized to those which have immediate time criticality and those whose time criticality is of lesser magnitude. Where immediate action must be taken, data must be processed to eliminate all undue delay and provide automatic backup of manual corrective action initiation. For those situations where some time can lapse before conditions become critical, automatic backup of manually initiated corrective action initiation may not be necessary. In either case, adequate safeguards must be provided to prevent inadvertent initiation of emergency action but still allow ground controlled initiation of required action (including initiation of preprogrammed automatic sequences as required) in case of crew incapacitation.

Key Issues. The two major issues in DM&I are (1) size of computer memory required, and (2) methods to be used for failure detection and redundancy management.

Memory Sizing. Similarity in GN&C software functions of the Shuttle/Agena Upper Stage and the existing Ascent Agena system provided a basis for a reasonably accurate estimate of memory sizing for the Agena synchronous orbit mission operational software program. The greatest area of uncertainty encountered was in the area of failure detection, isolation, and redundancy management. With an early realization that considerable effort would be required in this area in order to accurately define memory requirements, the decision was made to perform failure detection of the redundant IMU and controls electronics circuitry through existing hardware techniques used on Agena and other LMSC programs. Redundancy switching of time-critical circuits would be automatic and would be performed by complete strings, i.e., IMU/computer/CIU and electronics/thrusters.

Using this basic ground rule, the uncertainty in memory size estimate was reduced sufficiently that a minimal growth margin was believed to be acceptable.

Table 3.3.3-9 shows a comparison between Shuttle/Agena Upper Stage and the existing Ascent Agena memory requirements. The 13,308 words required for the Shuttle/Agena Upper Stage allows about a 17 percent growth margin vs the 16,000 word memory capacity of the selected computer.

Table 3.3.3-9

COMPUTER MEMORY REQUIREMENTS

Software Module	Shuttle/Agena Upper Stage (24 Bits)	Existing Agena (20 Bits)
• Inflight Executive		
• Major Cycle Guidance Flow	104	22
• Steering, Control and Compensation Flow	250	77
• Interrupt Processing	640	241
• Computer Self Test	1,010	
	2,004	340
• Navigation		
• Navigation (Includes Strapdown Algorithm)	1,126	101
• Gravity	48	
• Update	250	
• Compensation	374	274
	1,798	375
• Guidance		
• Flight Initialization	200	77
• Orthonormalization	140	140
• Coordinate Transformation	50	50
• Common	200	123
• Stage Initialization	250	50
• Orbit Targeting (Conversion)	250	106
• Stage Setup	230	195
• Waiting Guidance	140	41
• Powered Flight Guidance (Roadmap)	200	67
• Time-to-Go	250	159
• Targeting (Computation)	120	76
• Inclination Control	40	40
• Guidance	250	174
• Coast Phase Guidance	200	107
• Maneuvers	146	146
• Discrete Check	200	168
	2,866	1,719
• Steering	237	237
• Powered Flight Control	121	121
• Attitude Shaping Logic	243	243
• Booster Flight Control Interface	–	76
• Attitude Update	1,400	–
• Event Sequencing	92	392

Table 3.3.3-9 (Cont)

Software	Shuttle/Agena Upper Stage (24 Bits)	Existing Agena (20 Bits)
● On-Board Checkout		
● Test Interpreter	585	585
● Test Lockout	43	43
● Burn Commit Sequence	145	145
● Memory Dump	73	73
○ Stop Alignment	24	24
● Enable Basic Operating Sequence	24	24
● Steering Sequence	131	131
● Enable Attitude Control	15	15
● Alignment	350	491
● Bias Multiply	14	14
● IMU Go/No-Go	155	155
● Attitude Control Channel Test	35	35
● Hydraulic Loop Step Response	27	27
● Test Hold/Recycle	68	68
● Binary – Decimal – Degrees	94	94
● Status Work Adjustment	146	146
● Storage	145	145
● Input Optical Azimuth	–	53
● Computer/CIU Test	444	–
● Horizon Sensor Test	40	–
	2,586	2,295
● Utility and Constant Storage		
● Program Loading	207	207
● Matrix Rotation	12	12
● Normalization Routine	50	50
● Square Root	81	81
● DOT Product	24	24
● Cross Product	29	29
● Sine/Cosine Functions	37	37
● Constants Storage (Star Map, Gravity Model, Etc.)	1,521	1,021
	1,961	1,461
TOTAL MEMORY	13,308	7,259

Failure Detection and Redundancy Management (FDRM). The basic groundrule established for FDRM is that failure detection of IMU and controls electronics circuits will be performed through existing hardware techniques used on Agena and other LMSC programs. Automatic switchover will be performed during time and safety critical periods and, depending on where the failure occurs, the complete guidance, and navigational channel (IMU, CIU, Computer) or the control channel (electronics, thrusters) will be switched to simplify redundancy management.

Failures in one of the two IMU or computer strings mustbe rectified with little delay because errors of small magnitudes in guidance and navigation can cause large final position and velocity errors. To do this, the strings must be navigating in parallel so that switchover will result in minimum error. During operation in the vicinity of the Orbiter, both IMU and computer strings must be operating simultaneously to allow instantaneous switchover in case of a failure.

During powered flight or during operation in the vicinity of the Orbiter, the six IMU inertial outputs (incremental attitude and velocity) of each IMU will be monitored and hard failures will be detected using reasonableness checks. Reasonable bounds about the expected output rates and vehicle acceleration for the duration of engine burn will be established. Level detectors will be used to determine when these bounds are exceeded and the outputs of both IMU detector strings will be inputted to a logic "and" circuit. If both IMU detector outputs are of the same state, no switching occurs. If one shows a failed condition (a 1 state) and the other shows a normal or 0 state a command discrete is given to switch the control electronics inputs from the failed IMU/computer/CIU string over to the redundant string.

If the failure occurs in the controls electronics or the thrusters (or somehow is not detected by upstream failure detector circuits), a failure detector senses excessive thruster drive current on-time and sends a command discrete when a threshold period is exceeded. For detection of failures in and switching of servo amplifiers and as an alternative to the current-on-time detector, an excessive rate detector provides a discrete when a preset rate threshold is exceeded.

The discrete command is used to turn on the redundant electronic drivers, thrusters, and servo amplifiers, at the same time turning power off to the suspect electronics and closing the propellant isolation valve for that bank of thrusters.

During transfer or parking orbits, a failure in either the IMU or computer (for the period the computer is being used) will have little or no effect, as long as the failure is detected and the failed unit is taken off the line in a reasonably short time because the IMU and computer can both be re-initialized. The IMU is realigned on-board using the star tracker and current vehicle position and velocity can be loaded into the computer to set up initial conditions.

Time for corrective action is not as critical for this operation as it is for the powered GN&C as long as the failed unit is taken off the line since the vehicle can remain in the inertial state (even tumbling at rates below break up) for long periods and still be capable of regaining control. If attitude reference and control is lost, a search program is instituted from the ground using the horizon sensor, and a ground commanded pitch (or roll) maneuver.

Computer Self-Test and Output Reasonableness Checks. The objective of an on board computer self test is to check the maximum number of circuits and connections possible, yet minimize the computer time and memory utilized to do so. The DF224 computer provides some hardware features toward this end, and when used in conjunction with external circuitry which can detect the computer's failure to cycle properly and also to provide interrupt signals, will detect a large number of failure modes. A significant portion of the testing, however, must be accomplished by means of software programs stored in the computer's memory.

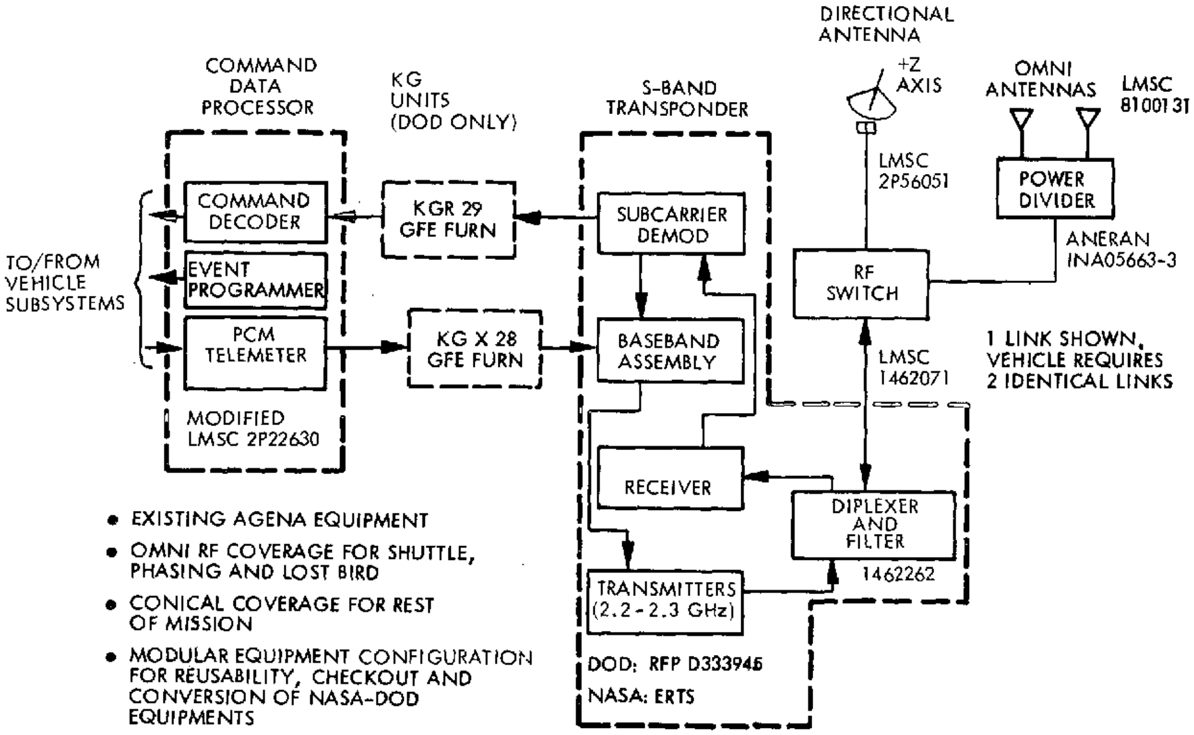
These software programs can be either of two types. The first type is problem oriented in which the actual operational program is used as part of the test software. This technique would be to use known variables for the computations and then check the results before using the real variables. This could be a useful approach to take for minor cycle rate computations, because the control mechanization typically has relatively few branches and because the allotted self test time is rather short. The other approach is to construct a special software program used strictly to check the computer. A set of instructions and data words are selected to test each active unit and the interconnections between units. Intimate knowledge of the computer design permits optimization of the program needed to best test the computer in the allowable time. This time may be in the neighborhood of 5 milliseconds for minor cycle rate testing and may extend to one or two seconds for the remaining testing.

A typical test executed at controlled rates might be one to check the IOU and data bus by outputting a set of numbers and then inputting them, test the memory by means of a partial sum check and memory write test, and test the CPU by executing a sequence of instructions which exercise the CPU logic and internal data bus.

These tests would be set up to pick the portions of memory and computer instructions used which require the maximum number of circuits and interconnects for each operation. The test required to exercise the remainder of the computer (all memory read and all computer instructions) can then be completed at a major cycle rate.

A "watch dog" timer will be provided in the Computer Interface Unit to provide interrupt signals and to determine if the computer has cycled properly. In addition to the computer self checks, reasonableness checks of the vehicle control output signals will be performed in the CIU to catch failures occurring upstream of this point which may have gone undetected.

3.3.3.4 Communication and Control (C&C). The C&C system consists of a transponder, a command data processor, and an antenna system. Two separate identical systems are provided to meet the fail operational requirement which applies to critical command and control circuitry. For DoD missions, redundant secure encryptors and decryptors are also provided. This system is shown in Fig. 3.3.3-6. It provides the capability of tracking (range and range rate), PCM status telemetry, and real time and stored program commanding. For NASA missions, the transponders will be compatible with the USB system.



- EXISTING AGENA EQUIPMENT
- OMNI RF COVERAGE FOR SHUTTLE, PHASING AND LOST BIRD
- CONICAL COVERAGE FOR REST OF MISSION
- MODULAR EQUIPMENT CONFIGURATION FOR REUSABILITY, CHECKOUT AND CONVERSION OF NASA-DOD EQUIPMENTS

Fig. 3.3.3-6 C&C Configuration

In the standby, or sleep mode, all units, except the receiver-demodulator, will be turned OFF. The receiver sections of the redundant links will be powered continuously to provide the capability of realtime commanding at any time during this mode of operation.

Command operations may be controlled either from the Orbiter or from ground stations. Safety reasons dictate, however, that command operations will not be performed simultaneously by ground stations and the Orbiter.

The preliminary RF link calculations provide the basis for selecting transmitters with adequate RF output power and receivers with a sufficient signal-to-noise ratio to close the RF command and tracking loop under worst case conditions.

The C&C subsystem controls the various Agena subsystem functions, by real-time commands from the Orbiter or from ground stations, and with a limited number of stored commands. It samples and formats all sensor inputs from the various spacecraft subsystems for transmission to the Orbiter or ground stations. Tracking is accomplished by utilizing the receiver-demodulator and the transmitter-baseband assembly as a transponder to provide range and range-rate data.

Commanding. The receiver-demodulators, in active redundancy, operate on preselected different frequencies in the range of 2.025 to 2.120 GHz for NASA missions and 1.75 to 1.85 GHz for DoD missions. Each unit receives input signals through a diplexer from its respective antennas which provide near omni-directional coverage during low earth orbits and high gain, narrow beam (35 deg) coverage during high altitude operations. An RF switch is provided to switch between the omni and directional antennas.

The uplink RF carrier is phase-modulated by frequency-shift-keyed subcarrier frequencies representing S (for enable and execute), binary 1 and 0 and an amplitude modulated 1000 pps clock signal. The S signals activate the demodulator circuitry which is operating in standby. The interrogated receiver-demodulator provides a power ON signal to the command decoder, activating the unit. The received command subcarrier signals are amplified, detected, filtered, and demodulated to provide respective output pulses to the command decoder for decoding.

When the command decoder recognizes a valid address, it generates an internal signal that enables the remaining part of the command decoder and permits the message to be processed. When the decoder recognizes the address to be incorrect, it generates an internal reset signal that disables the decoder circuitry to prevent execution of a wrong command.

When the decoder has recognized a valid address it accepts the remaining part of the command message containing the command address and discrete command function data. Prior to command execution by a final S signal, the 14 command function bits are telemetered to the Orbiter or the ground station, depending on where the command message originated, for verification. An internal odd 1 parity check is also made by the decoder. This check is to ensure that only a valid message has been accepted and no false command will be executed by the decoder. When the command address bits in the message are all zeros, a discrete command output pulse will be sent to the respective subsystem in the Agena.

When the command address is assembled of any combination of binary 1 and 0, other than all zeros, a specific output pulse will be generated allowing the remaining command function bits to be applied to the event programmer.

The event programmer has the capability of storing these command function bits and suitably processing them. After a predetermined time interval, the event programmer will provide an output pulse to the respective using subsystem. At present, provisions have been made for eight programmable output pulses.

Before a specific command can be executed, each command message must satisfy address, parity, and length verification checks. The command decoder has the capability of providing 32 discrete command output pulses and 15 command address commands to load the event programmer.

For secure commanding, a KG-R29 unit is added between the receiver-demodulator and the decoder. In conjunction with the KG-X28 unit, the encrypted command data are decrypted by the unit. Its output signals are then processed by the command decoder as described above.

Telemetry. Transducer output signals (0 to 5 VDC) in analog, bi-level, and digital form are applied to their respective input gates of the PCM telemeter. The PCM telemeter unit multiplexes the input data signals into a specific frame format. The PCM telemeter output in form of a PCM-NRZ-L wave train at a bit rate of 64 Kbps is then applied to the baseband assembly (BBA).

The PCM telemeter also has a second output which can be connected to a digital tape recorder. If a recorder is used, this provides the capability of storing the telemetry data while the Agena is out of station contact during transfer orbit. The reproduced data output of the tape recorder is also connected to the PCM telemeter which has the capability of selecting (by real-time command) between real-time PCM data to be transmitted to the Orbiter and/or ground stations.

The PCM-NRZ-L wavetrain biphase modulates a 1.7 MHz subcarrier oscillator (SCO) in the BBA. Its output, in turn, phase modulates the downlink RF carrier.

The transmitter operates on a fixed frequency within the range of 2.2 to 2.3 GHz. The transmitter output is connected through a diplexer to the antennas through an RF switch. The omni antennas are used during low earth orbits up to about 5000 nm (925 km) and the high gain directional antenna is used for higher altitudes. The diplexer provides the capability of simultaneously transmitting and receiving RF signals at different frequencies using the same antenna configuration.

For secure telemetry data transmissions the PCM-NRZ-L wavetrain, at high or low bit rates, is encrypted by the KG-X28 unit. Its output then biphase modulates the 1.7 MHz SCO in the BBA. To process the PCM data through the KG-X28 unit, clock signals are required to be sent to the unit on a separate line from the PCM telemeter.

Tracking. The receiver-demodulator accepts and amplifies the composite video signal, consisting of command subcarriers and/or PRN ranging codes. From the composite video signal the PRN ranging code is extracted, filtered, and fed to the BBA. For retransmission to the ground, it is summed with the SCO output signal which phase modulates the downlink RF carrier. In conjunction with the appropriate ground station ranging equipment the required range data are obtained. The standard 0.3 rad deviation for PRN signals on the downlink will be utilized in the SGLS configuration.

Key Issues. Two issues addressed during this study were (1) the use of omni antennas (plus a power amplifier) vs high gain directional antennas, and (2) selection of equipment compatible with both NASA and DoD missions.

Antenna Selection. A link analysis* was conducted using the following criteria:

a. 30 feet (9.15 M) antennas at ground stations
b. Two subcarriers required – 1.024 MHz and 1.7 MHz
c. 64 Kbps rate required (primarily for high speed GN&C data)
d. Maximum RF output power of 20 watts as a practical limit.

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*See ref 3-8

The results (Fig. 3.3.3-7) show that the altitude capability of the omni-antenna system is about 5000 nm (9265 km) under these conditions. By eliminating the second subcarrier (1.7 MHz), reducing the downlink data rate to 32 Kbps, and using 20 watts of RF power, the omni antenna system will just provide link closure with about +1.3 dB margin. Twenty watts of RF power requires about 70 watts of input power compared to 30 watts using the high gain directional antenna.

In the vicinity of the Orbiter, omni coverage is necessary since maneuvering and placement of either the Agena or Orbiter for the sole purpose of communication is undesirable.

Because of the need for an omni coverage system and since omni coverage systems are inefficient at high altitudes requiring large amounts of power, a combination of omni antennas for low altitudes and a high gain, parabolic antenna using a beam width of 35 deg was selected for the Augmented Shuttle/Agena Upper Stage.

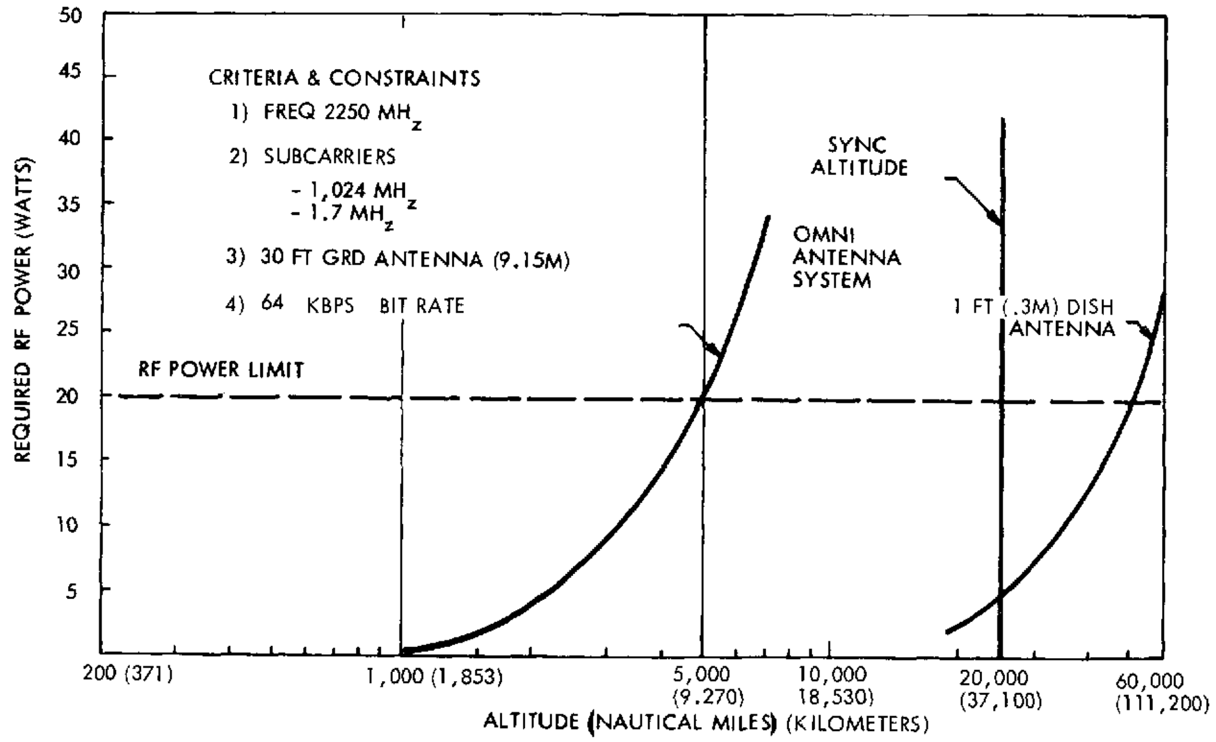


Fig. 3.3.3-7 Required Antenna RF Power – Omni Vs Directional

For the Nominal configuration the use of the same onmi-antennas throughout the mission simplifies operations somewhat and eliminates the RF switches. Overall weight is not decreased however, since power amplifiers of about the same weight must be added. Electrical power requirements are also increased by about 35 watts.

Rationale for Configuration Selection. Selection of equipment was based primarily on state-of-the-art hardware and qualified designs. The ERTS transponder, developed from the original Apollo USB design, was selected for NASA missions. It must be modified to include the baseband assemblies because these are not presently part of the ERTS design. Receiver-demodulators and transmitter-demodulator units are presently being developed by Motorola for a DoD program.

Flexibility was another important aspect in choosing the command data processor which incorporate the command decoder, the event programmer and the PCM telemeter. The basic circuitry on 4 x 5 inch printed circuit boards (PCB), which are standard at LMSC, is in existence. The fact that additional PCBs for data gates and command expansion can be added to the unit up to a certain limit, makes this configuration a good hardware candidate. This will also keep the design and development cost to a minimum.

There are two basic changes which must be incorporated into the C&C equipment. The S-band transponders (SGLS and USB) must be packaged in a way that allow ready exchange of either unit depending on whether the mission is for NASA or DoD. The existing command data processor must be modified to accommodate the event programmer and to be compatible with the USB transponder.

3.3.3.5 Electrical Power Supply and Distribution (EPS&D). The Agena EPS&D system is shown in Fig. 3.3.3-8. The electrical power is supplied by silver-zinc, non-rechargeable batteries. The power distribution and switching is provided by the power distribution box in the forward section of the vehicle and the aft instrumentation and control box in the aft section.

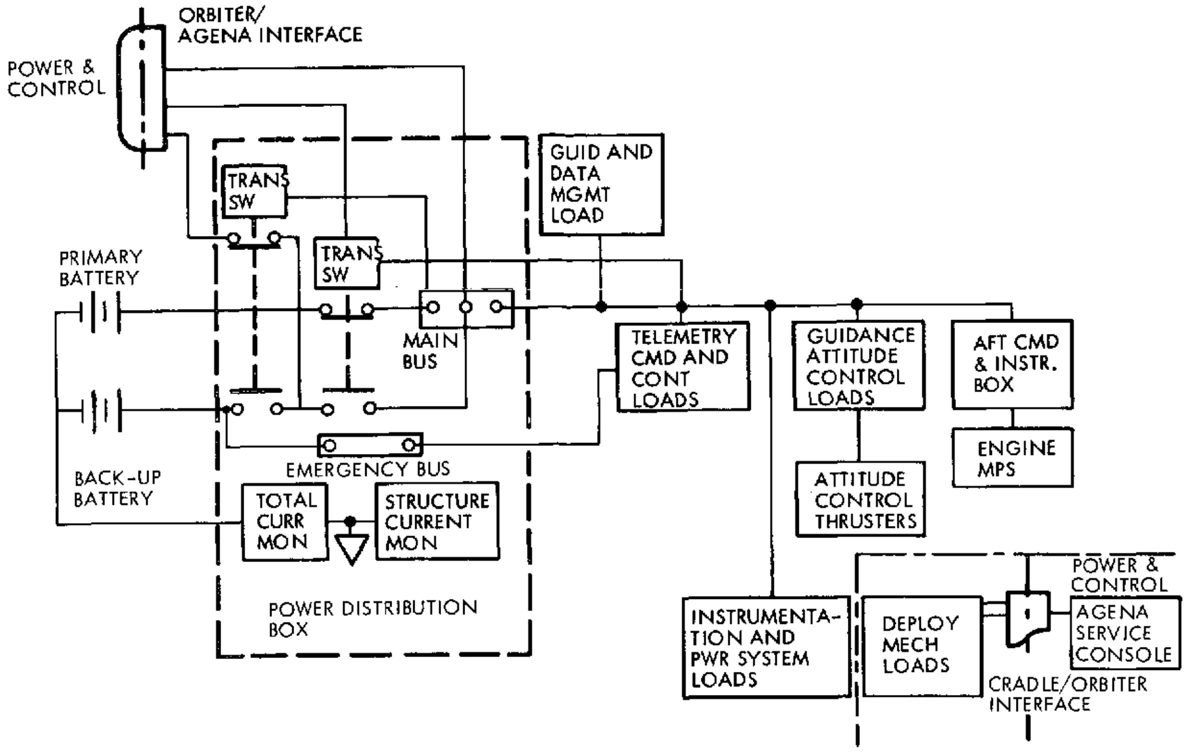


Fig. 3.3.3-8 Electrical Power Supply and Distribution Configuration

Prior to deployment from the Orbiter, power is supplied through the Orbiter/Agena interface connector and an isolation diode to the main power distribution bus. At deployment, the main power transfer switch is closed allowing the system to be transferred to internal power. An emergency power system consisting of a standby battery can be commanded ON in the event of a failure of the main bus batteries. The emergency battery can be connected to the main power bus by closing a transfer switch. It is also hardwired through interlock relays directly to the communication receivers. In case of primary power drop-out, the interlock relays will close the emergency circuit allowing the receivers to be powered from the emergency battery.

Power Distribution Box. The power distribution box is an adaptation of an existing flight program distribution box. This unit contains two power distribution buses, two power transfer switches, an Orbiter power isolation diode, two current sensors, and miscellaneous control and logic circuitry associated with the transfer switches. Minor engineering validation testing to the requirements is necessary to ensure high confidence in the unit for the Shuttle/Agena application. The main power transfer switch is commanded closed from the Orbiter prior to separation. This switch can be commanded open via an interlock with the close command for the emergency power transfer switch on the emergency battery. Under normal operation the main power transfer switch is never commanded open. The emergency power transfer switch may be commanded open or closed. When closed, it will supply the main bus with enough energy to operate the vehicle critical loads for at least 30 minutes. Whether it is closed or not, emergency power is available to the command receiver in the event of failure of the main battery. The total current monitor and the structure current monitor sensors are for diagnostic purposes to assist in evaluating the health of the vehicle. The Orbiter isolation diode is required to isolate the Orbiter bus from the Agena bus to prevent any discharge of the main batteries into the Orbiter loads.

Aft Instrumentation and Control Box. The aft instrumentation and control box is an adaptation of an existing flight program engine control box. The unit contains the electrical interface for controlling and monitoring the propulsion system and the aft section instrumentation. Circuits are included to control the tank pressure, and relays driven from DM&I computer signals are provided to furnish engine on and engine off commands to the engine control circuits.

Key Issues. Three key issues addressed during the study were (1) the energy level required for a 38-hour synchronous equatorial mission, (2) the type of energy source to be used (i.e., batteries vs solar cells (plus batteries) vs fuel cells), and (3) the depth of discharge to which batteries could be used.

Energy Requirement. The total energy required by the Agena for a 38-hour (active) synchronous equatorial mission is 11,402 watt-hours. The breakdown of the power required is shown in Table 3.3.3-10. Event-by-event energy requirements are shown in a detailed mission sequence of events included in ref 3-8.

Energy Source. A comparison of power source weight as a function of active mission time shows (Fig. 3.3.3-9) that for the baseline 38 hour synchronous equatorial mission, both tracking solar array and fuel cell systems weigh about 70 lbs (31.8 kg) and existing high efficiency primary batteries weigh about 140 lbs (63.6 kg) or about twice as much as the other two types of systems.

Table 3.3.3-10

AGENA POWER PROFILE – 38-HR SYN EQ MISSION – AUGMENTED AVIONICS

							Avionics Equipment on Single String							
SUBSYSTEM/EQUIPMENT	Engine Burn	Nav. Update Preparation (Ground Track, Warm-up, 43 min. Each Burn)	Engine Burn Preparation	Orbiter Rendezvous & Retrieval	Orbiter Approach	Nav. Update Operation (Ground Track, Warm-up, Att. Update, 17 min. Each Burn	Except STA Power OFF & Both C&C Links ON	Except STA	Except STA, HSA & PDE	Except STA, HSA, PDE, Transmitters	Except Computer CIU & STA Part Time (1) (Status Check)	Except Computer, CIU (Partial) & STA	Except Computer, CIU (Partial) STA, CDP, KG Units & Transm.	TOTAL
AVIONICS														
1. **Computer (Dual)**	162.0	81.0	162.0	162.0	–	81.0	81.0	81.0	81.0	81.0	16.0 Ave(1)	–	–	
2. **CIU (Dual)**	60.0	30.0	60.0	60.0	–	30.0	30.0	30.0	30.0	30.0	6.0 Ave(1)	5.0	5.0	
3. IMU (2)	220.0	370.0	230.0	220.0	370.0	250.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	
4. CEA/PDE	12.0	12.0	12.0	16.0	26.0	12.0	26.0	26.0	12.0	12.0	26.0	26.0	26.0	
5. STA	–	–	–	–	–	24.0	–	–	–	–	3.0 Ave(1)	–	–	
6. HSA	–	–	–	–	20.0	–	20.0	–	–	20.0	20.0	20.0	20.0	
7. Transponder (2)	37.0	37.0	37.0	37.0	37.0	37.0	60.0	37.0	37.0	14.0	37.0 (2)	37.0	14.0	
8. CDP (2)	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0 (2)	22.0	–	
9. Secure Com. Units (2)	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	–	
10. Electrical Units + Line Losses	15.0	15.0	13.0	13.0	14.0	13.0	12.0	12.0	12.0	11.0	11.0 Ave	11.0	11.0	
11. Instrumentation	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	4.0	
TOTAL	563.0	602.0	571.0	567.0	529.0	504.0	406.0	383.0	349.0	325.0	296.0	276.0	200.0	
PROPULSION														
1. **Gas Gen. Ox. Sol. Valve**	37.0	–	–	–	–	–	–	–	–	–	–	–	–	
2. **Gas Gen. Fuel Sol. Valve**	74.0	–	–	–	–	–	–	–	–	–	–	–	–	
3. **Pilot Op. Sol. Valve**	48.0	–	–	–	–	–	–	–	–	–	–	–	–	
4. **ACS Thruster Valves**	6.0	0.5	4.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	4.5	4.5	0.5	
TOTAL	165.0	0.5	4.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	4.5	4.5	0.5	
HEATERS														
1. **Hydrazine Tanks**	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	
2. **Thruster Catalyst Beds**	–	10.0	–	–	–	10.0	–	–	–	–	–	–	–	
3. **Thruster Valves**	–	10.0	–	–	–	–	–	–	–	–	–	–	–	
TOTAL	2.0	22.0	2.0	2.0	2.0	12.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	
VEHICLE TOTALS														
– **Peak**	730.0	624.5	577.5	569.5	531.5	516.5	408.5	385.5	351.5	327.5	298.5	282.5	202.5	
– **Duration (Hrs)**	0.31	3.58	0.69	0.97	0.75	1.42	0.02	0.52	1.02	1.69	1.83	1.12	24.08	38.0
– **Watt Hours**	226.0	2236.0	398.0	551.0	398.0	734.0	8.0	202.0	358.0	553.0	545.0	316.0	4875.0	11,402
– Ave Power	**300 Watts**													

(1) **Each string on for 2 minutes during 10 minute test.**

(2) **Each string on during 1/2 of status check**

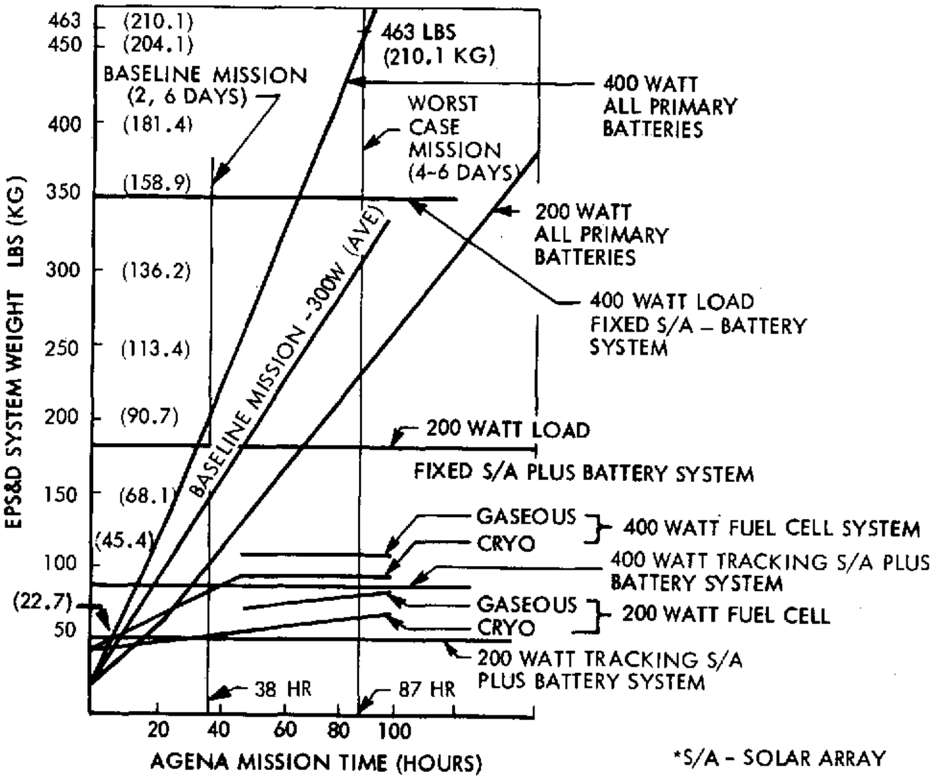


Fig. 3.3.3-9 EPS&D Weight Comparison

However, neither higher efficiency fuel cells nor retractable solar array systems meeting the reuse requirements of the Shuttle/Agena have been developed. A cost comparison of the three candidates shows (Fig. 3.3.3-10) that even with the cost impact of replacing primary batteries after each flight, the accumulated costs over 10 (and more) flights are significantly higher for the solar array and fuel cell systems because the high initial costs for developing such systems.

The selection of the primary battery as the electrical energy source was based on this cost differential. However, future development of 1 kilowatt fuel cell systems or practical retractable, tracking solar array systems may require reconsideration of this selection.

Battery Use History and Depth of Discharge. Agena programs have accumulated tens of thousands of flight hours on primary batteries. There are six primary silver-zinc batteries in current flight use by LMSC space systems division programs; the type IVB, VIA, 30, 31, 24, and 1902. The flight history characteristics are summarized in Table 3.3.3-11.

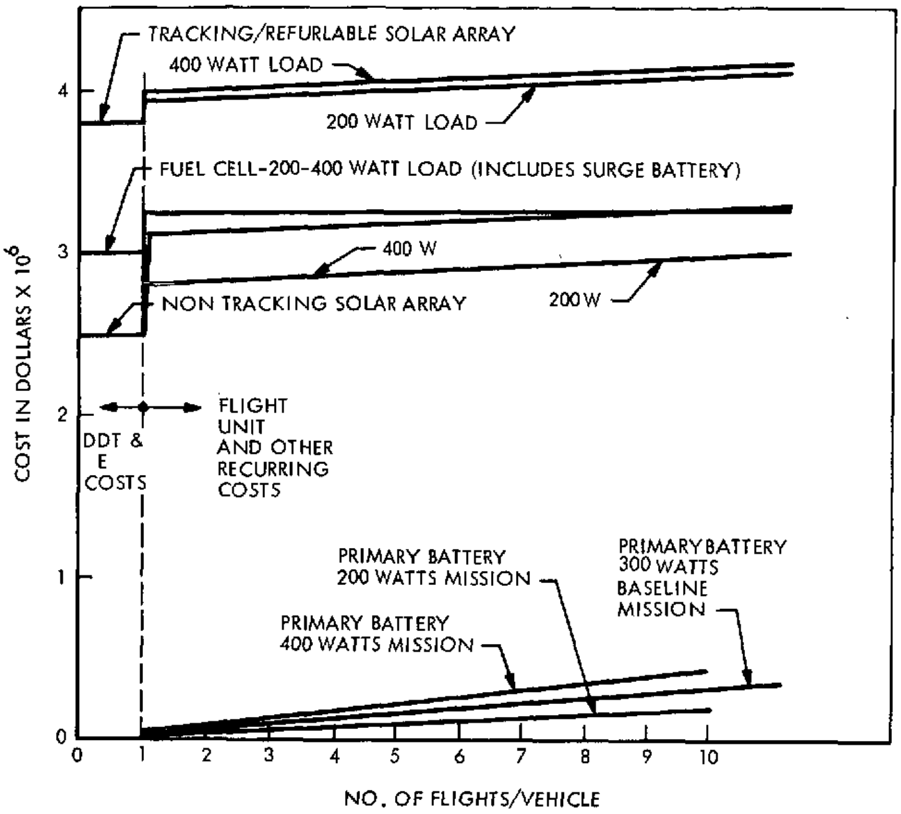


Fig. 3.3.3-10 Electrical Power Systems Cost Comparison

Table 3.3.3-11

BATTERY FLIGHT USE ON AGENA PROGRAMS

Battery Type	Number Batteries Flown	Flight Duration	Temperature Range °F (°K)	Nominal Current Loads	Peak Current Loads (amp)	Depth of Discharge (%)
30(1)*	14	90 Days	45-50 (280-283)	50-100 ma	25	5
30(2)	3	90 Days	45-50 (280-283)	30 Amp	45	67
1902(1)	48	30 Days	50-90 (283-305)	1-3 Amp	15	100
1902(2)	18	30 Days	50-90 (283-305)	7-8 Amp**	15	75
VIA	35	8 Hr	50-80 (283-300)	12 Amp	30	100
IVB (1)	6	1.5 Hr	45-70 (280-294)	12 Amp	20	85
IVB (2)	6	0.75 Hr	45-70 (280-294)	8 Amp	17	28
31	14	90 Days	45-50 (280-283)	40-50 ma	20	5
24	68	30 Days	55 (286)	10-15 ma	32	25

*Number in brackets indicate multiple use on different programs. (1) = Program 1
**Starts at 0.1 amp and ends at 7-8 amps (2) = Program 2

The currents given here as nominal represent the average currents in a continuously fluctuating current profile. The only flight failure occurred during application number 2 of the type 30 battery. This was a thermal runaway which resulted from mounting the battery in direct contact with the vehicle skin on the sun side of the vehicle. With sufficient consideration given to heat dissipation in the system design, a thermal runaway is not possible with any of the above batteries.

Battery Application to Shuttle/Agena. Of the batteries shown in Table 3.3.3-11, candidates considered for Agena application are: Types 30, 1902, and IVB. The Type 30 and 1902 units provide energy capabilities of about 400 and 625 ampere-hours respectively. Design parameters for these two high energy batteries are listed in Table 3.3.3-12. The specific energies are about 3 amp-hrs/lb for the Type 30 and 4.4 amp-hr/lb for the 1902. The IVB provides high peak power for short durations. The type 30 and 1902 batteries are applicable sources of primary (on-line) power. The type IVB is applicable for both standby backup stabilization system (BUSS), as well as for supplementing the higher energy primary units.

Depending upon the mission duration, equipment complement, redundancy management and resultant power profile, one or more of the above batteries or a combination thereof can be considered. For the 38-hour syn eq mission, the energy requirement previously derived is 11,402 watt-hours with average drains of 12 amps and peaks of 30 amps (Table 3.3.3-10). Using the minimum capability of 550 amp-hrs for the 1902 battery at rated voltage and with proper control of the operating temperature range (as described in thermal design, par. 3.3.4), 13.4 kw-hrs energy can be delivered. Using a typical depth of discharge of 85 percent (Table 3.3.3-11), 11.4 kw-hr are assured. This yields the required margin of 15 percent, illustrating that one type 1902 could be used for the 38-hour syn eq mission.

Alternatively, the less efficient type 30 batteries (3 amp-hrs/lb) can be incorporated. Again, depending on total energy requirements, one or more units may be necessary. In uses such as the 38-hour syn eq mission, one battery is insufficient and two batteries provide more energy than required (including margin) with resultant weight penalty. In this case, a combination of Type 30, and Type IVB can be used at less weight and still meet requirements.

Table 3.3.3-12

DESIGN CHARACTERISTICS OF TYPE 1902 AND TYPE 30 BATTERIES

Battery Design Parameter	Type 1902	Type 30
Battery Dimensions - inches-(centimeters)	15.54 x 11.30 x 8.00 (39.5 x 28.7 x 20.3)	18.46 x 11.44 x 8.00 (46.8 x 28.1 x 20.3)
Battery Weight-lbs-(kg)	143 (64.9)	134 (60.9)
Battery Weight-16 Cells-l lbs (kg)	143 (64.9)	115 (52.2)
Number of Cells	16	18
Cell Wall Thickness-inches-(centimeters)	0.060 (0.153)	0.100 (0.254)
Electrolyte	320 cc-1.35 SP GR KOH	290 cc-1.35 SP GR KOH
Separation*	N-V-C-PV-C-C-PE-P	N-V-C-PER-C-C-PE-P
Number Positive Plates	8	32
Number Negative Plates	16	33
Plate Dimensions-inches-(centimeters)	3.00 x 6.19 (7.62 x 15.7)	5.62 x 1.31 (14.3 x 3.31)
Total Plate Area (inches sq) (cm. sq)	297 (1915)	471 (2970)
Grid - Pos & Neg.	EXP. Ag-.005"-.33g/in^2 (0.0127 cm-0.05 g/cm^2)	EXP. Ag-.005"-.33g/in^2 (0.0127 cm-0.05 g/cm^2)
Positive Plate Thickness	0.138 (0.352)	0.057 (0.145)
Positive Plate Density	6.4 gm/in^2 (0.99 gm/cm^2)	4.9 gm/in^2 (0.76 gm/cm^2)
Grams Silver Plate	1584 gm	1030 gm
Oxygen Gain	12.5%	14.0%
Positive Group Weight	1800 gm	1160 gm
Negative Plate Thickness	0.080 inches (0.23 cm)	0.063 inches (0.160 cm)
Negative Plate Density	3.95 gm/in^2 (0.61 gm/cm^1	3.25 gm/in^2 (0.50 gm/cm^2)
Negative Group Weight	1318 gm	885 gm
Negative Mercury Pickup	3% Min	3% Min

*N = Negative Zinc Plate, V = Viscon = Unwoven Rayon,
C = Cellulose = Cellophane, PV = Polyvinyl Alcohol,
PER = Pemion = Irradiated Polyethylene, PE = Pellon = Unwoven Nylon,
P = Positive Silver Oxide Plate

Should peak load demands or operating temperatures pose a potential problem, the Type 1902 and Type 30 primary batteries can be subjected to tests at conservative conditions to demonstrate required capability, or undergo modification/development, or both.

Based on the available battery alternatives discussed above, the following combinations and weights are used for the 38-hour syn eq mission:

	Nominal Agena	Augmented Agena
Primary		
Type 30	134 lb	–
Type 1902	–	143 lb
Type IVB	17	34 (2 Batteries)
Margin	0 (1)	11
BUSS		
Type IVB	17	17
Total Weight	168 lb	205 lb

---

(1) Included in Type 30 battery which provides more than 15% margin (< 85% DoD) in this configuration concept.

3.3.3.6 Selected Hardware Development Status. All Shuttle/Agena Upper Stage avionics equipment except the service panel (in Orbiter crew compartment) are derived directly from existing hardware used on space programs. The development status of avionics equipment is summarized in Table 3.3.3-13. The inertial measurement unit is presently being used in the strapped down inertial guidance system of the Ascent Agena. It will be used without change. It is fully qualified for space use, but will require a mission duty cycle (reliability) test to demonstrate its reuse capability. The control electronics assembly is derived from the unit being used in the satellite control section of an LMSC managed program. The Shuttle/Agena will use analog circuits instead of the existing digital circuits. Therefore, circuits such as the bit-time-generator, the digital integrator, and the digital telemetry rate processor can be eliminated or greatly simplified. This unit will require full qualification and mission duty cycle testing.

Table 3.3.3-13

AVIONICS DEVELOPMENT STATUS

Equipment	Supplier	Existing Equipment		New
		Part No.	Mods Reqd	
GN&C				
Inertial Meas Unit (2)	Honeywell	1460979	None	
Control Elec. Assy	LMSC	8103450	Add dual high level ACS drivers, analog integrator	
Horizon Sensor	Quantic	Mod IVA	Delete Redundant Electronics and Upgrade piece parts	
Star Tracker	Bendix	Skylab ATM	Increase sensitivity to +3 magnitude	
DM&I				
Computer Interface Unit	LMSC		New Interfaces	
Computer	Rockwell, Inc.	DF224	Change to dual string	
Agena Service Console	LMSC			✓
C&C				
Transponder-DoD (2)	Motorola	RFP 333945	Interface compatibility with CDP and NASA/DoD compatibility	
or				
Transponder-NASA (2)	Motorola	ERTS		
Data Processor (2)	LMSC	2P22630	Repackage, make compatible with transponder & add event programmer	
Power Divider (2)	Aneran	10514-3	None	
RF Switch (2)	Transco	1462071		
Antennas-Direct (2)	LMSC	2P56051	Strengthen antenna Structure	
-Omni (4)	LMSC	8100131		
EPS&D				
Battery	Eagle-Picher	Types 1902, 30, IVB	None	
Power Dist. Box	LMSC	1389613	Add Functions and Interfaces	
Aft Control & Instrumentation Box	LMSC	1389660	Add Functions and Interfaces	
Harnesses	LMSC			✓

The horizon sensor assembly under consideration is presently in prototype form. A model of this unit is scheduled to be flown as an experiment on an LMSC vehicle. The electronics will be repackaged into a smaller, compact unit. This unit will be subjected to the full qualification and mission duty cycle tests.

The star tracker assembly selected is the Bendix system used for the Apollo telescope mount on the Skylab. The only change anticipated is that the sensitivity of the optics must be increased to cover +3 magnitude stars for Agena use. This will not require any change to the optics, but will be accomplished through a minor change in the level detector circuitry. No formal tests are proposed because of long demonstrated use of the system and because it has undergone a full space qualification.

The computer interface unit is derived from a similar unit being used for another LMSC program. The same subassembly cards containing analog-to-digital, digital-to-analog, parallel digital-to-serial digital, serial digital-to-parallel digital and other standard computer interface circuits will be used for the Shuttle/Agena. The unit will be repackaged because of the different numbers of standard subassemblies required. A full qualification and mission duty cycle test program is planned.

The computer will be a modified DF224 now being developed for another LMSC program. The Augmented Shuttle/Agena computer will be dual string (dual CPU, dual IOU) with a dual set of 16,000 word memory banks compared to the triplex, 48,000 word configuration. A full qualification and mission duty cycle test program was not proposed for this unit because the change from the triplex design involves taking out 6 of the 18 cards, rewiring the multilayer interconnect board and shortening the chassis by about 4 inches (10 cm). All modules or subassemblies would be used without change. The triplex unit will be subjected to full qualification and reliability life testing.

The Agena Service Panel (ASP) to be located in the Orbiter crew compartment will be the one entirely new set of equipment. Even for the ASP however, existing equipment will be used wherever possible to provide the integrated system. This unit will be subjected to the full qualification and mission duty cycle test program.

The NASA USB transponder is derived from the dual ERTS system which was based on Apollo design. It will be modified to include the baseband assembly. The DoD SGLS transponder will be a unit which combines existing transmitter - baseband and receiver - demodulator units. It is expected that such a unit will exist before Shuttle/ Agena IOC. Full requalification and mission duty cycle testing of the modified systems is not recommended although a quite extensive engineering evaluation test program, including thermal vacuum and vibration environment, is planned.

The power divider, RF switches and antennas are basically existing units. The parabolic antennas may require a change to a stronger dish. However, these dishes are standard and presently exist. No formal testing beyond engineering evaluation tests are recommended for these items.

The type 1902 battery option would require discharge tests at the loads specified for the Shuttle/Agena. No other tests are recommended at this time.

Both the power distribution and aft control and instrumentation boxes are derived from units serving similar functions on existing Agena programs. The same standard circuit used on all these applications will be used for Shuttle/Agena even for the new functions. The aft control and instrumentation box will contain many more new functions integrated into one unit. For example, the triplex voting logic for the propellant pressurization system will be provided in this unit.

The circuits and external packaging of the power distribution box will be little changed from existing units. Therefore, only the aft control and instrumentation box will be subjected to the full qualification and mission duty cycle test although both units will undergo extensive engineering evaluation tests.

3.3.4 Thermal Control Subsystem

The thermal control subsystem (TCS) must control the temperature of the components and the vehicle within temperature limits for all missions within the model. In determining a thermal design that satisfies all mission requirements, the following tasks were performed: review and establishment of the environments to which the Shuttle/Agena is exposed; review of the passive thermal control surfaces and techniques used on the existing ascent and orbital Agenas and their application to the Shuttle/Agena; assessment/generation of key thermal requirements and groundrules; thermal design analyses and formulation of a design concept; and establishing the development status of the proposed design. Results of these tasks are presented in the following paragraphs.

3.3.4.1 Expected Environments. The Shuttle/Agena and its components will be exposed to various thermal environments during manufacture, assembly and checkout, transportation, preflight, flight, post-flight, and refurbishment.

Ground. Terrestrial environments include manufacture, assembly and checkout, transportation, pre- and post-flight, and refurbishment. The only terrestrial environment that can be at other than ground level is transportation. For ground level environment, the controlled factory environment temperature extremes of 40 deg F to 100 deg F, and a relative humidity of 50 percent or less is expected. Pre-flight and Shuttle Orbiter mating will be done in a controlled environment similar to the factory environment. Special conditioning is necessary for ground checkout if prolonged checkout of high power equipment is necessary. The propellant upper temperature limit is 80 deg F, and the environment must be controlled to maintain this upper limit.

For post-flight conditions, the Orbiter is required to keep the cargo bay walls below 200 deg F (366 deg K) for all conditions, and this requires air conditioning within 30 minutes after touchdown. Amplification of this condition is presented in par. 3.3.4.4.

Transportation of the Agena from the manufacturing location to launch site may be either by ground or air. This transportation in all cases will be done with the Agena in a controlled environment. This environment may be supplied with a special container or by the transportation unit. In the case of failure of environment control equipment, the Agena could be exposed to temperature, pressure, and humidity excursions. This should not pose a problem because components are qualified to meet these and other off-nominal conditions.

Refurbishment will be done in a controlled environment similar to that at the factory.

Moving the Agena between controlled environments will be time limited and will depend on the local environment. Protection will be afforded as required.

Flight. The space environment the Agena will be exposed to consist of ascent in the Orbiter cargo bay, space flight, and reentry in the cargo bay. Within the cargo bay during ascent the walls are approximately room temperature, with the pressure venting to the local ambient. For reentry the cargo bay also is vented to local ambient, with the temperature of the walls limited as shown in Fig. 3.3.4-1.

For free flight the Agena will be exposed to near-earth space environment. This is a space temperature of -460 deg F (0 deg K). The incident energy will be direct solar, reflected solar, and earth radiation. These direct solar energies are a function of a vehicle orientation, while the reflected solar and earth radiation are functions of both vehicle orientation and orbit altitude. The solar and earth energies are:

Solar Constant (1 AU) = 1354 Watts/in^2
Earth Albedo = $0.30^{+.30}_{-.15}$
Earth Temperature = -19^{o}C $(292^{o}$R)

3.3.4.2 Existing Agena Thermal Design. Current Agena thermal control systems use passive thermal control techniques with supplemental heaters on specific items. Passive thermal control uses the thermo-optical properties of surfaces, thermal capacities and conductivities of materials, and the use of shields and multilayer insulation to control the heat balance of a spacecraft. The Agena thermal design controls the temperature of the vehicle forward equipment section, propellant tank, and aft section.

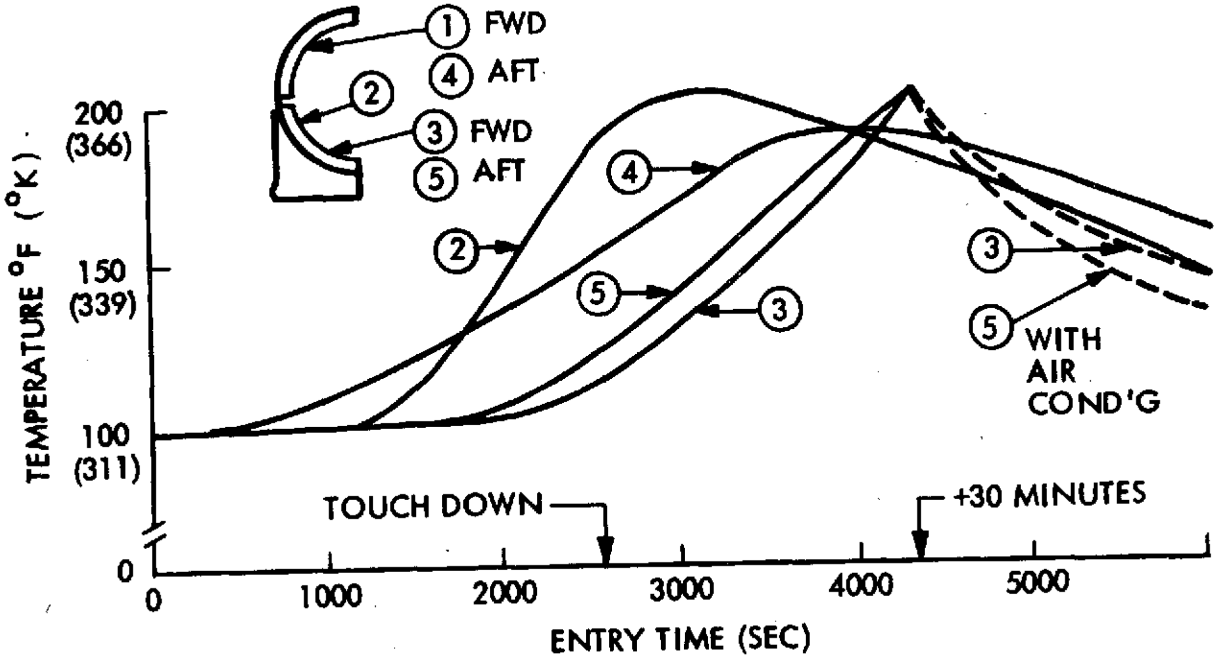


Fig. 3.3.4-1 Shuttle Cargo Bay Entry and Post-Landing Temperatures

Forward Section. The forward equipment rack carries the power system, attitude control system and communications equipment. This equipment includes components with narrow operating temperature limits (batteries) and high power dissipation items such as on-board computers, inertial measuring units (IMUs) and transmitters. On the ground, conditioned air controls the temperature and humidity until just prior to liftoff.

To maintain the energy balance and ensure that components are within their temperature limits on orbit, both external and internal thermal surfaces are used. The external thermal surface patterns consist of a matrix of paints such as black and white silicones; tapes such as mystic aluminum tape; other surfaces such as polished aluminum, alodizing or anodizing of metals, vacuum deposition of aluminum and gold; and applied surfaces such as anodized titanium. On interior surfaces or skins, the thermal design uses either shielding, multilayer insulation (MLI), or low ϵ surfaces to block energy transfer, or high ϵ paints to enhance energy transfer. The proper combination of external and internal surfaces depends on mission requirements, vehicle configuration, power dissipation, location, and allowable temperature limits and duty cycle of materials of construction and components.

Batteries have high weight and relatively low power density and are located where there is a minimum variation in environment. Usually this is along the center line of the vehicle. However, batteries have been flown in all sections of the forward rack as well as the aft rack using shielding and conduction isolators to minimize the effect of environmental changes, maximize energy exchange, and obtain required environmental conditions. Equipment containing oscillators and gyros that usually have heaters is located to minimize heater power requirements. The environment to which these components conduct and radiate is kept relatively constant so that minimum heater power is consumed. High power dissipating equipment (IMU) require either radiation plates that view space directly, or high rate heat transfer paths to space.

Propellant Tankage. The main tank of the Agena is a dual tank with a common bulkhead between the oxidizer and fuel. For current orbital Agenas the tank temperature is controlled by external surface pattern. For ascent conditions an isolator (cork) is bonded to ullage areas. The LMSC satellite control section (SCS) incorporates a monopropellant engine and uses MLI (Mylar) to control the temperature of the propellant and tanks, and selected equipment. The Agena incorporates both Mylar and Kapton MLI for aft and forward section control. Both the Agena and the SCS are earth-oriented and operate in the low earth-orbit ranges. For ascent Agenas flying high energy missions up to 12 hours life, MLI is not used.

Aft Section. This section consists of the thrust cone and aft rack. These assemblies are covered by MLI with thermal surfaces. In addition, thermal surfaces are applied to areas not covered with MLI. The engine turbine and exhaust duct are covered with high temperature insulation. The hydrazine RCS tanks and thrusters are protected with MLI and by gold-plated radiation shields; heaters are used to keep the catalyst beds warm enough for efficient performance.

The above briefly describes the thermal design of current Agenas and the SCS. The basic energy balance between the vehicle and its environment is controlled by component location and passive techniques. This approach satisfies requirements for high power density components, components with narrow allowable temperature limits, and variable duty cycles. Use of heaters is restricted to the monopropellant RCS.

3.3.4.3 Shuttle/Agena Requirements, Groundrules and Guidelines. Basic thermal design requirements/groundrules are as follows:

- The thermal control subsystem will maintain the vehicle and equipment within required temperature limits using the existing Agena passive thermal control concepts to the maximum extent possible and active thermal control only where necessary.
- The Agena is not required to provide for thermal control of the payload (spacecraft).
- The Orbiter will provide temperature control for the Agena while in the cargo bay.

- The Agena will not impose selective orientation in orbit to maintain thermal control.
- Material used for the thermal control subsystem is selected considering safety, life, refurbishment capability, availability and current state-of-the-art.

Other groundrules, assumptions and criteria relate to mission requirements, propellant selection, component selection, physical constants used, and past experience.

Mission requirements dictate mission types, mission life, and mission-related parameters such as burn time, time between burns, propellant choice, and propellant loading for different missions. The six mission types discussed in the requirements section were considered in this analysis. These missions result in a broad range of beta angles and related thermal design parameters to which the Agena must be designed. In addition, the maximum mission life is 6 days in orbit, with the capability of launching at any time. The propellants chosen also impact the thermal design as this choice dictates the allowable temperature limits of the propellants (+20 to +80 deg F), (266 to 300 deg K) tanks, lines, valves and other components. The vehicle power consumption and duty cycle as shown in par. 3.3.3 was used for energy balance calculations. Properties such as solar constants were obtained from NASA Technical Memo TM X-64627: "Space and Planetary Environment Criteria Guidelines for Use in Space Vehicle Development, 1971 Revision." The solar data from this document is listed in par. 3.3.4.1.

3.3.4.4 Shuttle/Agena Thermal Analysis. A preliminary thermal analysis was conducted to determine design requirements for thermal surface materials, locations of multilayer insulation and shielding, and component locations. The thermal analysis was conducted manually, but based on extensive data available from computer analyses and flights of existing Agena vehicles. The thermal analyzer program (Univac 1108) accommodates thermal math models that have up to 1000 nodes. Thermal analyzer support programs include subroutines that calculate geometric viewfactors, radiation constants, and orbital planetary and transfer orbit heat rates for planet-oriented or inertially-oriented vehicles. These programs are also used for terrestial thermal analysis (forced and free convection, and conduction at ambient conditions). Flight data from orbital and ascent Agenas is and has been used to develop temperature response of earth-oriented vehicles in relatively low earth orbits (long life) and at high altitude (short mission durations).

The thermal designs for the forward section, the center propellant tankage, and the aft section are presented below. The overall design approach is illustrated in Fig. 3.3.4-2.

Forward Section. The forward section is designed to keep components within their temperature limits and to minimize energy transfer to the payload. To accomplish the latter, a multilayer blanket is placed at the forward surface of the forward section. In addition, a Titanium insulator (washer) is mounted between the payload and Agena to control conduction.

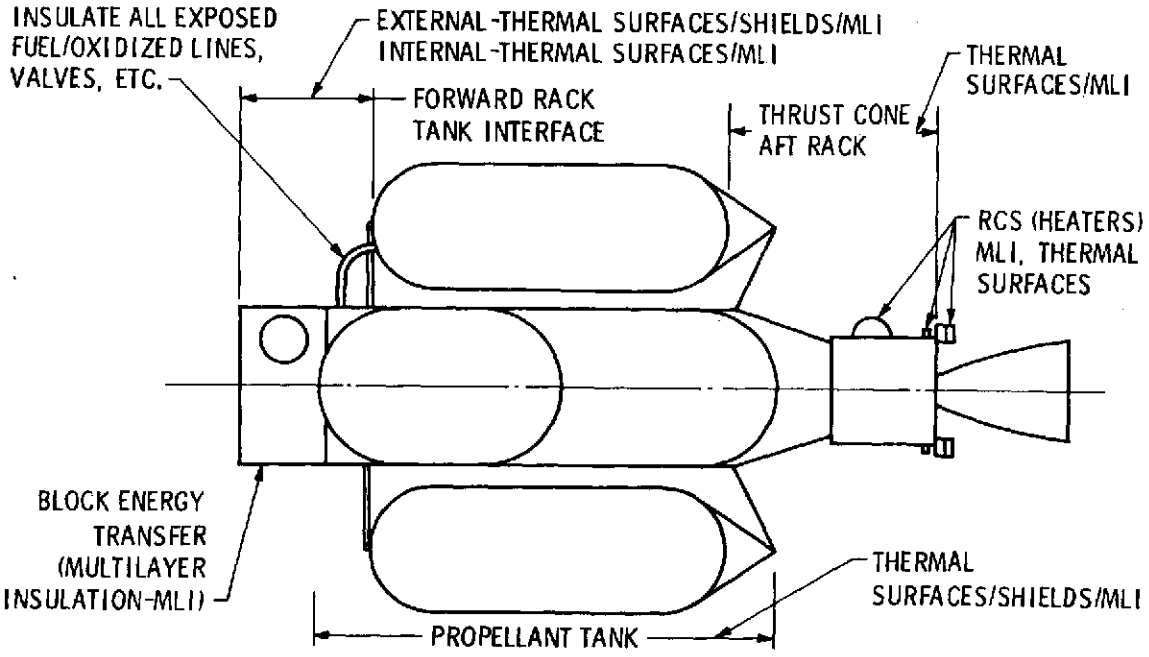


Fig. 3.3.4-2 Thermal Control Design Approach

The forward section thermal design consists of an external surface pattern of aluminum and FOSR (flexible optical surface reflector). The interior of the skins use either a high- or low-emissivity surface, depending on equipment arrangement/location, as discussed below.

Because of tight temperature limits, the batteries are located in the center bay to minimize the effect of vehicle orientation. The exterior of the battery is covered with a high-emissivity surface to radiate internally generated energy to the environment. When batteries are added for longer-life (6-day) missions, they are mounted in the side bay, conduction-isolated by phenolic isolators and radiation-isolated by shields from the side bay environment. This technique is used on several Agena programs.

The high power dissipating equipment (computer, IMU, transponder, power amplifier) in the forward section require specific thermal control/conditioning. The computer is normally operated prior to and during engine burn, and will not exceed its upper temperature limit, in the location selected, with its high emissivity surface and resultant coupling to the surrounding environment, especially to the skin. Refer to par. 3.4.3 and 3.4.4 for equipment installation and layout.

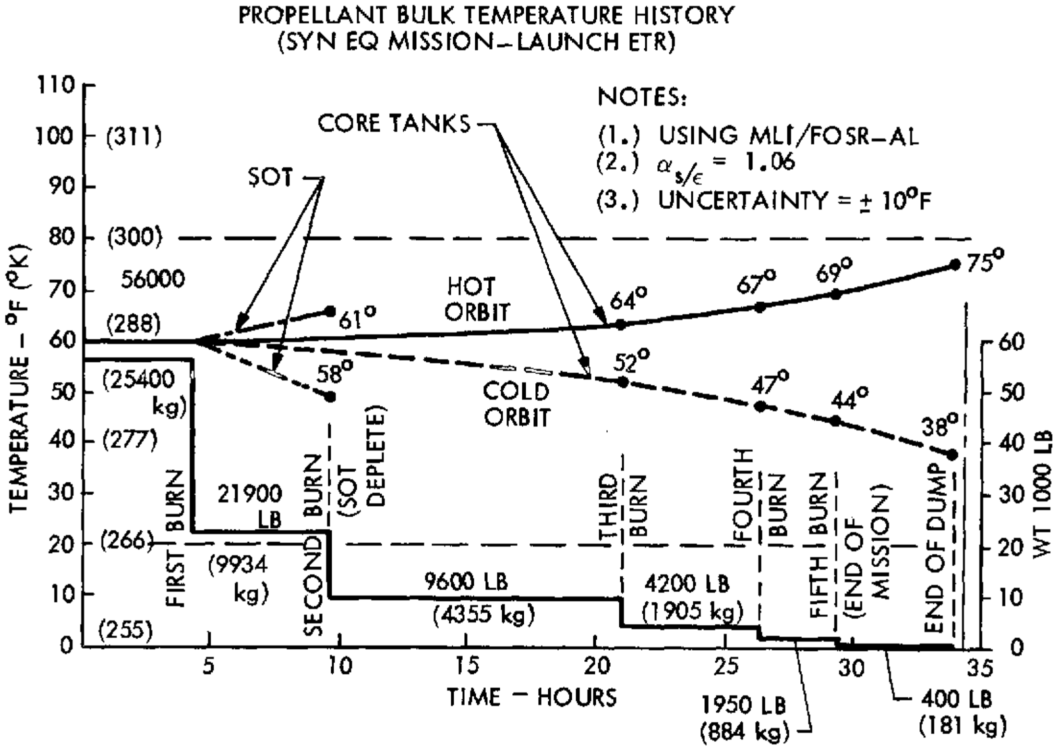
The Shuttle/Agena incorporates either one or two inertial measuring units (IMU) mounted on a baseplate. This baseplate mounts either the dual or single IMU and the star sensor. The IMU dissipates energy as a function of temperature. For the dual IMU configuration, (mounted in-board) the operation is one unit on continuously while the second is turned on for one hour (prior to, during, and after) per engine burn. Because of the high power density, the IMU baseplate incorporates a FOSR and aluminum surface pattern that radiates energy to space. The single IMU is mounted on the external surface of the radiator plate with a FOSR/Al pattern on the IMU as well as on the plate. For the dual installation, calculations show that the primary IMU will be running at 80 to 100 deg F (300 to 311 deg K) with the backup IMU at 65 to 80 deg F (291 to 300 deg K). For worst-case warmup (orbit), the maximum bulk temperature of the IMU at the end of operation is 145 deg F (336 deg K). These values are within the qualification limit for the IMU. The single IMU alternative will operate within the same limits.

The horizon sensors (redundant avionics configuration) are mounted on an extension box to provide unobstructed view of the earth around the strap-on tanks. To maintain HSA and electronics within required limits, the box is covered with MLI incorporating an FOSR/Al pattern.

Propellant Tank Section. The center section contains the propellant storage and transfer system. This includes the main propellant tanks, SOT, transfer lines and valves, and pressurization lines.

Orbit – Energy balance for the six types of missions was assessed to derive propellant temperature variations in the core and strap-on tanks during orbit conditions. It was determined that a synchronous equatorial mission with a 1-hour coast at synchronous altitude would yield the worst case temperature variations; therefore this mission was selected as the basis for the thermal design analysis. The reason that this mission reflects the most pessimistic temperature profile is that one trajectory places the vehicle broadside to the sun (hottest condition) and an alternating trajectory requires a vehicle orientation into the sun (minimum solar incidence and coldest condition). Nodal as well as bulk propellant temperatures of the Agena have been analyzed in detail in the past. It was found that temperatures of certain nodes may be greater or less than the bulk values; however further analyses and extensive flight data have shown that effects of nodes on net tank pressure and tank and propellant temperatures are secondary. Hence the bulk temperature has evolved as the key design criterion and has been similarly used for Shuttle/Agena tank thermal design purposes. The resulting thermal design uses multilayer insulation incorporating FOSR/Al surface pattern around each tank to maintain the bulk propellants within the required limits of +20 to 80 deg F (266 to 300 deg K). All center section propellant and pressurization lines and valves are also covered with MLI as are the aft and forward SOT support structures.

The baseline synchronous equatorial mission required 38 active hours (see par. 3.3.3 and 3.4) so that the vehicle remains at synchronous equatorial altitude for 11 hours to accommodate nodal regression ΔV requirements. The thermal design described above (one hour at syn eq altitude) was then analyzed for performance in the planned 38-hour mission (11 hours at synchronous altitude). Results are shown in Fig. 3.3.4-3 and -4. Figure 3.3.4-3 shows that the SOT thermal design (MLI-FOSR-Al) readily


PROPELLANT BULK TEMPERATURE HISTORY
(SYN EQ MISSION–LAUNCH ETR)

NOTES:
(1.) USING MLI/FOSR-AL
(2.) $\alpha_{s/\epsilon} = 1.06$
(3.) UNCERTAINTY = ± 10°F

Fig. 3.3.4-3 Propellant Bulk Temperature History

maintains propellants within required limits up to the time of depletion (within +5 to -10 deg F (258 to 250 deg K) of the core tank). The average temperature of the He and vapor remaining in the SOT after depletion is the same as the core bulk propellant temperatures. This results not only from the thermal design but because all tank pressurization lines remain open, allowing mass/heat transfer between tanks for the rest of the mission.

The core tanks also maintain required temperatures as shown within the indicated uncertainty of ±10 deg F. The proposed design controls temperatures within the required limits for all missions in the model. However, if narrower limits should be required for specific missions, the external thermal pattern can be varied to further reduce the temperature excursion after deployment.

Analysis was also conducted to determine the propellant temperature profile without MLI on the tanks. Results, shown in Fig. 3.3.4-4, indicate that the core propellants become marginal at the end of the mission and that a relatively high ΔT exists between

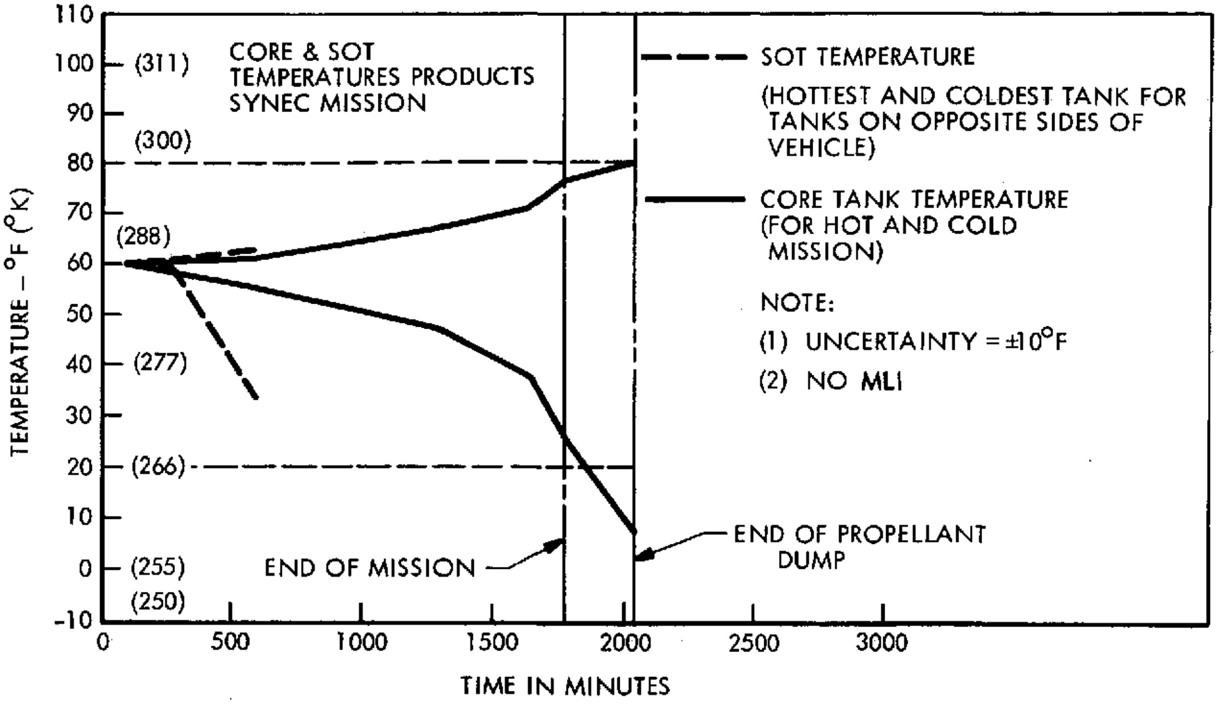


Fig. 3.3.4-4 Propellant Bulk Temperature History

SOTs prior to and after their depletion. The core condition could possibly be tolerated, pending further propulsion analysis. However, the differential between SOTs could cause some liquid propellant transfer from the hot to the cold tanks. The resulting CG offset can be accommodated by the TVC, but the potential increase in oxidizer SOT residual is undesirable.

Ascent and Reentry – The cargo bay, and hence Agena, are essentially at room temperature during ascent. Further, the tanks are full, and with the large thermal capacity there is minor temperature (and vapor pressure) change even if the cargo bay temperature should exceed allowable limits. Ascent conditions therefore pose no thermal design problems.

The cargo bay wall temperatures are not to exceed 200 deg F (366 deg K) for reentry and post landing, based on availability of air conditioning 30 minutes after landing. The impact of this temperature on Agena design was assessed for three cases.

(1) Full tanks (assumed abort landing, but not a structural or safety requirement)

(2) Tanks empty except for the very small predicted residuals remaining after orbital dump

(3) Off-rated condition of 1000 pounds (454 kg) of HDA and 100 pounds (45.4 kg) of MMH remaining at landing (distributed equally among SOTs and core).

Results are shown in Fig. 3.3.4-5 and Table 3.3.4-1. Case 1 results in a negligible temperature rise, requiring no vent reconnects or similar operating/design accommodations. For Case 2, the bulk temperature of the tanks and propellants approximate 135 deg F (330 deg K); although the oxidizer vapor pressure increases significantly (above the 85 deg F (302 deg K) design pressure), the tank design pressures and bulkhead ΔP capability are not exceeded because there is not enough liquid available to produce saturation pressure even though all the fluid is vaporized. Again vent reconnect would not be necessary. The temperature for Case 3 is 100 deg F (316 deg K) maximum. This results in a vapor pressure of 31 psia (2.1×10^5 N/M^2) for HDA while the fuel vapor pressure is 2.5 psia (1.7×10^4 N/M^2), exceeding tank bulkhead design pressure (ox/fuel ΔP) and requiring vent reconnect.

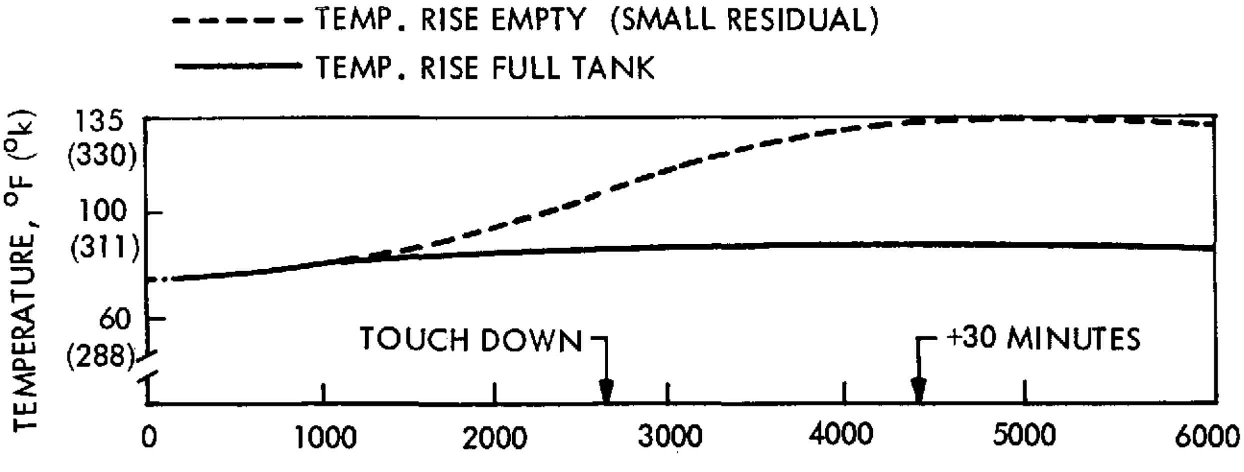


Fig. 3.3.4-5 Agena Tank Temperatures

Table 3.3.4-1

TANK VAPOR PRESSURES FOR REENTRY CONDITIONS

Condition	ΔT °F (°K)	T (Final) °F (°K)	Vapor Pressure Ox. psia (N/m^2)	Vapor Pressure Fuel psia (N/m^2)
(1) Full Tanks	Less than 5 (258)	Less than 72 (295)	12 (8.3×10^4)	0.78 ($.54 \times 10^4$)
(2) Normal Mission (Small Residuals)	58 (287)	135 (330)	51 (35.2×10^4)	4.40 (3×10^4)
(3) 1000 lb 454 kg Ox/ 100 lb (45.4 kg) Fuel	43 (278)	110 (316)	31 (21.4×10^4)	2.50 (1.7×10^4)

Aft Section. The aft section thermal design consists of an MLI blanket around the aft rack and thrust cone, with Mystik aluminum tape on the aft bulkhead of the aft rack. The MLI incorporates an external FOSR/Al pattern. This design is similar to that used on current orbital Agenas and maintains the aft section and its equipments within ±10 deg F of 70 deg F (294 deg K) for a beta angle range of ±60 deg.

For the RCS, MLI and heaters are installed on the tanks, lines and shields, and heaters are installed on the thrusters and valves, similar to the SCS and Agena RCS designs. This design maintains the propellant above 40 deg F (277 deg K) and the thruster catalyst beds above the 90 deg F (305 deg K) minimum required for performance purposes. The heater power requirements have been included in the power profile presented in par. 3.3.3.

3.3.4.5 Development Status Summary. The effective emissivity of the MLI, the methods of attaching the MLI to the structure, and FOSR adhesive will be confirmed or developed to ensure the proper operation of these materials for the life, duty cycle, and reuse requirements.

The determination of the effective emissivity of the MLI is necessary to define the number of layers in the MLI blankets which have different requirements depending upon location in the vehicle.

Because the MLI will be used for more than one flight and will be removed after each flight, techniques will be developed to provide the most efficient and reliable attach-detach design.

An adhesive compatible with the outgassing requirements must be developed. Adhesives compatible with outgassing requirements exist, but are not used on FOSR. It is planned therefore, to develop an adhesive meeting outgassing requirements.

3.3.5 Shuttle Interface

3.3.5.1 Cargo Bay Support Structure (CBSS). Early studies lead to the conclusion that an auxiliary structure provides the best means of support for the Shuttle/Agena while stowed in the Orbiter cargo bay. A direct Orbiter-to Agena attachment which satisfies the statical-determinacy requirement results in a high weight penalty to the Agena. Thus, early in the Reusable Agena contract studies, a number of concepts of a CBSS were evaluated (see ref 3-8). A statically-determinate structural concept that would provide a self-equilibrating load retention interface with the Orbiter that would avoid asymmetric transverse load distributions and resultant severe torsion and would minimize both vehicle and CBSS weights, was the objective for the design selected for the Shuttle/Agena Upper Stage, with and without the SOT option. The design is shown in Fig. 3.3.5-1 and 3.3.5-2, and data in addition to that presented below is provided in ref 3-8).

CBSS With SOT Option. The CBSS is designed basically for the Shuttle/Agena Upper Stage with the SOT installed. This configuration is shown in Fig. 3.3.5-1 and the load retention points used for this design are shown in Fig. 3.3.5-2. When compared with ref 3-2 the latest data allows for improvement both in proximity and number of points and concentricity between the sill and keel points.

The CBSS comprises a forward section which reacts vertically transverse loads from the Shuttle/Agena only and an aft section, completely separate from the forward structure, which reacts loads in all directions. Although the forward section of the CBSS uses four vertical-transverse (Z-direction) load retention points, the system does not induce redundant loads to the Orbiter. It comprises two side trussed-frames, each supporting one of the Agena trunnions, located on the forward equipment section, and connected to each other by two transverse pin-jointed struts. The structure therefore does not transmit shear between frames or develop moment across the frames, thus guaranteeing statically determinate load distribution.

The aft section of the CBSS comprises a stiffened shell supported by an exterior trussed frame to give the structure torsional rigidity in bridging the distances between the Agena and the three Orbiter load reaction points used. Two load reaction points,

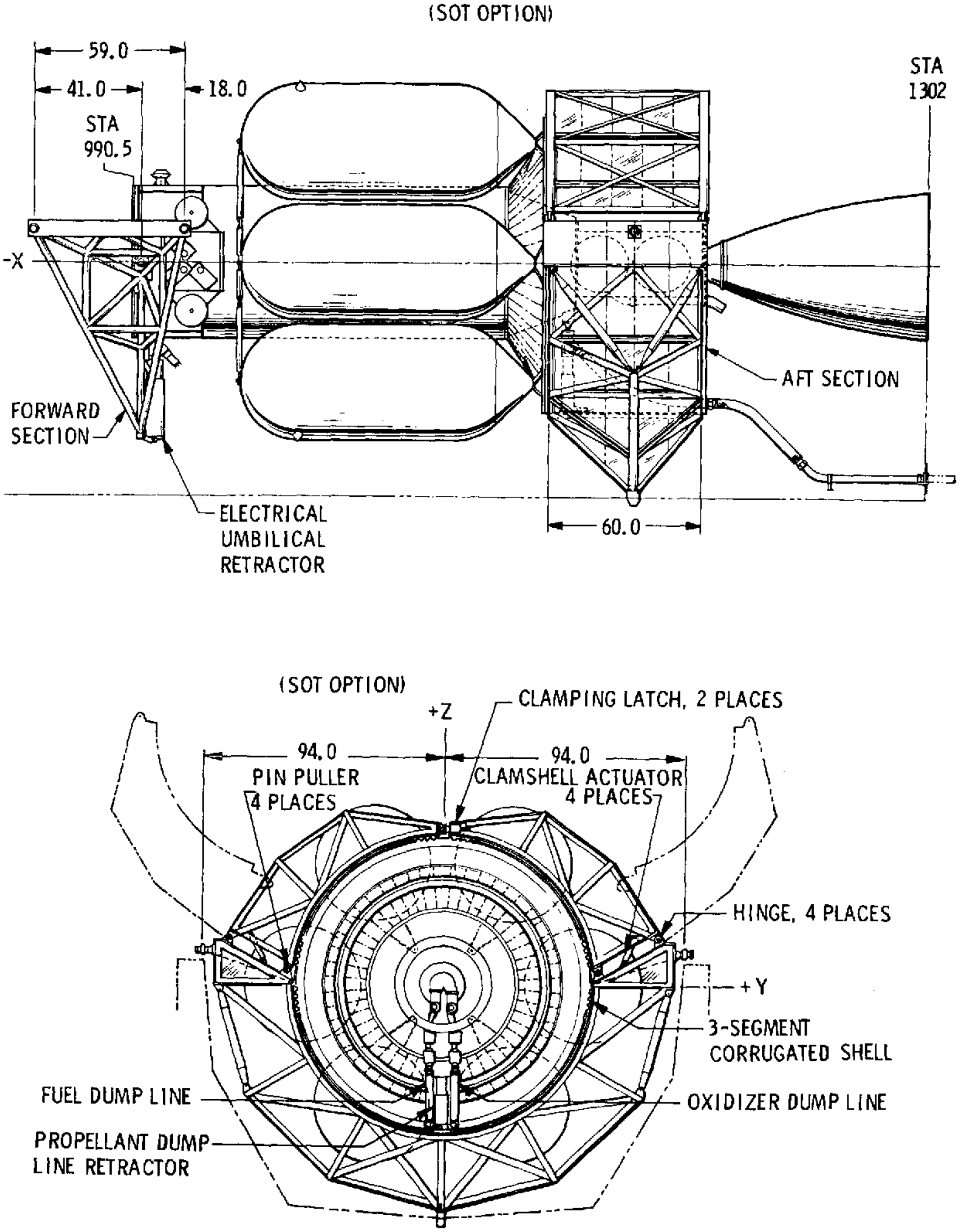


Fig. 3.3.5-1 Cargo Bay Support Structure

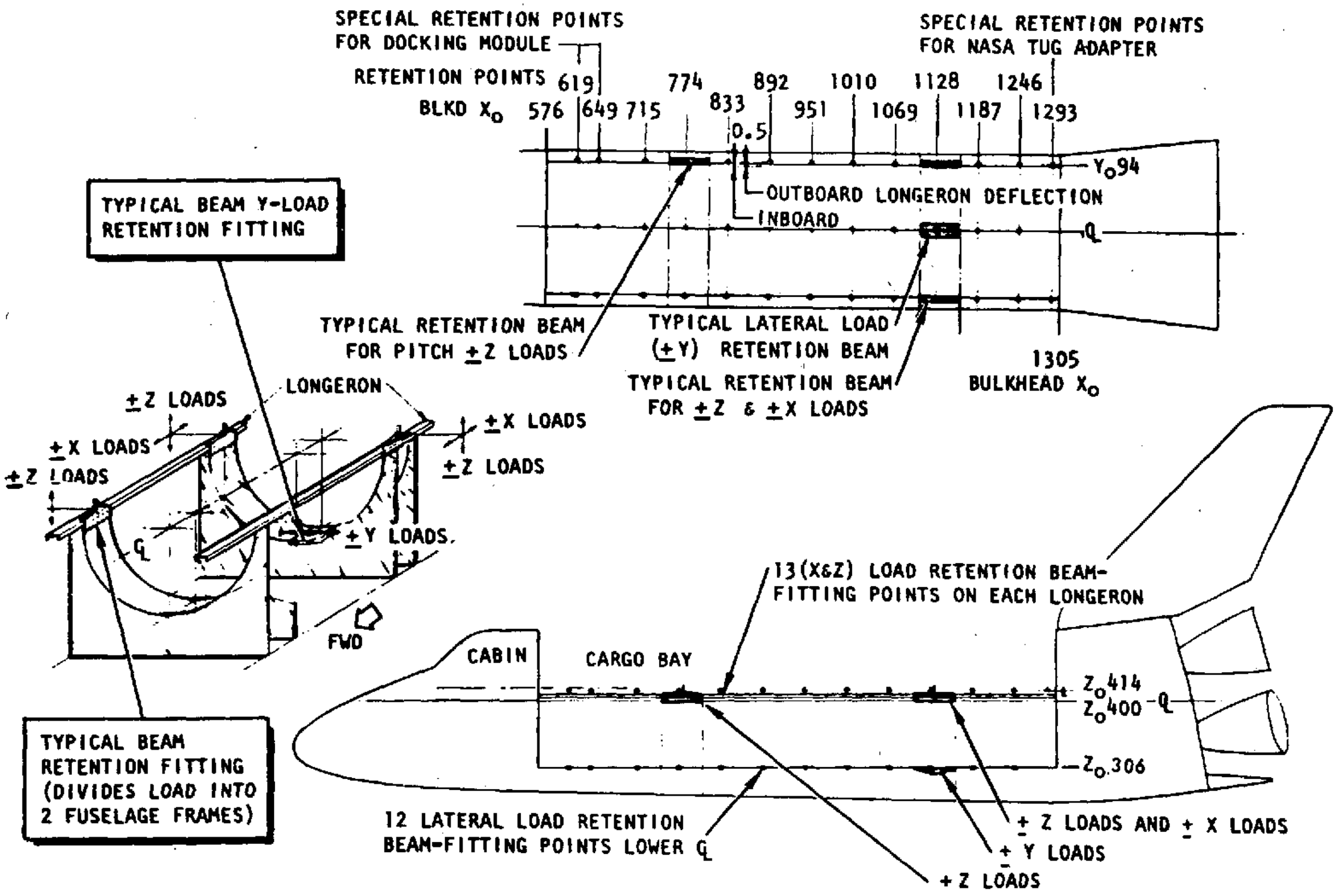


Fig. 3.3.5-2 Payload Retention

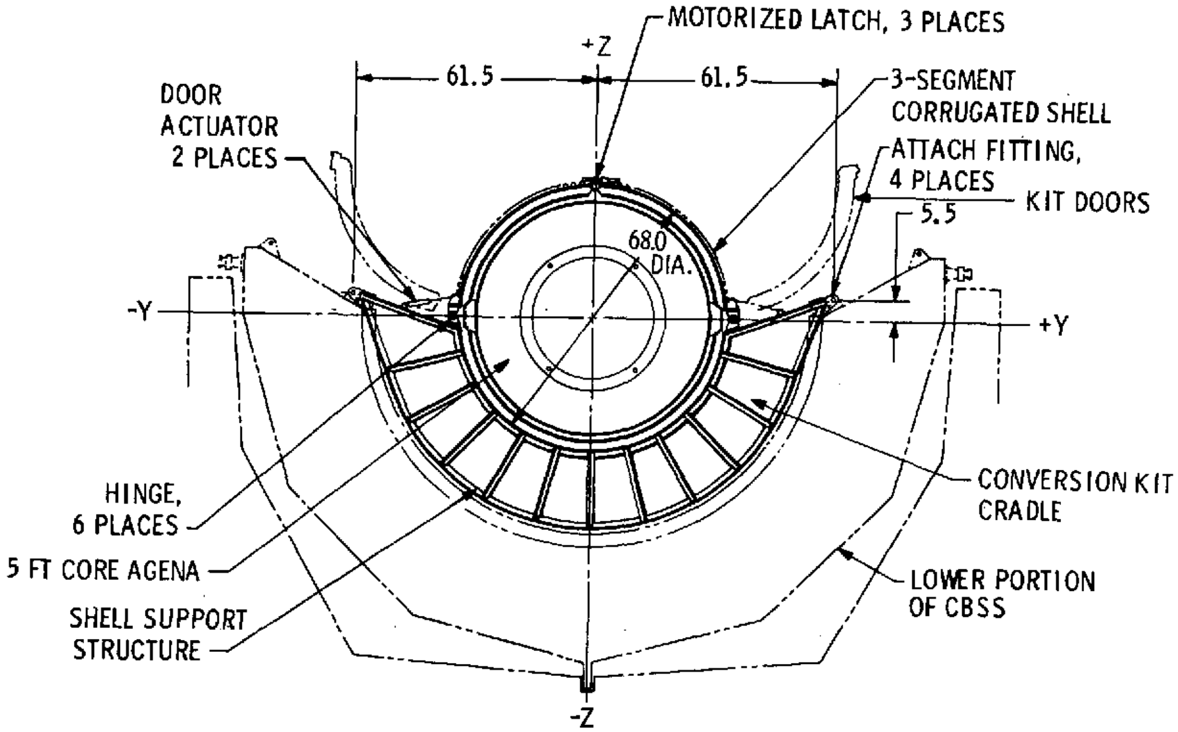
located on the cargo bay sill, react longitudinal and vertical-transverse loads (i.e., load parallel to the X-axis and Z-axis). The transverse side loads (i.e., loads parallel to the Y-axis) are reacted by the interface slot located in the cargo bay keel.

As noted in the Fig. 3.3.5-1 the aft assembly shell and external frames are structurally hinged at three locations (pin puller, door pivot hinge and door top center latch). This permits the structure to open for ingress and egress of the Agena. To provide for greater frame stiffness, the side hinges are double-hinged at pin puller joint and at door hinge. After the cargo bay doors are opened, the inner side hinge pins are pulled to permit the upper section to open for Agena deployment: Because the Agena is empty after being retrieved from space the upper section of the CBSS is closed without reinstalling the inner hinge pins.

The primary purpose of this aft structure is to support the Agena at only three points in the cargo bay, but then to distribute these highly concentrated loads to a relatively uniform load distribution by the time the loads are reacted into the flight vehicle at the V-band/aft cone structure. The inner stiffened shell of the CBSS is provided for this load distribution.

The basic truss-framing will be fabricated using bolted 7075-T73 aluminum tubes, supplemented by other extruded shapes, as required. The alternative is to use 2021-T81 welded tubing. The inner-cylindrical shell is fabricated using the weld-bond process to attach the corrugation stiffening. Analysis of the CBSS shows a weight of 1140 pounds (516 kg) (See ref 3-8). This weight is based on two design conditions. The first condition considers a vehicle filled with propellant and subjected to the maximum ascent acceleration condition.. The other condition considers a vehicle supporting the heaviest payload (6000 pounds (2720 kg), but with all propellant dumped or expended, and subjected to the crash load factors cited in Table 3.3.1-1 of par. 3.3.1.1.

CBSS Without SOT Option. A conversion kit to the basic CBSS design has been devised, as shown in Fig. 3.3.5-3, to minimize the fabrication requirements and still provide support for the Agena in the cargo bay without the SOT attached.



(AGENA CORE STAGE) (VIEW LOOKING FORWARD)

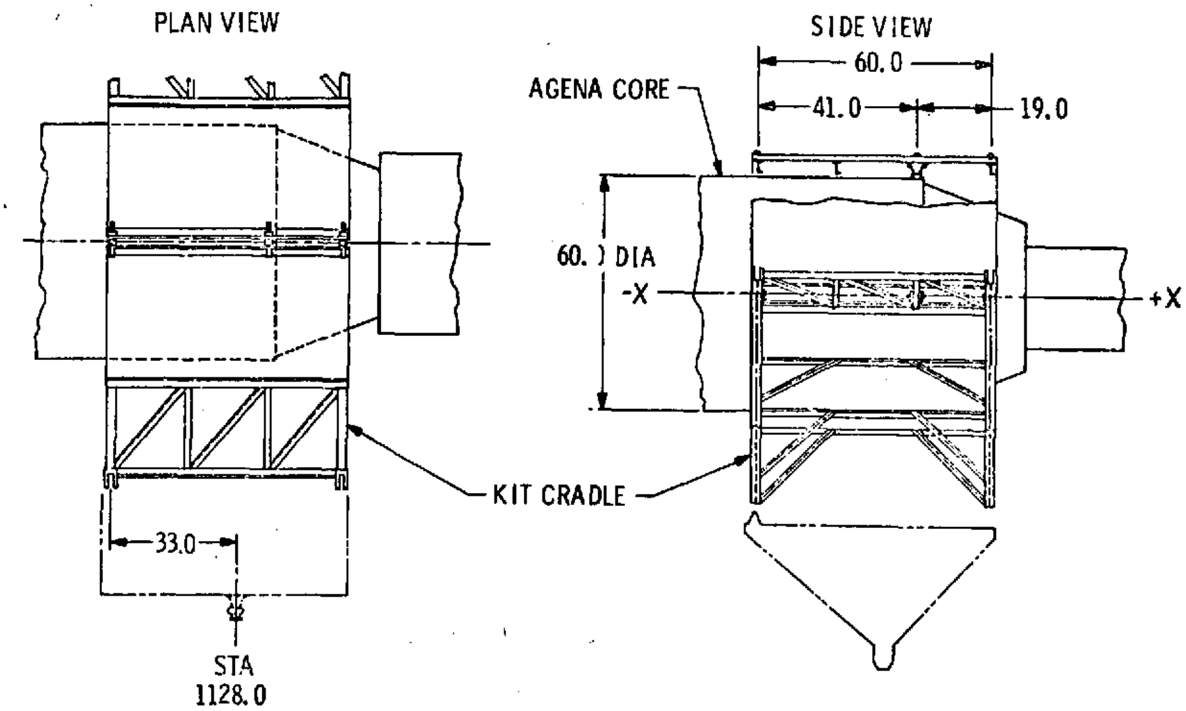


Fig. 3.3.5-3 CBSS Conversion Kit

This conversion kit, which concerns only the aft section of the basic CBSS, is simply a wrap-around cradle with clam-shell doors which fits into the lower half of the basic CBSS. The structure comprises a stiffened cylindrical shell, the lower half of which is integrated with two curved beams, laterally supported by struts, and attaches to the four inner hinges of the basic CBSS. The upper half of the shell consists of two single-hinged doors to permit deployment and retrieval of the core stage. The core stage is secured within the shell by the V-clamp ring assembly, located at the tank skirt/thrust cone juncture as shown in the Fig. 3.3.5-3. As was the case for the larger V-clamp ring used with the SOT option, its purpose is to transmit longitudinal loads to the Agena core tank in a uniform distribution. Unlike the SOT option configuration, the longitudinal forces do not induce transverse loads on the ring juncture.

To complete the conversion kit, the upper section doors of the basic CBSS are removed. The load transfer of the kit structure to the Orbiter is through the lower section of the basic CBSS, as shown in the Fig. 3.3.5-2. There is no change to the forward section, as the interface to the Agena remains the same as for the SOT option.

The net weight increase for the conversion kit is approximately 100 pounds (45 kg) (addition of the cradle and the smaller doors, and deletion of the larger, heavier doors of the SOT option).

Retractor and Couplings. The fluid system interface between the Agena and the CBSS consists of two propellant disconnects (oxidizer and fuel) mounted on a retractor. The propellant disconnects are open as indicated in Fig. 3.3.5-4 and are a modification of the current Agena disconnect in that the poppets and internal actuating mechanism have been removed. Propellant isolation is achieved by valves upstream of the disconnects. The lines are open to the atmosphere downstream of the disconnects. A 2 1/2-inch line is used in the Agena up to the disconnects and 3 1/3-inch lines are used in the Orbiter from the disconnects to the exit.

The retractor, shown in Fig. 3.3.5-5, provides for disconnect, a 2 1/2-inch movement away from the Agena, and subsequent reconnect when the Agena is retrieved into the cargo bay. When the retractor motion is initiated by the motor and ball screw drive,

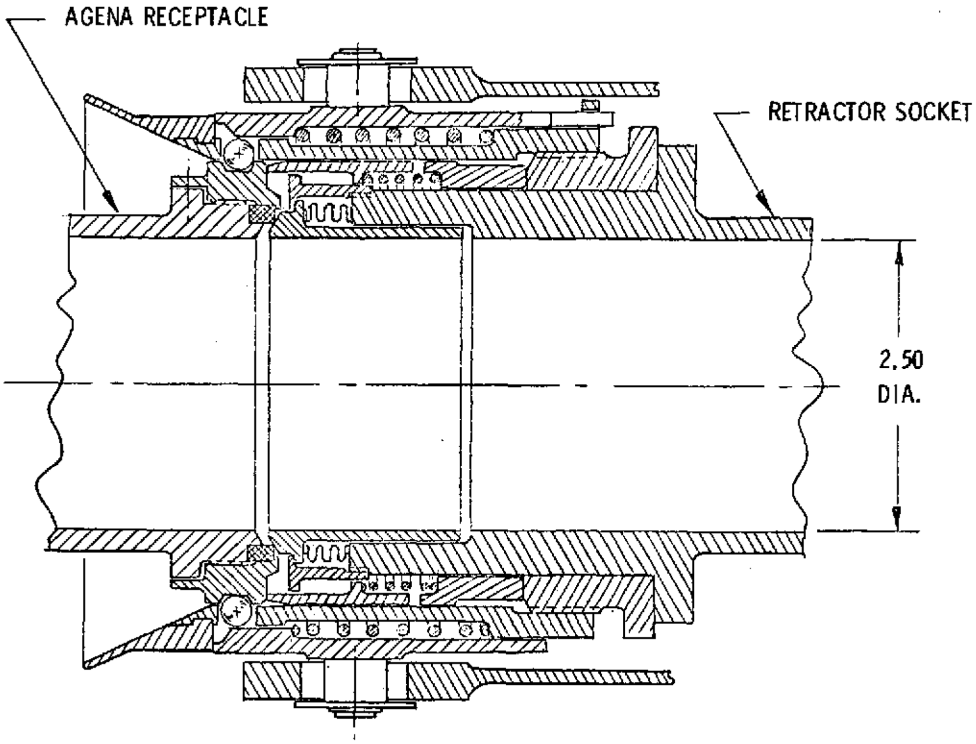


Fig. 3.3.5-4 Propellant Dump Line Disconnect

the sleeves of the disconnect are first pulled back. This allows the latching balls to disengage and hold the sleeve in the open or disengaged position. Continued motion by the retractor moves the entire disconnect away from the flight half of the disconnect.

After the Agena is retrieved, the retractor motion is reversed and it is moved toward the disconnects. A conically shaped end on the disconnect helps guide the mating surfaces of the disconnects and as they mate a spring-loaded sleeve that holds the balls in the open position is pushed back. The balls then latch the flight half of the disconnect and the sleeve slides over them holding them in place.

The disconnects are attached to the retractor by slotted brackets thereby permitting motion in two planes. After the disconnects are engaged the retractor is backed off slightly and only small loads from the flex lines are transmitted to the Agena.

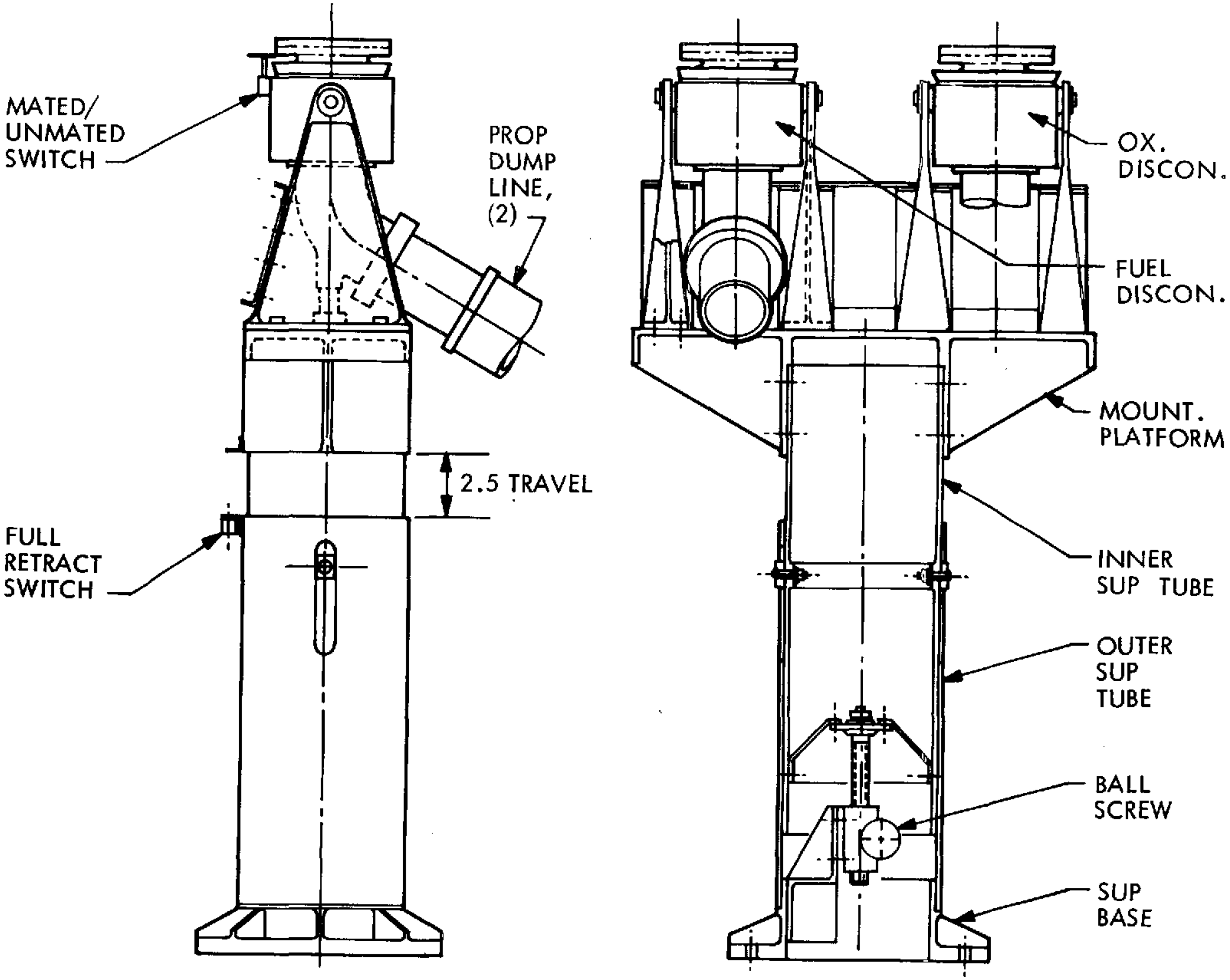


Fig. 3.3.5-5 Fluid Disconnect Retractor

3.3.5.2 Agena Service Panel (ASP). The Agena Service Panel is located in the Orbiter crew compartment and consists of a cathode ray display tube, a data input keyboard, a minicomputer to process the safety and operational data from the Agena, input-output processor for interfacing with Agena and Orbiter functions, a power converter to supply the ASP and cradle mechanism (actuators, motors) power, a recorder and miscellaneous lights and indicators for status, caution and warning, and control switches to provide commands to the Agena and cradle system. This equipment is shown in Fig. 3.3.5-6 and a short equipment summary is shown in Table 3.3.5-1. The ASP could be installed in the Mission Specialist Station (MSS) console.

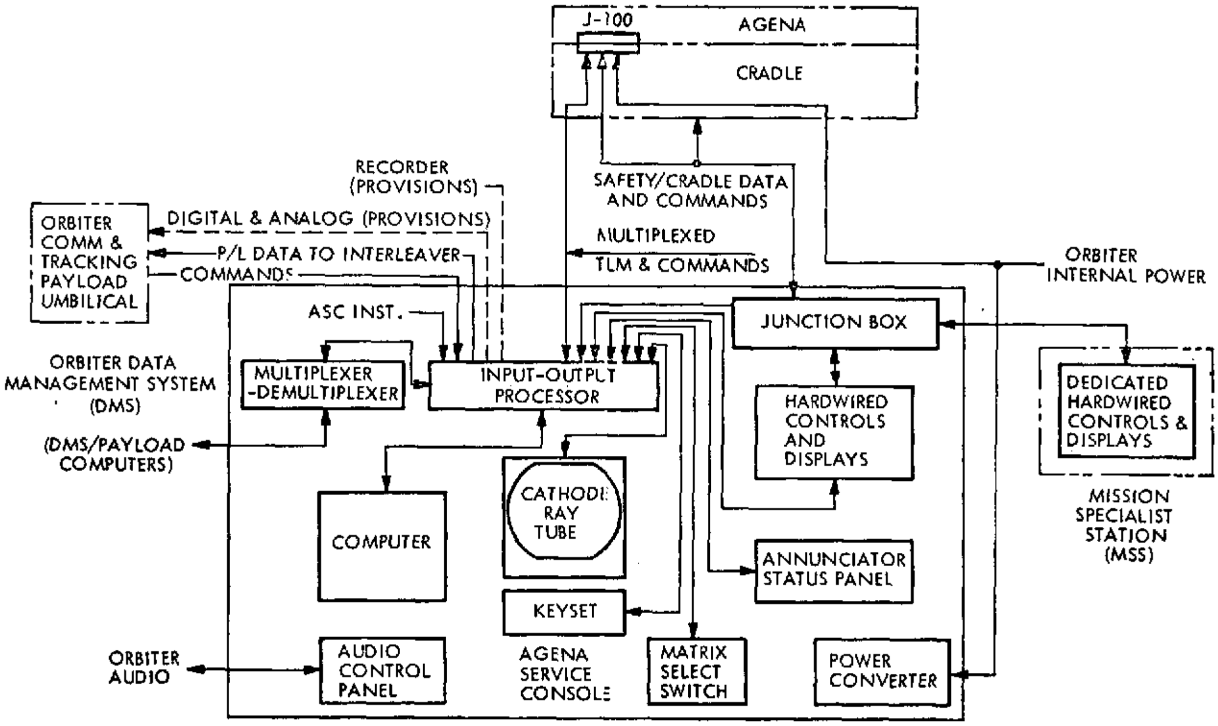


Fig. 3.3.5-6 Agena Service Panel

Table 3.3.5-1

AGENA SERVICE PANEL EQUIPMENT WEIGHT AND POWER ESTIMATE

	Number Required	Unit Weight lb (kg)	Unit Power (Watts)
Panel Structure	1	38 (17.2)	–
Meters	17	9 (4.1)	17
Status Lights	31	6 (2.7)	120*
Switches	27	5 (2.3)	–
Switch Lights	54	5 (2.3)	108*
Annunciator Panel	1	3 (1.4)	5
Power Supply	1	10 (4.5)	100
MDM	1	12 (5.4)	15
Matrix Select Switch	1	4 (1.8)	5
IOP	1	13 (5.9)	30
Keyset	1	11 (5.0)	9
Computer	1	21 (9.5)	65
J-Box	1	8 (3.6)	–
CRT Display	1	16 (7.3)	80
Comm Panel	1	5 (2.3)	5
Connectors	9	4 (1.8)	–
Wiring	–	13 (5.9)	–
Total	–	183 (83.0)	559

*One-half status and switch lights will be active at any one time

The ASP interface with the Agena during mated operations is provided in two ways. The safety critical monitor points and command interface are provided, dedicated hardwired, directly from the monitored sensors or the commanded circuitry. All other data (including safety critical data provided redundantly) are interfaced through the Agena PCM telemeter and command decoder systems. The information to and from the Agena is transmitted using multiplexed data streams. The cargo bay mechanism status monitors and command links are hardwired, non-multiplexed dedicated lines.

During mission segments where the Agena/cradle electrical umbilical is disconnected, all command and data transmissions accomplished through the Agena S-band and RF link and Orbiter S-band communications/data management systems. The ASP will operate as a data management system (DMS) crew station under these circumstances, employing the cathode ray tube (CRT)/keyboard controls and displays for control of the Agena subsystems, and the intercommunication station provided at the mission specialist station (MSS) for voice. This same data interface between the ASP and the Orbiter is used to provide a launch support interface between ground support facilities and the installed Agena system prior to liftoff.

Agena prelaunch and predeployment monitoring is designed to verify the continuing flight readiness status of the vehicle and support equipment. Any no-go condition detected following Agena installation in the Orbiter will be analyzed at the ASP to verify the no-go condition and to establish the potential impact on mission success. No-go analysis is conducted at the ASP by commanding and displaying additional data from hardwire (via the Agena umbilical) or from the telemetry PCM bit-stream. If additional analysis is required or decision coroboration is needed, data can be transmitted to the ground via the Orbiter RF link. Normally all analyses will be accomplished on board the Orbiter at the ASP.

Agena safety and health parameters will be continuously cycled through the ASP computer following installation of the Agena in the cargo bay. All parameters are cycled through the computer and examined for compliance with go/no-go limits at critical mission points, e.g., before liftoff, before deployment, and before retrieval.

Command and control of the Agena vehicle, its support equipment, and safety displays are shared between the mission specialist station (MSS) and the ASP. Safety data from both the Agena and support equipment can be monitored directly on the ASP and MSS fixed display panel with no intermediate signal processing required. Telemetry data must be decommutated and scaled before being displayed. Emergency dump can be accomplished either as an automatic sequence controlled by the ASP computer or as a full manual operation.

The mission specialist (MS) flight engineer, is responsible for payload (Agena system) operations management. Flight safety dedicated displays are located at the MSS with complete dedicated controls to permit the MS to safe the Agena.

The Agena system provides for all data management hardware and software computation with the exception of those hardware items (and attendant software) necessary for RF intercommunication between the Agena vehicle, Orbiter vehicle and earth control centers, and pre-launch interface with the Orbiter ground checkout system.

The single-point interface between the Agena system and the Orbiter data management subsystem is a multiplexer/demultiplexer (MDM). The characteristics of this element are assumed to be those of an equivalent Orbiter unit. The MDM is supplied by the Agena and installed within the ASP equipment group.

The CRT, keyset, audio control panel and MDM can be Government-furnished equipment (GFE), identical to the Orbiter program hardware.

Computer. The computer selected is a simplex DF224 configuration as used in the Agena avionics. Only the plug-in modules and multi-layer interconnect boards of the DF224 series are used because installation-provisions and interconnects can be furnished within the console.

The reason the simpler DF224 hardware was selected was to eliminate any interface problem between the ASP and the Agena caused by the use of different machines and software languages.

At this stage of definition an 8000-word memory appears sufficient for ASP operations.

CRT. No firm requirement for graphics has been identified, permitting use of a relatively unsophisticated display employing alphanumerics only. It is anticipated that the operator would also employ a simple manual with graphic troubleshooting flow guides in lieu of a larger memory and a graphic display capability. Full use of hardwired control/display is also anticipated in checkout and fault isolation modes of operation.

Matrix Select Switch. A predefined set of subsystem configuration subroutines are addressed by switch selection as an operator convenience.

Annunciator Status Panel. A master warning light signifying a go/no-go condition is provided. Selected areas of critical interest are represented by individual annunciators which inform the operator of the general nature of the alert. If the ASP is combined with the MSS, this panel can be deleted.

Input/Output Processor (IOP). The IOP is identical in basic concept with the computer interface unit of the Agena DM & I assembly. Module functions differ but the basic hardware modules and internal bus design are the same. Unique requirements such as buffering the telemetry interface, analog/digital (A/D), and digital/analog (D/A) conversion are employed to interface the computer to the differing peripheral requirements.

3.3.5.3 Orbiter/Cargo Bay Equipment Summary. A summary of the non-flyaway equipment located within the Orbiter, as discussed in the above two subsections, is provided in Table 2-2.

3.3.5.4 Mass Properties. The mass properties for the Shuttle Agena Upper Stage with SOT option is provided in ref 3-8. The resultant cg characteristics for the Agena when installed in the Orbiter are provided in Fig. 3.3.5-7.

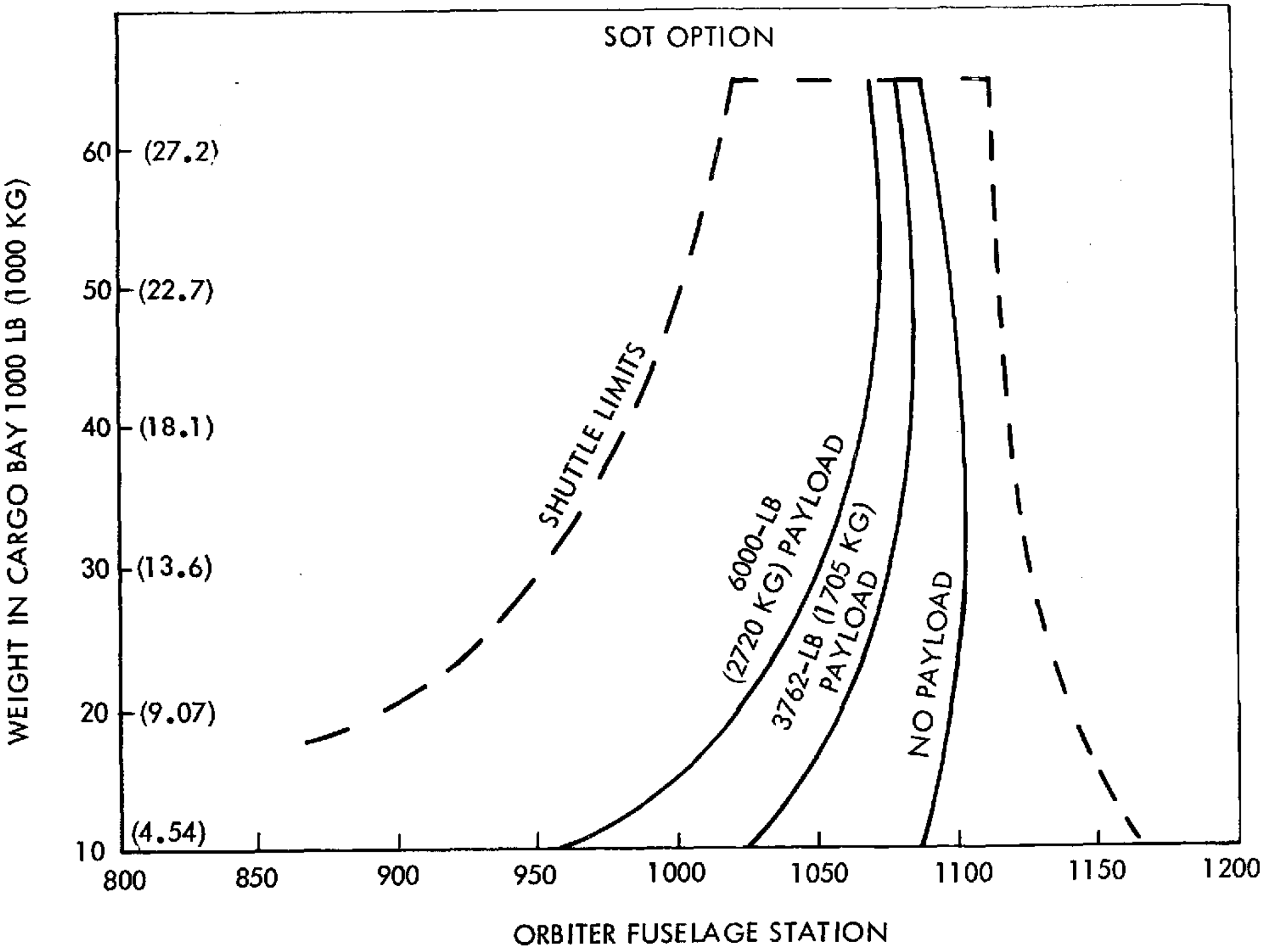


Fig. 3.3.5-7 Nominal Shuttle/Agena cg Characteristics In Orbiter

3.4 CONCEPT DESCRIPTION

The recommended interim Space Tug concept is the Shuttle/Agena Upper Stage with the strap-on-tank (SOT) propellant load option. As shown in Fig. 3.4-1, this concept utilizes the existing Lockheed Agena space vehicle in a building block approach that can accommodate the strap-on-tank option and minimum modifications necessary to meet Tug requirements. An 8.5-inch (21.6 cm) extension is added to the fuel tank, monomethyl hydrazine fuel is substituted for unsymmetrical dimethylhydrazine, a 150:1 nozzle extension is substituted for the existing 45:1 extension, an Autonetics DF-224 computer is substituted for the Honeywell computer, and a star sensor is added for use in guidance update. From an avionics standpoint the concept can be designed either as a Nominal (single string) configuration or as an Augmented (dual string) configuration.

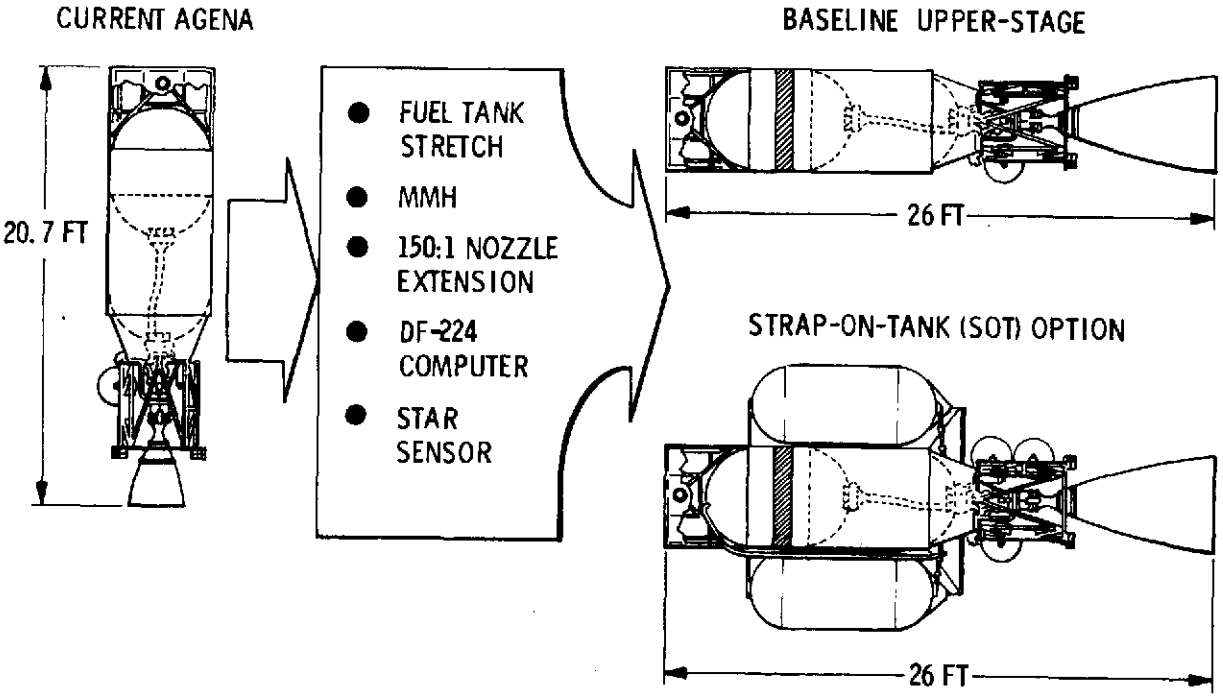


Fig. 3.4-1 Building Block Concept

Nominal Shuttle/Agena Upper Stage. An inboard profile of the Nominal Agena Upper Stage concept is shown in Fig. 3.4-2. In this concept the Agena uses the existing 6061 aluminum main propellant tanks; existing forward rack, aft rack, and thrust cone, and can use an optional six strap-on-tank (SOT) propellant load option. The SOTs are supported at their forward end by rod-type struts (Fig. 3.4-3) and at their aft end by a stiffened shell cone frustum that ties into the Agena Y ring located at the aft end of the main propellant tanks.

The main engine is the Bell 8096L with a 150:1 nozzle expansion ratio and with a multi-start system that permits as many as 15 main engine restarts during one mission. The hot gas attitude control system uses hydrazine with dual high mode thruster clusters. A separate, small, hydrazine tank is used as backup for the retrieval operation.

Electrical power is derived from batteries located in the forward equipment rack. A single string Autonetics DF-224 computer, single Honeywell IMU, and dual Ball Brothers star sensors provide guidance, navigation, and attitude control. State vector updates from the ground provide for navigation reinitialization prior to each main engine burn.

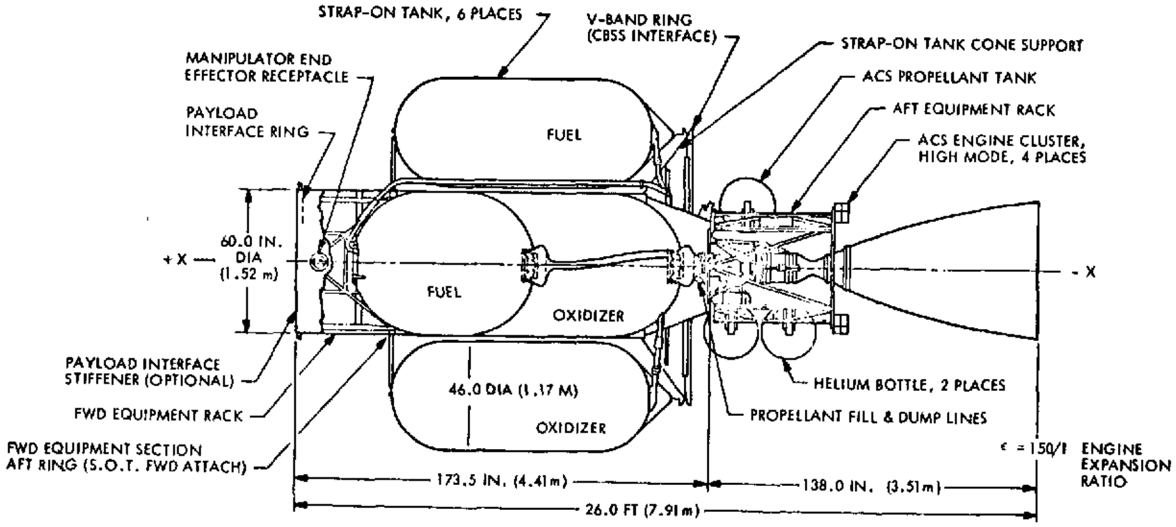


Fig. 3.4-2 Nominal Shuttle/Agena Upper Stage (SOT Option)

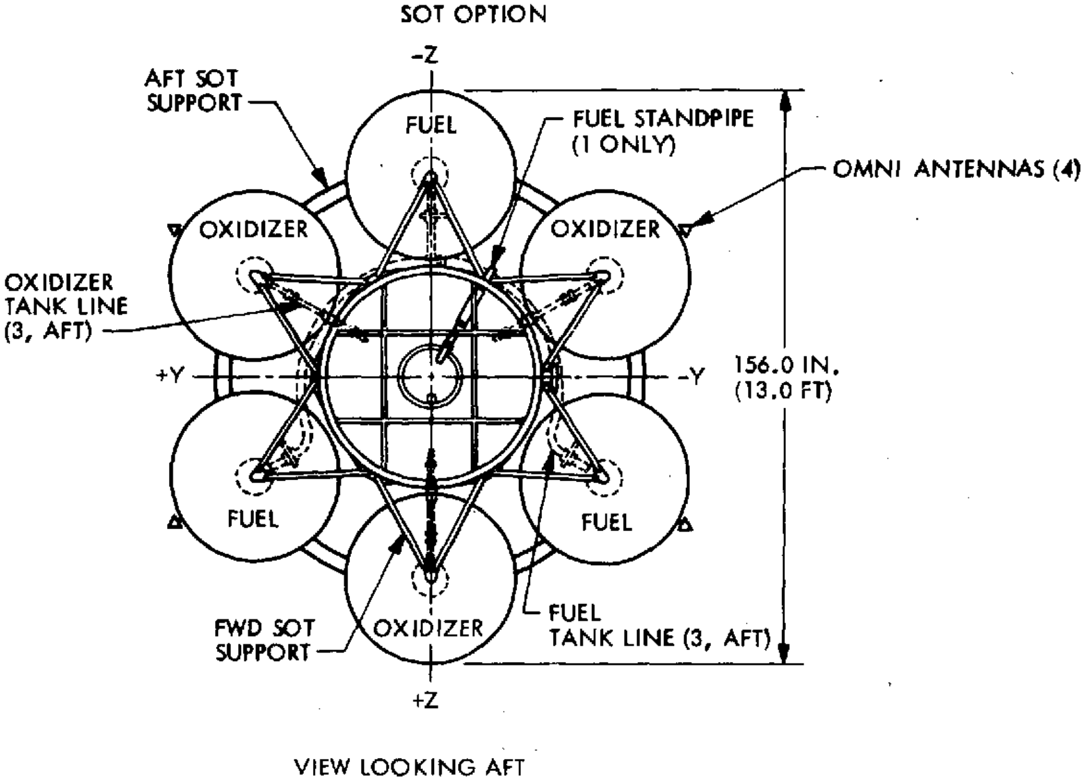


Fig. 3.4-3 Nominal Shuttle/Agena Upper Stage (SOT Option)

Backup attitude control electronics and dedicated battery, with the dual high mode ACS thrusters, provide complete backup stabilization capability for emergency use during the Shuttle retrieval operation. The redundant communications system permits astronaut override control of the Agena either during deployment or during retrieval.

Augmented Shuttle/Agena Upper Stage. The Augmented Agena Upper Stage concept is presented in Fig. 3.4-4 and Fig. 3.4-5. The operation of the Augmented system is very similar to that of the Nominal concept. However there are some major differences in configuration. The main propellant tanks are fabricated of 2219 aluminum. The SOT option installation and Bell 8096L engine are the same. The major differences are in the avionics area. In the Agumented concept, dual Honeywell IMUs are used with a dual string Autonetics DF-224 computer. A single Bendix star tracker and a 3-head horizon sensor provide accurate stabilization control and reinitialization. Single low mode thruster clusters back up the dual high mode clusters. The backup retrieval stabilization electronics are not needed since the redundant IMU furnishes this function. The emergency backup battery and small hydrazine tank are retained to maintain a completely redundant emergency backup retrieval stabilization system. Fully redundant communication systems are also retained.

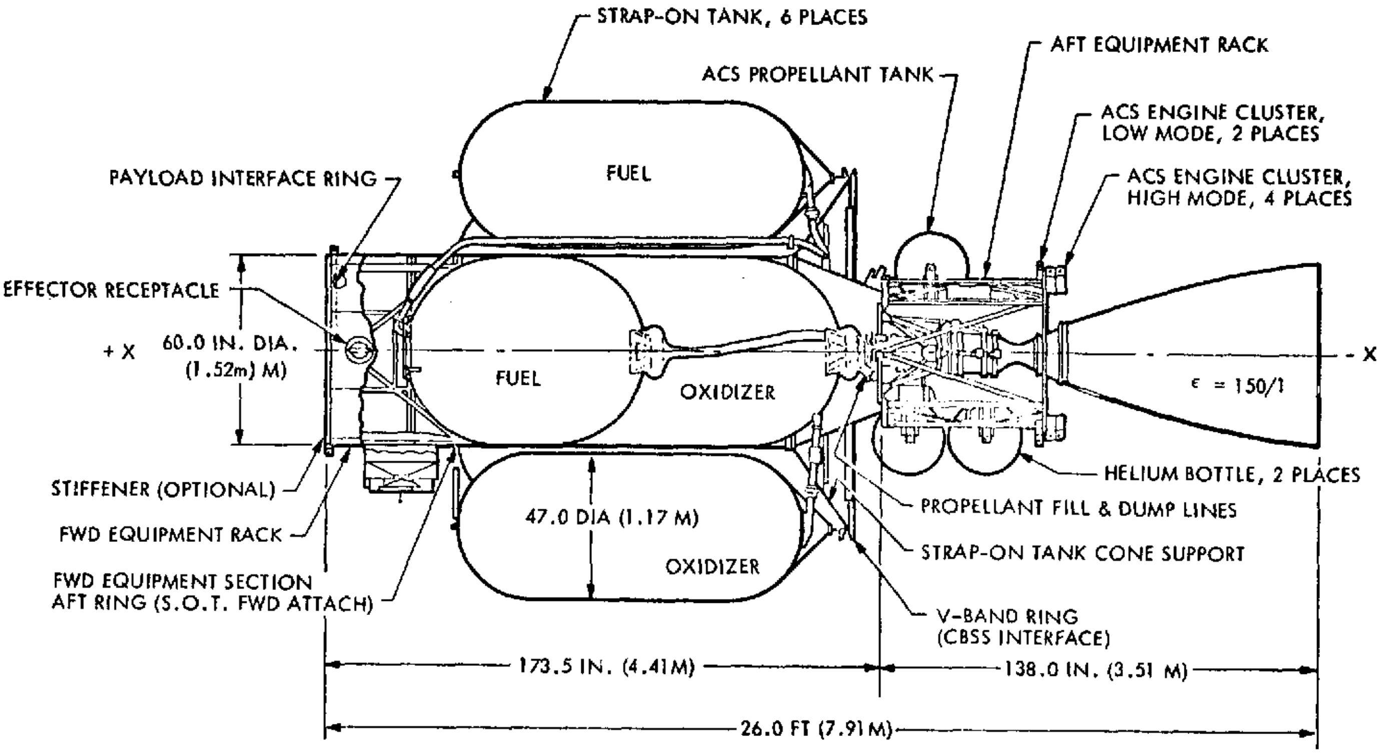


Fig. 3.4-4 Augmented Shuttle/Agena Upper Stage (SOT Option)

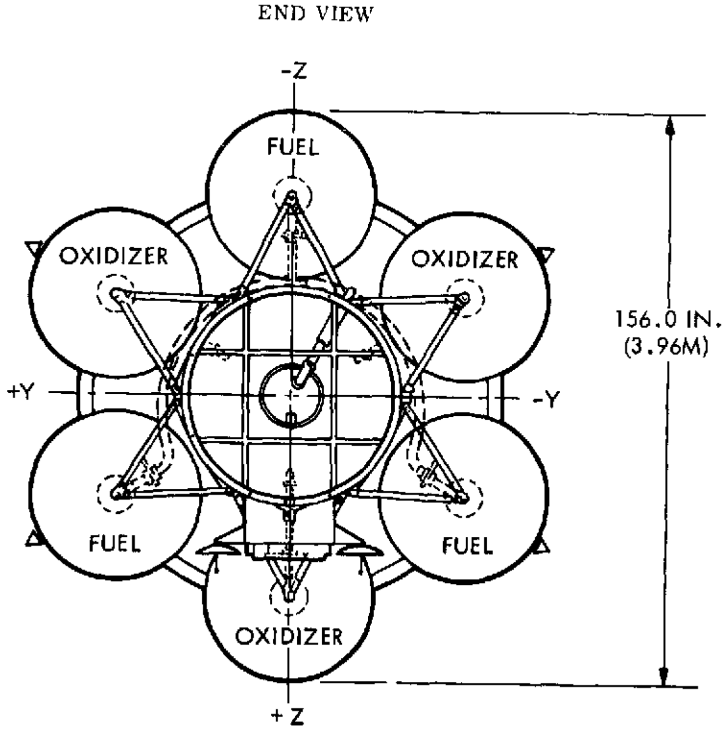


Fig. 3.4-5 Augmented Shuttle/Agena Upper Stage (SOT Option)

With the SOT option the dry weight of the nominal concept is 85 lb (38.6 kg) lighter than that of the augmented. A summary weight statement for the two concepts is presented in Table 3.4-1.

Table 3.4-1

NOMINAL AND AUGMENTED AGENA UPPER STAGE SUMMARY WEIGHTS

Item	Nominal Agena Upper Stage		Augmented Agena Upper Stage	
	Core	SOT & Core	Core	SOT & Core
Structure	610	1,295	568	1,253
Propulsion	568	768	573	774
Avionics	595	617	694	770
Thermal Control	27	57	27	57
Contingency*	83	175	103	194
Dry Weight, lb (kg)	1,833 (854)	2,912 (1,321)	1,965 (891)	3,048 (1,383)

*10 percent on new or modified,
2 percent on existing

Nominal and Augmented Shuttle/Agena Forward Equipment Installation. The installation of the avionics in the forward equipment section is shown in Fig. 3.4-6 for the Nominal configuration and in Fig. 3.4-7 for the Augmented configuration. This section readily accommodates the dual avionics configuration with two bays available for growth.

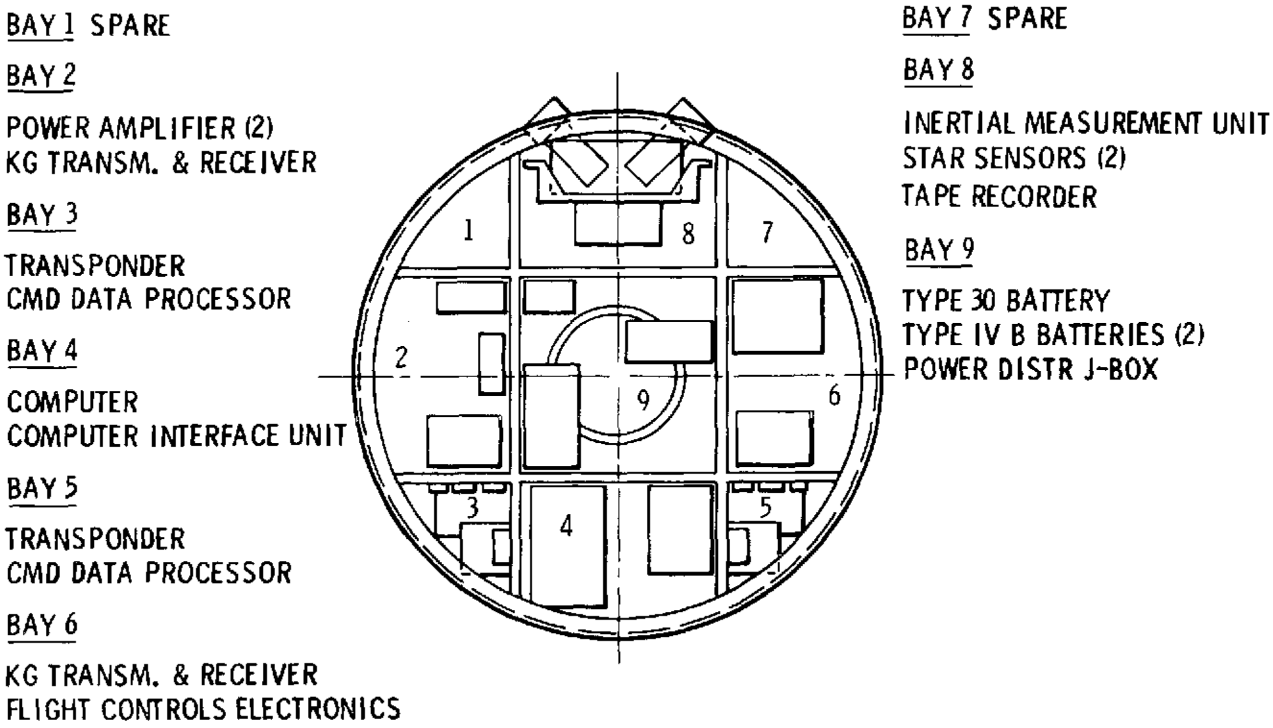


Fig. 3.4-6 Nominal Shuttle/Agena Upper Stage Forward Equipment Installation

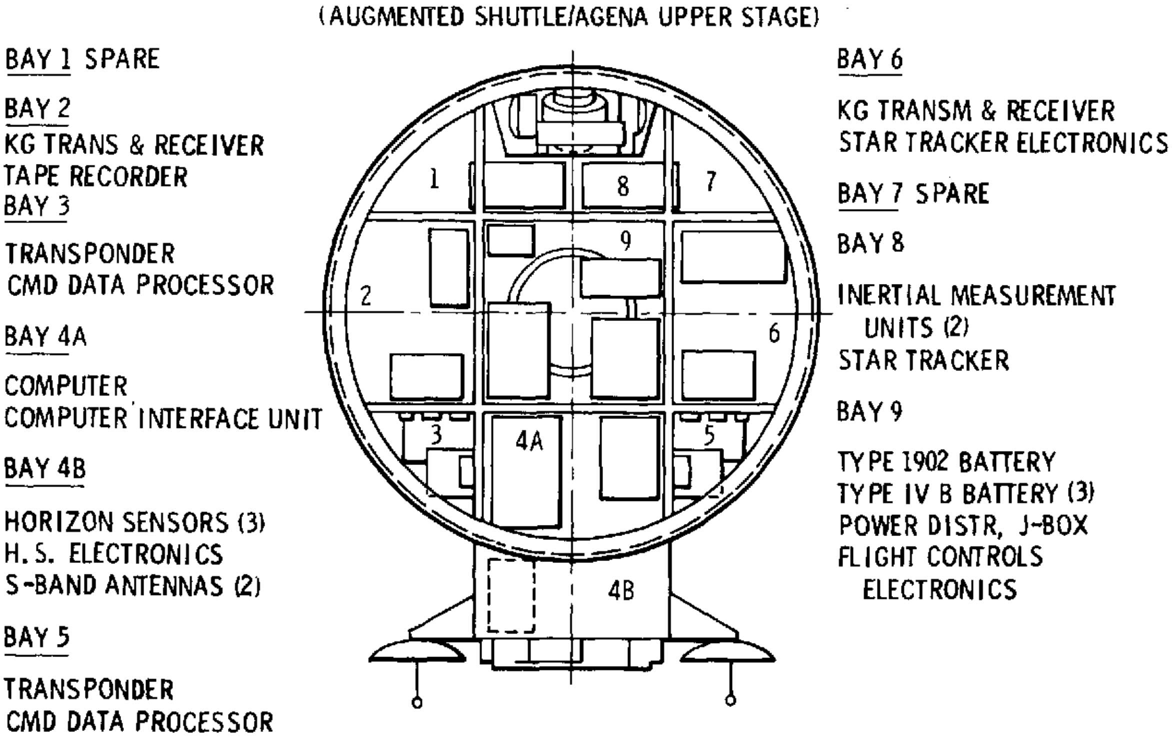


Fig. 3.4-7 Augmented Shuttle/Agena Forward Equipment Installation

3.5 PROGRAM DEFINITION

This section discusses the composition, time phasing, and expenditure requirements of a program to implement the reusable Shuttle/Agena Upper Stage for service with the Space Shuttle. This program has three major elements:

- Design, Development, Test and Evaluation (DDT&E) Phase. Covers the steps needed to develop the Agena vehicle and its support systems for operational service; also covers other one-time functions such as base construction and activation.
- Production (Investment) Phase. Covers the events associated with acquisition of a reusable vehicle fleet sufficient to perform a stipulated operational program; also covers the acquisition of initial spares for that fleet.
- Operations Phase. Covers the recurring events that support mission use of the Agena, including launch, mission control, recovery and refurbishment.

The programmatic and cost data in this section refer primarily to the recommended Shuttle/Agena Upper Stage concept with strap-on-tank option (reusable core stage with add-on tanks; dual-string reliability). Any changes in the baseline programmatics/costs caused by alternative concepts are so noted.

3.5.1 Schedules

A master schedule covering the life-cycle events associated with a Shuttle/Agena program is presented Fig. 3.5-1. This schedule is keyed to provide an initial operational capability (IOC) at mid-calendar year 1980. Authorization to proceed with Phase C/D activities is assumed to take place in July 1976. For purposes of this study, the nominal operational program duration is three and one half years, and the fleet is sized to meet the flight activity level associated with such a program.

3.5.1.1 DDT&E Phase Schedule. The DDT&E phase of the Shuttle/Agena program starts 48 months prior to IOC, but the major events of the development program are concluded in 38 months (September 1979). The development program, described in par. 3.5.2, includes the fabrication and ground testing of three vehicle-level test articles. No flight testing is included. A Phase-B study of the Shuttle/Agena Upper Stage system is assumed to have taken place in advance of the DDT&E program start date.

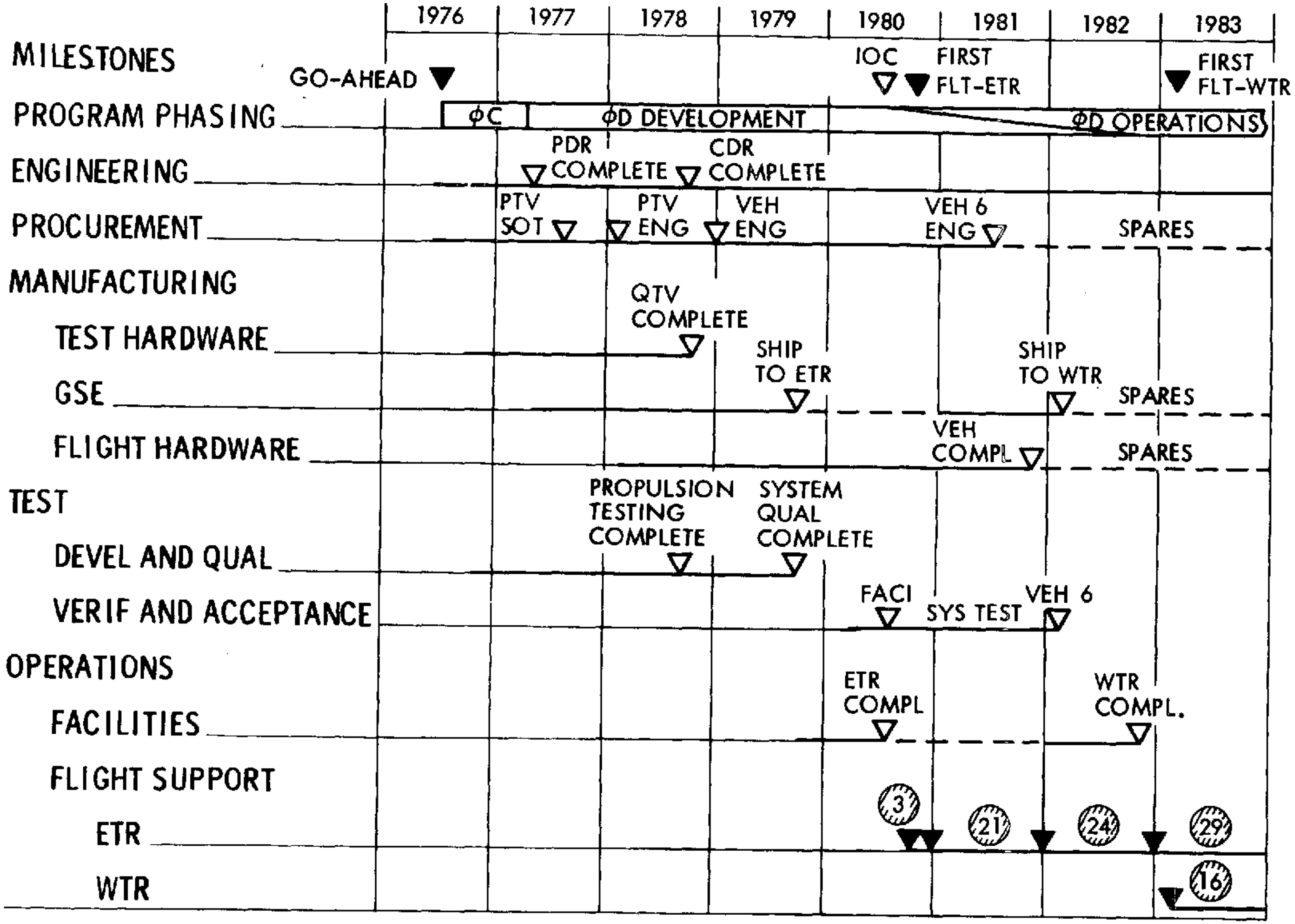


Fig. 3.5-1 Agena Upper Stage Master Schedule

Parallel developments bearing on the DDT&E program schedule are the Model 8096 engine product improvement and the DF224 computer development. The BAC Model 8096 engine currently used on the Agena vehicle is undergoing a continuous program of product improvement that is funded under Company- and Government-sponsored projects. A key engine modification is the change of the existing thrust chamber injector to a new baffled injector. An Agena-using program has initiated funded development of the baffled injector with a first flight to occur by 1976.

The Rockwell International Model DF224 computer is under development in connection with an ongoing hardware program. Under this program the DF224 will have completed full qualification testing by 1975, well in advance of the start of Phase C activities on the Shuttle/Agena program.

3.5.1.2 Production and Operations Phase Schedule. The schedule for the production and operations phases of the Shuttle/Agena program, Fig. 3.5-2, reflects the fabrication and mission use of six vehicles to accomplish the stipulated Tug mission model for four calendar years; this requires 93 flights between 1980 and 1983. Alternative schedules calling for Agena Upper Stage activity over six and eleven calendar years were also evaluated. The levels of flight activity required (by agency and by launch site) to fulfill the mission model over the three reference time periods are listed in Table 3.5-1. The six-vehicle fleet appears adequate to support the six- and eleven-year models, provided that the vehicles are refurbished continuously. The eleven-year program would require a second lot buy of spares about halfway through the operational period; moreover, the availability of a refurbished qualification test vehicle (QTV) could provide added assurance against Agena losses in operation over this eleven-year period.

3.5.1.3 Impact of DoD Procurement. No major schedule differences have been identified as a result of the DoD procurement practices that would be implemented with Air Force acquisition of the Shuttle/Agena system. Such procurement procedures, which are documented in Air Force Systems Command Pamphlet 800-3 (AFSCP 800-3), affect the way in which the vehicle life cycle is divided into phases. The objective of AFSCP 800-3 is to reduce the risk of cost growth in the production of high-value

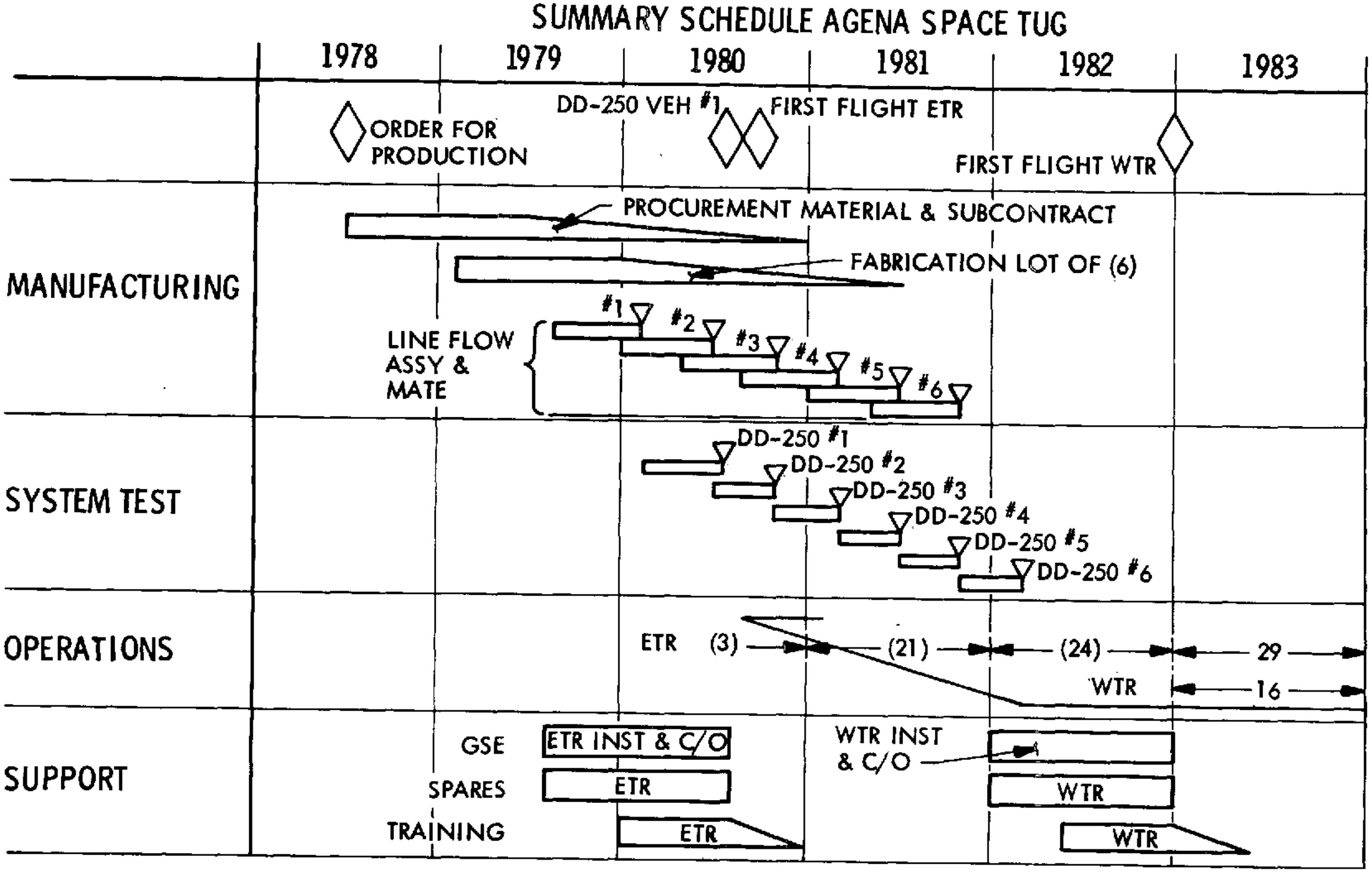


Fig. 3.5-2 Schedule for Production/Operations Phases

Table 3.5-1

FLIGHT ACTIVITY REQUIRED TO FULFILL MISSION MODEL WITH AGENA

Agency	Calendar Year											4 Yr Total	6 Yr Total	11 Yr Total
	80	81	82	83	84	85	86	87	88	89	90			
NASA	3	16	12	23	17	22	16	24	16	26	15	54	93	190
DoD	0	5	12	22	17	12	16	17	15	14	16	39	68	146
Total	3	21	24	45	34	34	32	41	31	40	31	93	161	336

Launch Site	Calendar Year											4 Yr Total	6 Yr Total	11 Yr Total
	80	81	82	83	84	85	86	87	88	89	90			
ETR	3	21	24	29	29	23	25	33	27	24	26	77	129	264
WTR	0	0	0	16	5	11	7	8	4	16	5	16	32	72
Total	3	21	24	45	34	34	32	41	31	40	31	93	161	336

weapon systems by emphasizing fly-before-buy and prototyping practices. With the low production volume and relatively low unit cost of the Shuttle/Agena, it would be consistent with the intent of AFSCP 800-3 to be flexible in interpreting the applicability of fly-before-buy practices to this program.

The LMSC interpretation of Shuttle/Agena program phasing under NASA and DoD procurement practices is presented in Fig. 3.5-3.

3.5.2 Development Program

The development program for the reusable Shuttle/Agena system features low-cost, high-confidence approaches that have been proven in space propulsion systems with 100 percent mission success. Minimum cost is attained by substituting rigorous ground testing for flight testing, and keeping test hardware to a minimum.

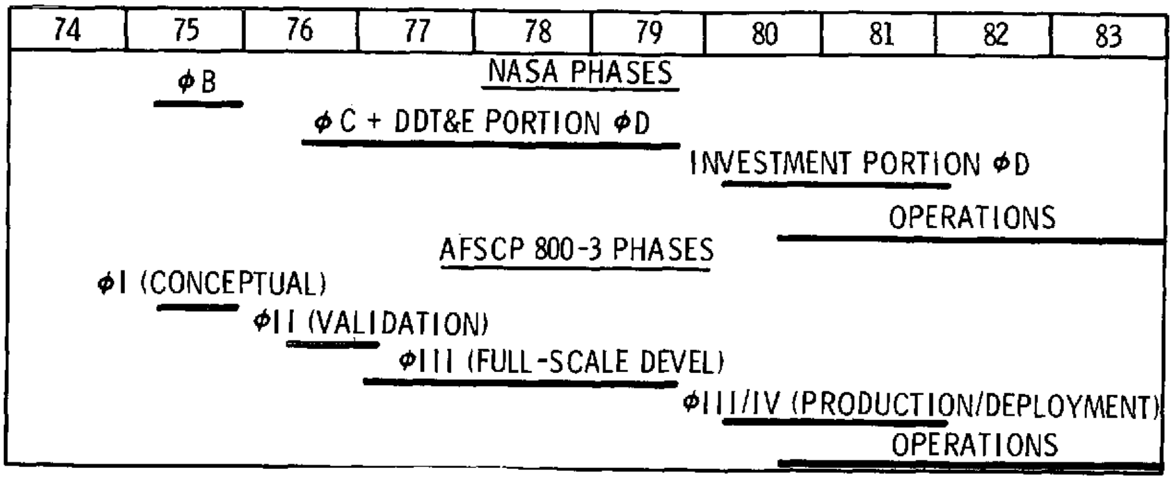


Fig. 3.5-3 Comparison of NASA and DoD Procurement Practices For Agena Program

The logic flow of the vehicle ground test program is summarized in Fig. 3.5-4. The sequence of testing is from component-level to subsystem-level to vehicle-level hardware. Where schedule risk and test severity permit, common test hardware is carried forward from test to test, thereby reducing the investment in such hardware. The development program incorporates three system-level test articles:

- Structural Test Article (STA)
- Propulsion Test Vehicle (PTV)
- Qualification Test Vehicle (QTV)

As an example of the carryover of test hardware, the QTV is built up as follows. Structures and propulsion subsystem components of the PTV (refurbished as necessary) form the basic core; to this core is added a nearly complete set of avionics (mounted in a forward equipment rack), that was previously used in the integrated avionics test article. When a set of flight instrumentation and an aft instrumentation J-box (both new) are integrated into this test article, the QTV buildup is completed.

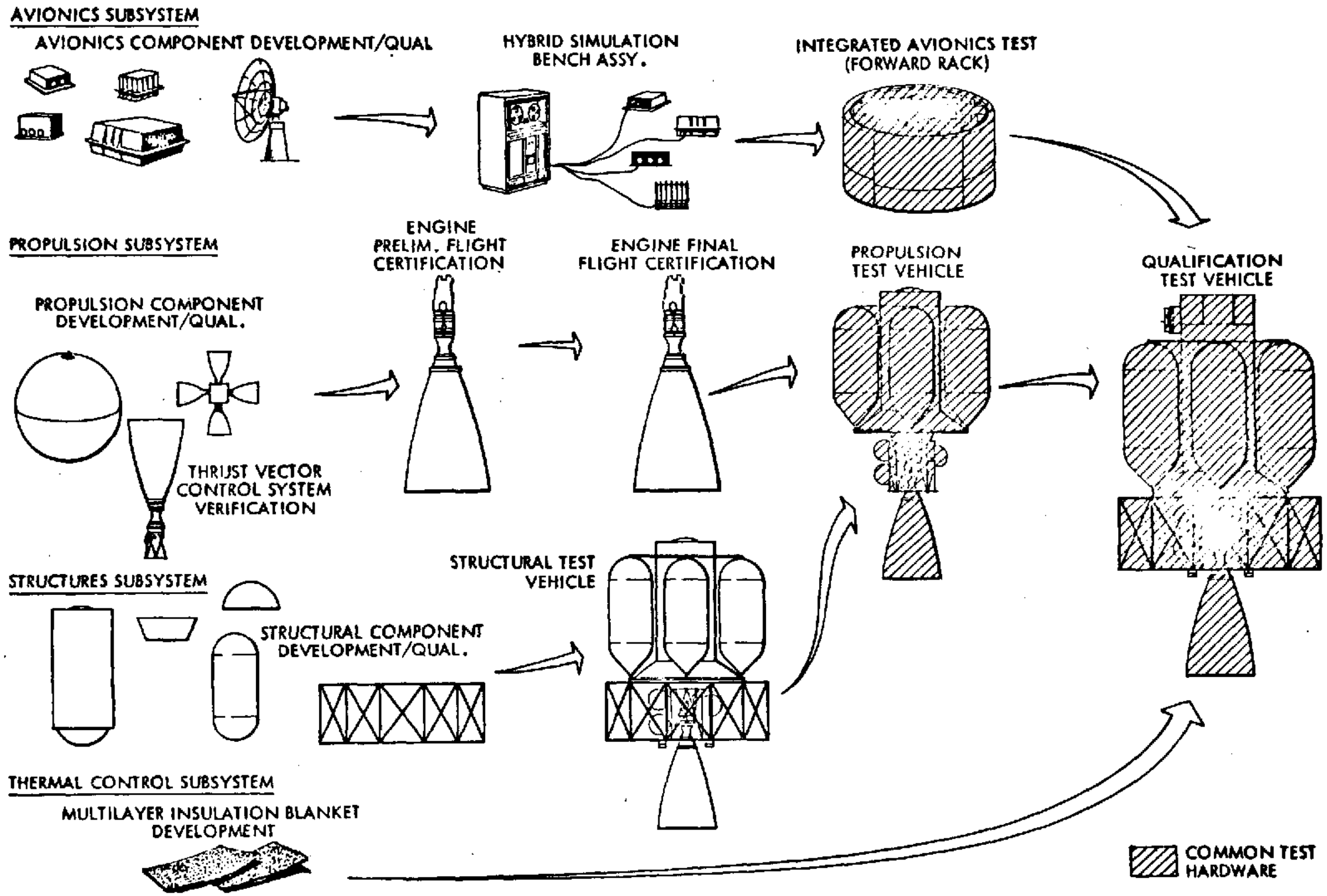


Fig. 3.5-4 Agena Ground Test Logic Flow

The test plan takes full advantage of prior effort. At the component level, development testing is performed on those components that are new or substantially modified in either design or in mission application (e.g., core tanks reused for three flights). Qualification and life tests are performed only on those components for which no such prior test data exists.

A summary of the principal tests performed during the DDT&E phase of the Shuttle/Agena program is contained in Table 3.5-2. This table defines the major levels of hardware indenture, describes the test hardware, and identifies the test operations required to demonstrate flight readiness at each level.

The only differences in testing between the Augmented and Nominal Shuttle/Agena concepts are that: (1) the Nominal concept uses existing 6061 aluminum tankage in the core stage, thus eliminating development tests of the Augmented 2219 aluminum design, and (2) backup stabilization system electronics equipment must be development-tested for the Nominal single-string avionics concepts.

3.5.3 Facilities and Ground Support Equipment (GSE) Plan

Existing facilities and GSE will fulfill most of the needs of the Shuttle/Agena system. The facilities/GSE required to develop and implement the system were assessed by reviewing, on a function-by-function basis, the requirements for specific buildings; test stands; environmental chambers; machinery; handling equipment; servicing equipment; and checkout, control and monitoring consoles, across the complete life cycle of the program. These requirements were then compared against the inventory of existing Government and LMSC facilities and GSE. Where the existing facility or item of GSE was found to meet a specific requirement, the size, capability, status, and availability of that item were confirmed before adding it to the inventory of Shuttle/Agena facilities and equipment.

3.5.3.1 Facilities Plan. The facilities status is summarized in Table 3.5-3. Note that one or more existing facilities has been identified to fill each major Shuttle/Agena program requirement. Manufacturing of the Agena stage and its Orbiter interface equipment can be accommodated in existing LMSC fabrication buildings at Sunnyvale.

Table 3.5-2

TEST SUMMARY MATRIX

Level	Category	Hardware	Plan
Vehicle System	Qual	Structural Test Vehicle: • Complete Set of Agena Structures • Mass Simulated Propellants and Components • Complete Cargo Bay Structure	Structures Tests: • Acoustic • Modal (Free-Free and Supported) • Static and Cyclic Loads • Shock Synthesis • Mechanisms Functional Test Next Use of Hardware: • Launch Base Physical Interface Validation
	Devel	Propulsion Test Vehicle: • Complete Propulsion System • Complete Structures Less Forward Equipment Rack • Instrumentation and Interconnect Harnesses	Propulsion Tests: • Cold Flow Feed/Fill/Drain • Emergency Dump • Malfunction Tests • Hot Firing Next Use of Hardware: • Incorporated Into QTV
	Qual	Qualification Test Vehicle: • Complete Functional Vehicle (Refurbished Propulsion Test Vehicle Plus Refurbished Integrated Avionics Test Article) • Complete Set of Orbiter Interface Equipment	Qualification (Certification) Tests: • Ground/Vehicle Compatibility • EMI Test • Acoustic Environment • Thermal/Vacuum Simulation • Ambient Revalidation Next Use of Hardware: • House Spacecraft and/or • Backup Flight Article
Structures Subsystem Level		(Not Applicable; Testing Done at Next Higher Level)	

Table 3.5-2 (Cont.)

Level	Category	Hardware	Plan
Structures (Cont.)			
Core Tankage	Devel	New/Modified Structural Components: • Core Tank (With Sumps) • Common Bulkhead • Oxid. Tank Material Coupons	Design Verification Tests: • Tank Leak/Proof Test* • Tank Cycling/Burst • Sump Proof/Burst* • Bulkhead Compression Buckling* • Oxid. Tank Material Toughness/ Flaw Propagation
Strap-On-Tank System	Devel	All Structural Components of Strap-On Tank System: • Fuel Tanks • Oxid. Tanks • Tank Attachment Structures • Tank Sumps	Design Verification Tests: • Tank Leak/Proof Test • Tank Slosh Test • Tank Cycling/Burst • Sump Proof/Burst • Support Structure Static/ Dynamic
Cargo Bay Support Structure	Devel	All Structural and Mechanical Components of CBSS	Design Verification Tests: • Static Limit Load (CBSS and Fittings) • Cyclic Load
Thermal Control			
Multilayer Insulation	Devel	Multilayer Blanket Panels	Design Verification Tests • Thermal/Vacuum Performance and Reuse Degradation • Mechanical Strength
Avionics			
Subsystem Level	Devel	Hybrid Simulation Bench Assy. • Complete Guidance/Navigation System • Complete Data Management Sys. • Interconnections to Hybrid Computer • Software Tapes	Design Verification Test: • Software Validation • Hardware/Software Functional Compatibility

*Augmented Concept Only

Table 3.5-2 (Cont.)

Level	Category	Hardware	Plan
Avionics (Cont.)			
Subsystem Level (Cont.)	Devel	Integrated Avionics Test Article: ● Complete Avionics Subsystem Less Batteries, Instrumentation, and Aft Instrumentation J-Box ● Forward Equipment Rack Structure	Design Verification Test: ● End-To-End Avionics Subsystem Operation (Ambient) ● GSE/Avionics/Software Compatibility ● Thermal/Vacuum and Thermal Cycling ● Acoustic Environment Next Use of Hardware: ● Qualification Test Vehicle
Component Functional Development	Devel	New (and Major Mod) Avionics Components: ● Controls Electronics Assy ● Computer (Vendor Test) ● Computer Interface Unit ● Agena Service Console ● Transponder (Vendor Test) ● Command Data Processor ● Power Distribution J-Box ● Aft Control/Instrumentation J-Box ● Backup Electronics Assy** ● Backup J-Box**	Design Verification Test: ● Ambient Functional Check ● Vibration ● Temperature/Power Variations
Component Mission Life	Devel	Components Without Prior Life Testing: ● Controls Electronics Assy ● Computer Interface Unit ● Agena Service Console ● Aft Control/Instrumentation J-Box	Mission Duty Cycle Testing: o Thermal Cycle Capability (12 hour Cycles)

**Nominal Concept Only

Table 3.5-2 (Cont.)

Level	Category	Hardware	Plan
Avionics (Cont.)			
Component Qualification	Qual	Components Without Prior Qual Test: ● Controls Electronics Assy ● Computer Interface Unit ● Agena Service Console ● Command Data Processor ● Aft Control/Instrumentation J-Box	Qualification Tests: ● Temperature Variation ● Power Variation ● Thermal/Vacuum ● Vibration (Random, Sine) ● Acceleration ● Shock ● EMI ● Humidity
Propulsion			
Subsystem Level	Devel	Thrust Vector Control System: ● Hydraulic Power Package ● Hydraulic Actuators ● Main Engine Mass Simulation	Design Verification Test: ● Gimbal and Response Rate
	Devel.	Fluid Systems Scale Test Article: ● Scale Model Core Tank ● Scale Model Strap-On Tanks/Lines	Design Verification Test: ● Fluid Flow ● Residuals Behavior
Engine Development and Preliminary Flight Certification (Vendor Tests)	Devel	Model 8096L Main Engines (3)	Design Verification and Preliminary Flight Certification Tests: ● Sea Level Performance ● Altitude Performance
Engine Final Flight Certification (Vendor Tests)	Qual	Model 8096L Main Engine (1)	Final Flight Certification Tests: ● Sea Level Mission Duty Cycle ● Maintenance/Refurbishment Procedures

Table 3.5-2 (Cont.)

Level	Category	Hardware	Plan
Propulsion (Cont.)			
Engine Component Development (Vendor Tests)	Devel	New/Modified Engine Components: • Turbopump • Multistart Kit • Valves/Controls • Thrust Chamber Assembly	Design Verification Tests: • Durability • Performance • Stability • Heat Rejection
ACPS Thruster Life Demonstration (Vendor Test)	Qual	Attitude Control Propulsion System (ACPS) Thrusters: • High Mode • Low Mode	Mission Duty Cycle Tests: • Sea Level Performance • Maintenance Procedures
Pressurization System Component Development	Devel	New/Modified Pressurization System Components: • Helium Tank • Pressure Regulator	Design Verification Tests: • Tank Proof/Burst/Cycling • Regulator Performance/ Cycling • Vibration

Table 3.5-3

MAJOR FACILITIES SUMMARY

REQUIREMENT	SPECIFICATIONS	EXISTING FACILITY
MANUFACTURING/ASSEMBLY/CHECKOUT		
• CORE STAGE + ADD-ON TANK FABRICATION AREA	UP TO 5 FT DIAMETER HARDWARE SIZE	LMSC BLDG. 103
• CARGO BAY SUPPORT STRUCTURE FABRICATION & ASSEMBLY AREA	HARDWARE SIZE 16 x 7 x 5 FT	LMSC BLDG. 159
• FINAL ASSEMBLY & CHECKOUT COMPLEX	COMPUTER CONTROLLED CHECKOUT; HARDWARE SIZE 13 x 16 x 30 FT.	LMSC BLDG. 104 OR BLDG. 156 HIGH-BAY AREAS
TEST		
• CAPTIVE FIRING STAND	16,000 LB THRUST, EARTH STORABLE PROPELLANTS	LMSC SANTA CRUZ TEST BASE COMPLEXES A&B
• SPACE SIMULATOR	13 FT DIA x 26 FT SPECIMEN SIZE	LMSC BLDG 156 CHAMBER A-1
• ACOUSTIC TEST CELL	13 x 16 x 30 FT SPECIMEN SIZE	LMSC BLDG. 156 REVERBERANT CHAMBER
LAUNCH AND REFURBISHMENT (EACH SITE)		(EXISTING KSC, CKAFS, VAFB FACILITIES)
• HYPERGOLIC PROPELLANT LOADING FACILITY	4,000 SQ FT INCL 2,000 SQ FT HIGH BAY WITH 50-TON CRANE	
• HYPERGOLIC VEHICLE FLUSHING FACILITY	6,400 SQ FT INCL 3,200 SQ FT HIGH BAY	
• REFURBISHMENT/INTEGRATION FACILITY	60,000 SQ FT SHOP 8,000 SQ FT OFFICE; 5-TON CRANE	
• LAUNCH PAD HYPERGOLIC OFFLOADING FACILITY	2 x 500 SQ FT AREA; 4,000 GAL. STEEL TANKS (2)	

Two computer-controlled high-bay areas are available at Sunnyvale for final assembly and checkout of the Shuttle/Agena vehicles; one is the existing Agena complex in Building 104 and the other is an area in Building 156 used for larger vehicles. For thermal/vacuum and acoustic testing of complete vehicles, both in the DDT&E phase and in the acceptance of flight articles, the Building 156 complex contains a large space simulator and a very large acoustic test cell. The vehicle can be captive fired (sea-level conditions) and cold-flow tested at the LMSC Santa Cruz Test Base. Existing buildings and stands at ETR and WTR are sufficient to meet the launch and refurbishment facility requirements of the Shuttle/Agena system.

In summary, all major Shuttle/Agena facility requirements can be met without any significant commitment to construction of facilities (C of F) expenditures.

3.5.3.2 GSE Plan. The plan for allocating GSE on the Shuttle/Agena program is to maintain only two sets of GSE hardware. One set will be permanently located at ETR.

The second set will be used at the Lockheed Sunnyvale plant until the fleet of 6 vehicles is accepted by the customer. This set will then be shipped to WTR for use when Shuttle/Agena operations are initiated there.

Table 3.5-4 lists the new items of GSE hardware that must be produced to support the Shuttle/Agena program. In general, new GSE is required only to handle the larger configuration (including its strap-on propellant tanks), to accommodate Orbiter interface equipment, and to check out new avionics hardware and interfaces. Existing Agena propellant/fluid servicing equipment, and core-stage handling and transport equipment will be used without significant modification.

3.5.4 Manufacturing and Acceptance Test Plan

The manufacturing and acceptance test procedures for the Shuttle/Agena Upper Stage are closely similar to those of the current Ascent Agena. Differences that arise are attributable to the hardware differences in the Shuttle/Agena system (e.g., the strap-on tanks and their attach mechanisms, and the Orbiter interface equipment). For the Shuttle/Agena it is planned to manufacture and acceptance test the fleet of six vehicles in a single block. Following customer acceptance, four vehicles will be shipped to ETR and the two for WTR will be stored in an appropriate facility at the Sunnyvale plant until initiation of Shuttle launches.

3.5.4.1 Manufacturing Plan. There are two major elements in the Shuttle/Agena system manufacturing plan: (1) the production of the Agena core stage, and (2) the production of Shuttle/Agena-peculiar hardware (i.e., strap-on tanks, CBSS) and final assembly of the system. The manufacturing plan for the Agena core stage, which is documented in Volume 8 of ref 2-1, is virtually identical to the manufacturing flow sequence for current Agena vehicles. The manufacturing plan for Shuttle/Agena-peculiar hardware, and for Shuttle/Agena vehicle assembly, is summarized in Fig. 3.5-5a and is described in the following paragraphs.

Table 3.5-4

NEW GSE SUMMARY

Item	Number Required	
	ETR	Factory / WTR
Transport/Handling Equipment		
Vehicle Assembly Stand	2	1
Vehicle Flushing Stand	2	1
Vehicle Hoist Frames/Slings	4	2
Vehicle Horizontal Transporter	2	1
Vehicle Vertical Transporter	2	1
Vehicle Handling Dolly	6	3
Strap-on Tank Handling Dolly	12	0
Strap-on Tank Hoist Sling	4	0
Strap-on Tank Hoist Fixture	6	0
CBSS Dolly	6	3
CBSS Sling	3	1
Protective Covers	6	6
Checkout Equipment		
CDC 3100 Computer System	1	0
Automatic Data Evaluation/Processing Set	1	0
Antenna System	1	1
Decommutator/Compressor	1	0
Remote Receivers	1	0
Remote CRT	1	0
IMU Position Rate Table	1	1
Interface Test Unit	1	1
Star Simulator	1	1
Horizon Sensor Target*	1	1
Automatic Data Set	1	1
System Test Set	1	1
Power Control Consoles	1	1
Agena Service Console Simulator	1	1
Orbiter Simulator	1	1
Payload Simulator	1	1

*Applies only to Augmented concept.

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- Strap-On-Tank Fabrication. The strap-on tank fabrication sequence is based on use of bulkhead spin-form tooling available at Precision Sheet Metal Division of Fansteel Corporation, Los Angeles, California. Tank bulkheads of the exact 46 in. (1.17 m) diameter required for the add-on tanks have been produced by Fansteel in 2219 aluminum alloy for use in LMSC technology development programs.

  These bulkheads are formed by hydraulically assisted spinning techniques. Heat from an oxy-acetylene flame is applied as necessary up to 300°F to improve the metal flow during forming. Subsequent to forming, the outside surface of the shells is machined to a constant wall thickness while still supported on the forming tool. Further membrane reductions and sculpturing can be accomplished by chemical milling methods, if required by the final design. To obtain optimum material properties, the shells are age-sized on a special fixture after they are received from the forming vendor.

  Cylinders for the strap-on tanks are rolled, trimmed, welded and then sized and aged to obtain matching properties with the dome sections.

  Weld assembly of the tank sections uses the TIG welding process. Welds are non-destructively tested by radiographic and penetrant-inspection techniques.

- Support Structures Fabrication. In parallel with the tank fabrication process, the support cones and struts used to attach the add-on tanks to the core stage are fabricated. These structures are manufactured using coordinated tooling to ensure that the tanks will be properly aligned.

- Final Assembly. The strap-on tanks and supports are brought together with the core stage, described earlier, and assembled into a complete vehicle. During the integration process the Cargo Bay Support Structure (CBSS) is used as an assembly fixture. The CBSS, produced on a separate assembly line, is of conventional aerospace tube-and-frame construction and offers no particular fabrication problems.

  After final assembly the vehicle is delivered to the systems checkout complex to begin a series of acceptance tests.

The 10-foot diameter single-tank Growth Stage version of Agena Upper Stage requires manufacturing procedures that differ from the building block concept just described. The steps peculiar to this configuration are illustrated in Fig. 3.5.5b.

The most important difference from the building block concept is in the fabrication of tank bulkheads. A manufacturing analysis of these bulkheads has resulted in the recommendation that these shells be produced using the double-action draw forming process. This process has been successfully demonstrated by Lockheed in experimental 2219 aluminum tanks ranging up to 110 in. diameter.

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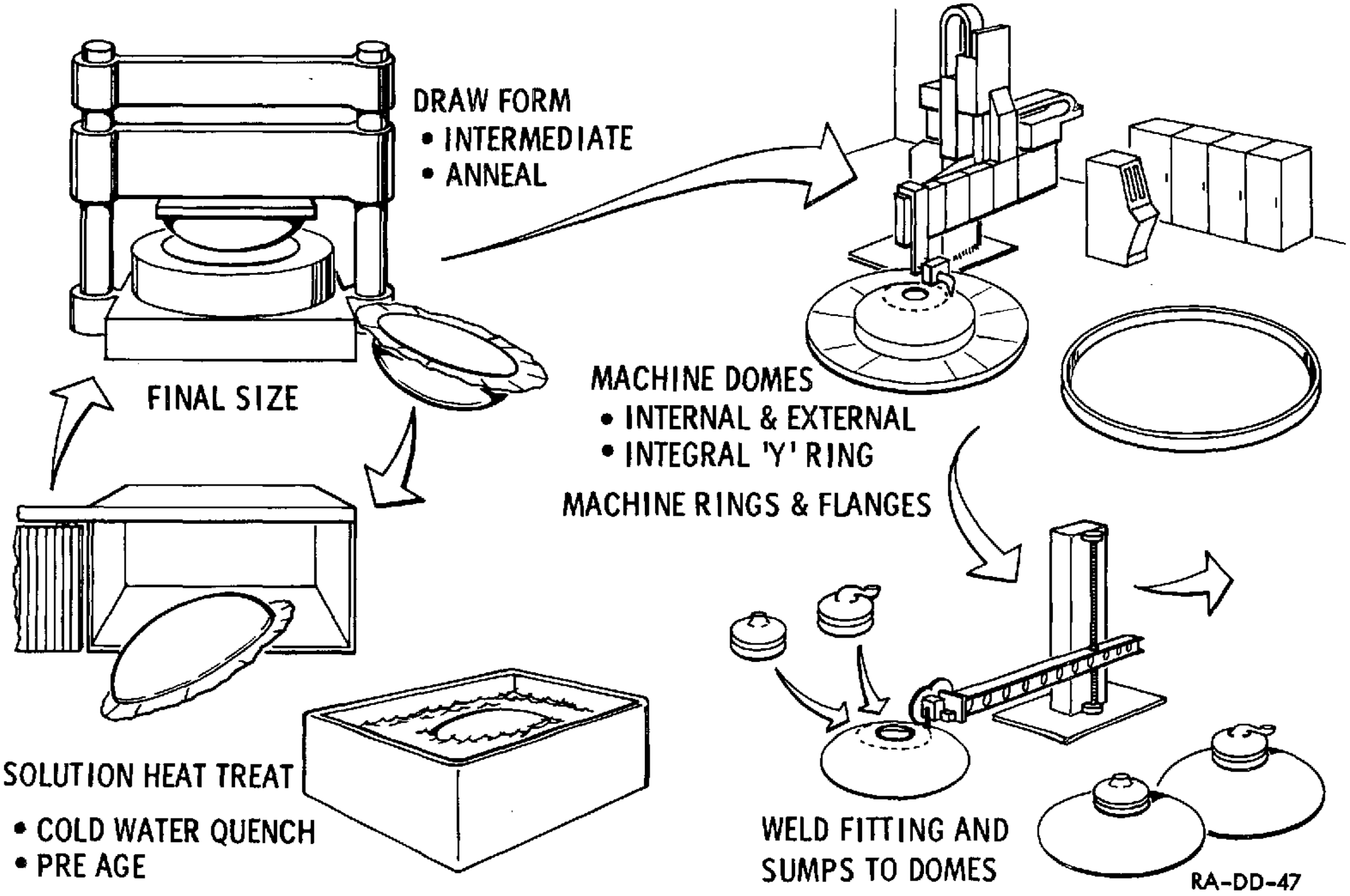

Fig. 3.5-5b (Part 1) Tank Fabrication

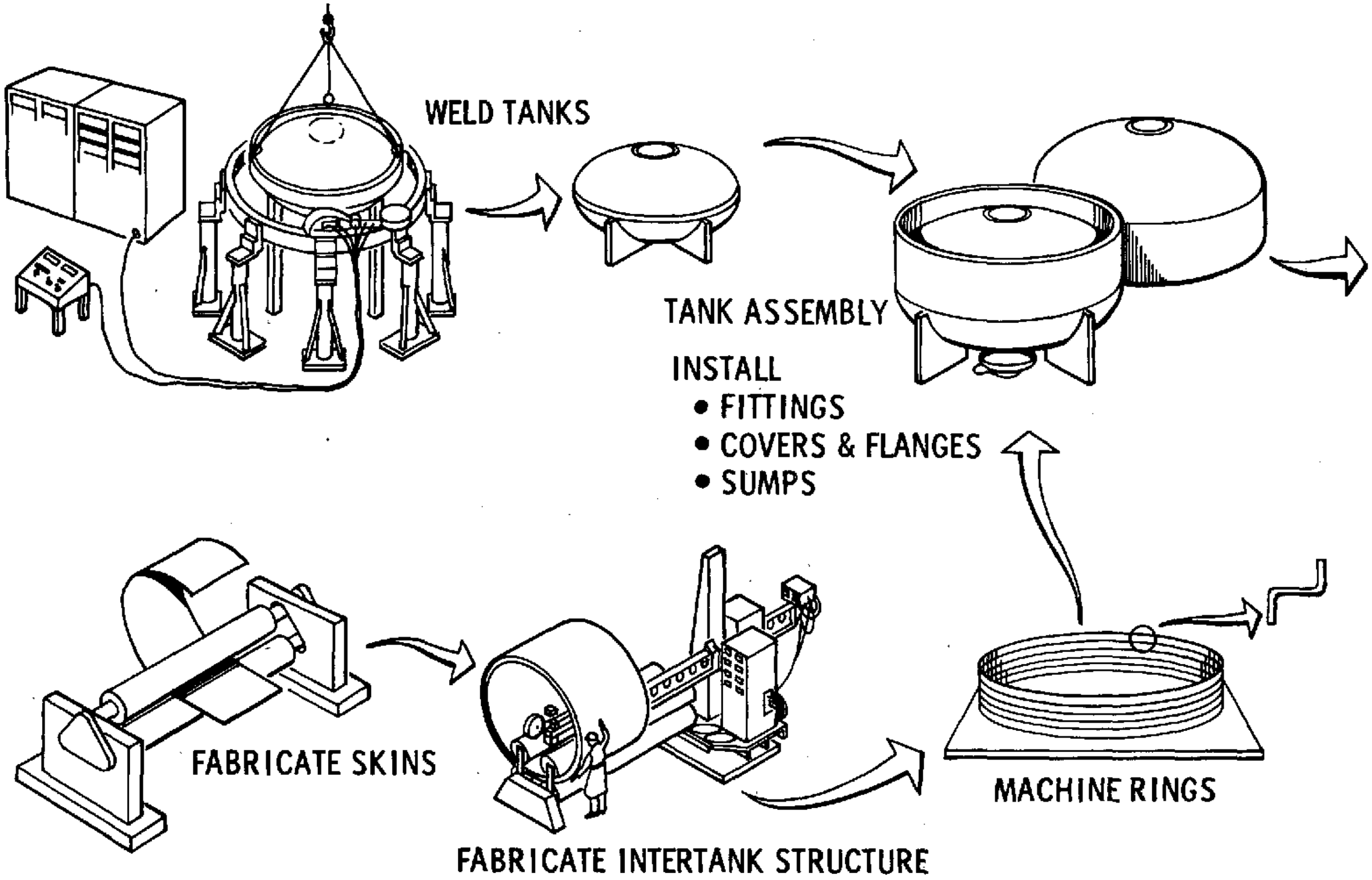

Fig. 3.5-5b (Part 2) Propellant Tank Assembly

The intertank structure draws on manufacturing concepts and tooling available from LMSC 10-foot diameter aerodynamic fairings. The forward equipment section is a modified existing structure, and the thrust cone and the aft equipment rack are likewise existing; hence no major tooling or processes are required for their manufacture.

The requirements for major items of new or modified tooling and manufacturing test equipment to support the Shuttle/Agena Upper Stage manufacturing plan are summarized in Tables 3.5-5 and 3.5-6 respectively. The tooling requirements for the building-block concept take advantage of existing Agena structures tooling for the core stage and the strap-on tanks. The Growth Stage uses existing tooling for the forward and aft equipment sections, and for the engine thrust structure.

Table 3.5-5

MAJOR NEW TOOLING REQUIREMENTS FOR AGENA UPPER STAGE

Item	Building Block (SOT Option)	Growth Stage
Tankage		
Bulkhead Forming Die	Existing	New
Bulkhead Age Size Tool	New	New
Bulkhead Machining Tool	N/A	New
Cylinder Sizing Shoes	New	N/A
Tank Welding Fixture	New	New
Intertank Adapter		
Cylinder Forming Tool	N/A	New
Adapter Welding Fixture	N/A	New
Vehicle Assembly		
Tank Handling Fixture	New	New
Adapter Handling Fixture	New	New
Assembly Fixture	New	New
Cargo Bay Support Structure		
Assembly Fixture	New	New

Table 3.5-6

ITEMS OF MANUFACTURING TEST EQUIPMENT FOR AGENA UPPER STAGE

Test Set	Building Block	Growth Stage
Command Data Processor	Modified	Modified
Controls Electronics Assy.	Modified	Modified
Inertial Measurement Unit	Modified	Modified
Omni Antenna	Modified	Modified
Directional Antenna	Modified	Modified
Power Distribution J-Box	Modified	Modified
Aft Control/Instrumentation J-Box	Modified	Modified
Wire Harness	New	New
Agena Control Panel	New	New

3.5.4.2 Acceptance Test. After final assembly, each vehicle produced for the Shuttle/Agena Upper Stage fleet will undergo a rigorous acceptance test. The testing sequence is illustrated in Fig. 3.5-6. This sequence, which is very similar to the acceptance tests now performed on all Ascent Agena vehicles, includes the following elements:

- A full systems test at ambient conditions
- An acoustic environment test on the complete vehicle
- A high-pressure test of the propulsion systems
- A thermal/vacuum environmental test of the complete vehicle
- A post-environmental-test systems checkout

3.5.5 Cost Data

The Shuttle/Agena Upper Stage features low cost across its complete life cycle, i.e., the DDT&E, production, and operations phases. DDT&E costs are low because the Shuttle/Agena takes advantage of inheritance both in design (from the existing Agena vehicle) and in subsystems hardware (from ongoing LMSC and collateral programs). The production costs are low because of simple stage design and use of earth-storable propellants. The operations costs are low because this vehicle exhibits high mission efficiency; that is, it can fulfill a mission model in a reusable delivery mode without jettisoning expensive hardware or using large numbers of kick stages.

The life cycle costs of the Augmented concept (dual-string avionics) and the Nominal concept may be summarized as follows:

	DDT&E	Production	Operations
Augmented Concept	\$52.5 M	\$57.8 M	\$83.8 M
Nominal Concept	\$49.7 M	\$53.3 M	\$81.0 M

The costs (and driving technical/schedule parameters) for the Augmented concept are summarized in Fig. 3.5-7; this figure is in the NASA stipulated format for Space Tug configuration cost-summary data. Peak total funding for both concepts is just over \$37 million in fiscal year 1980.

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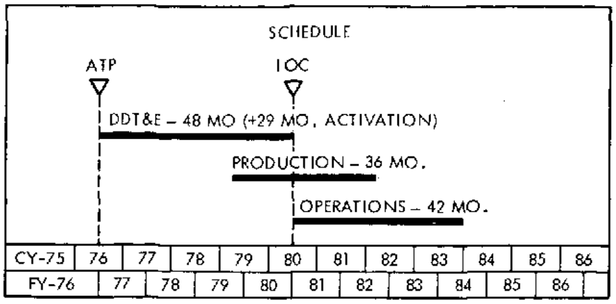
CHARACTERISTICS

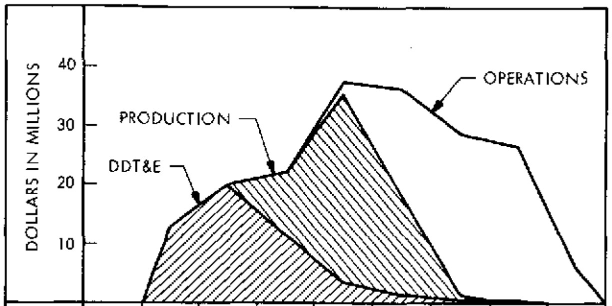
PHYSICAL

DRY WEIGHT	3134 LB
PROPELLANT LOADING	55,518 LB
MASS FRACTION	0.943
LENGTH	26.0 FT
DIAMETER	13.0 FT

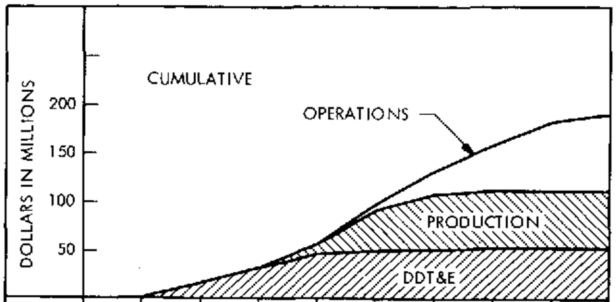
TECHNICAL

PROPELLANTS	HDA/MMH
THRUST	16,000 LB
I_{SP}	324 SEC
PAYLOAD MODE	DELIVERY (RETURN EMPTY)





FY	76	77	78	79	80	81	82	83	84
DDT&E		13.8	19.7	11.9	4.4	2.1	.5	.1	
PROD				10.7	31.2	13.9	2.0		
OPER					2.2	21.0	26.7	27.5	6.7
TOTAL		13.8	19.7	22.6	37.8	37.0	29.2	27.6	6.7



FY	76	77	78	79	80	81	82	83	84
DDT&E		13.8	33.5	45.4	49.8	51.9	52.4	52.5	52.5
PROD				10.7	41.9	55.8	57.8	57.8	57.8
OPER					2.2	23.2	49.9	77.4	84.1
TOTAL		13.8	33.5	56.1	93.9	130.9	160.1	187.7	194.4

Augmented Concept

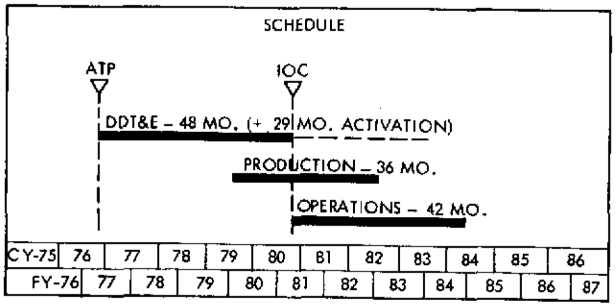
CHARACTERISTICS

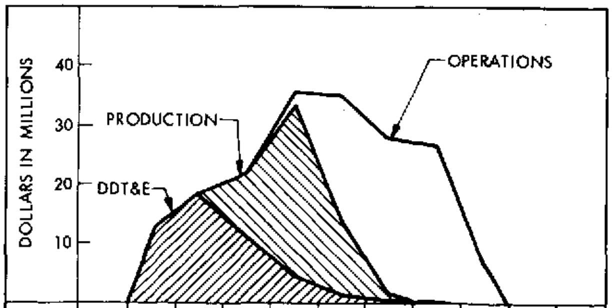
PHYSICAL

DRY WEIGHT	2,912 LB
PROPELLANT LOADING	55,519 LB
MASS FRACTION	0.946
LENGTH	26.0 FT
DIAMETER	13.0 FT

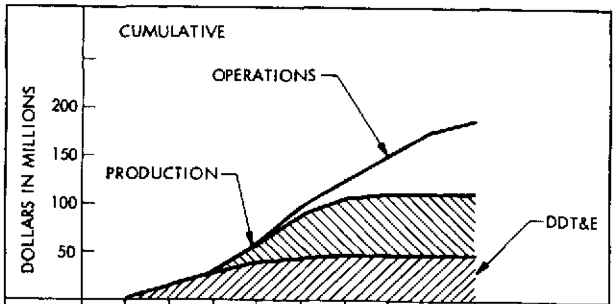
TECHNICAL

PROPELLANTS	HDA/MMH
THRUST	16,000 LB
I_{SP}	324 SEC
PAYLOAD MODE	DELIVERY (RETURN EMPTY)





FY	76	77	78	79	80	81	82	83	84	85	86
DDTE		12.7	18.4	11.6	4.3	2.1	.5	.1			
PROD				9.9	28.7	12.8	1.9				
OPER					2.2	20.1	25.7	26.6	6.7		
TOTAL		12.7	18.4	21.5	35.2	35.0	28.1	26.7	6.7		



FY	76	77	78	79	80	81	82	83	84	85	86	90
DDTE		12.7	31.1	42.7	47.0	49.1	49.6	49.7	49.7			
PROD				9.9	38.6	51.4	53.3	53.3	53.3			
OPER					2.2	22.3	48.0	74.6	81.3			
TOTAL		12.7	31.1	52.6	87.8	122.8	150.9	177.6	184.3			

Nominal Concept

Fig. 3.5-7 Cost Data Summary

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The following paragraphs contain a discussion of the costing approach and present details of the estimates derived for the various Shuttle/Agena concepts.

3.5.5.1 Costing Approach. The methodology used to cost the Shuttle/Agena program (Fig. 3.5-8) was a bottom-up approach, as contrasted to parametric or top-down estimating techniques. Detailed costs were generated against a NASA-supplied work breakdown structure (WBS). Element-of-cost inputs (e.g., labor hours, material/subcontract dollars) were generated at the lowest levels of the WBS, converted to dollars, and summed upward by levels. The LMSC computer program DBANK was used to sum the costs; to accurately apply labor rates, burdens, etc.; and to calculate the proper levels of support services (QA, planning). Sources of the input estimates were time-phased manloadings generated by the line engineering, manufacturing, and test organizations; manpower and material records from the Agena and other current LMSC space vehicle programs; and labor hour breakdowns from analogous historical programs. Cross checks were made between the derived estimates and the historical data base to ensure consistency and credibility.

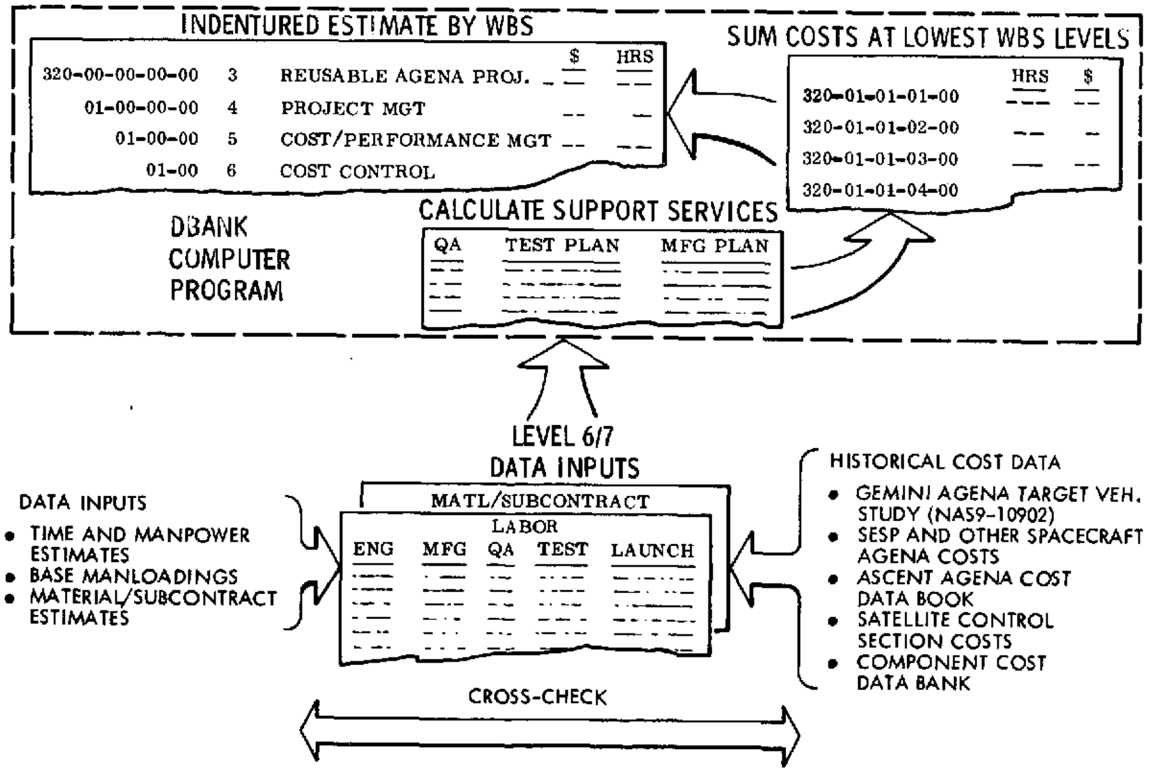


Fig. 3.5-8 Costing Methodology

General guidelines and assumptions used in generating the cost estimates were as follows:

- The costs were calculated in dollars of 1973 value, and the labor/overhead rates used to calculate these costs are typical of calendar year 1973.
- Prime contractor fee was excluded.
- Costs paid entirely by the Government, and hence outside of the LMSC cost data base, were omitted. These include costs of facility ownership (e.g., operation and maintenance of the tracking network, the launch base, and the mission control center), and Government program management.
- Costs for shared activities, such as direct charges for Shuttle/Agena mission control crews, were included. In these cases, the total costs were included, i.e., there was no prorating between contractor and Government crews.

3.5.5.2 DDT&E Costs. Costs for the Design, Development, Test, and Evaluation (DDT&E) phase of the Shuttle/Agena program are estimated at $52.5 million for the Augmented concept, and $49.7 million for the Nominal concept. These costs represent a high-inheritance program that incorporates the ground test program exactly as shown in par. 3.5.2. This DDT&E program is assumed to make maximum use of existing facilities and GSE, to be manned for maximum efficiency (i.e., small project office with assistance on call from the discipline groups), and assumes Agena launches at both KSC and VAFB.

The breakdown of Shuttle/Agena program DDT&E costs is presented in Fig. 3.5-9; on this chart and all subsequent cost breakdown displays, the costs for the Nominal concept are presented in parentheses below the Augmented-concept values. Major elements of the DDT&E cost are defined as follows:

- Project Management. The cost to sustain a project office for the duration of the development portion of the DDT&E program (through third quarter of 1979). This cost element covers technical direction and data management/documentation functions. No costs are included in this item for cost and performance management as these functions are performed by indirect employees.
- Systems Engineering and Integration. The costs for vehicle-system-level analysis, design, integration, and planning; product effectiveness activities (reliability, safety); and control of external interfaces.
- Vehicle Main Stage. The costs for design, analysis, tooling, and testing at the subsystem and lower levels.

SHUTTLE/AGENA PROJECT
52.451
(49.733)

PROJECT MANAGEMENT	SYSTEMS ENGINEERING/ INTEGRATION	VEHICLE MAIN STAGE	LOGISTICS	FACILITIES	GSE	VEHICLE TEST	FLIGHT OPERATIONS, DOD	FLIGHT OPERATIONS, NASA
1.146	4.234 (4.022)	26.895 (24.629)	1.078	0.587	5.704	6.355 (6.115)	0.412	6.040
Cost/Performance Management (Indirect) Project Direction 0.926 Information Management 0.220	Vehicle Systems Engineering Overall Veh. Anal. & Des 1.425 (1.347) Configuration Management 0.285 Reliability/Quality 0.671 (0.537) Safety 0.427 Test Planning 0.715 Mfg. Plans/Services 0.440 Shuttle Interface 0.171 Payload Interface 0.100	Structures 2.042 (1.643) Thermal Control 0.302 Avionics 10.118 (9.469) Propulsion 8.558 (7.940) Orbiter Interface 2.490 Auxiliary Tanks 2.683 Final Assembly/Checkout 0.102	Training Simulators/Equipment 0.175 Ground Crew Tng. 0.673 NASA Flight Ops. Crew Tng. 0.115 DoD Flight Ops. Crew Tng. 0.115	ETR Maint./Refurb 0.197 ETR Launch 0.142 WTR Maint./Refurb. 0.144 WTR Launch 0.104	Manufacturing GSE Site Activation 0.252 Software 0.089 ETR GSE Hardware 2.581 Site Activation 0.840 Maintenance 0.084 Software 0.237 WTR GSE Hardware 1.148 Site Activation 0.329 Maintenance 0.084 Software 0.059	Ground Test Hardware Propulsion Test Vehicle 2.171 (2.089) Structural Test Article 0.520 Qualification Test Vehicle 0.393 Mockup 0.152 Ground Test Operations Propulsion Test Operations 1.113 Structural Test Operations 1.572 (1.414) Qualification Test Operations 0.434	Flight Support Software Vehicle Software 0.0 Mission Control Software 0.412	Flight Support Software Vehicle Software 5.628 Mission Control Software 0.412

NOTE: Nominal-Concept Costs in Parentheses

BY SUBDIVISIONS OF WORK	
Engineering	10.8
Manufacturing	4.2
Tooling/STE	2.1
Reliability/QA	0.7
Test (Hardware & Opns.)	13.8
Management/Other	4.4
Software	6.8
Component Development (Vendor)	9.7

Fig. 3.5-9 DDT&E Cost Breakdown ($ Millions)

- Logistics. As applied to the DDT&E phase, this entry covers only training of ground and mission control crews.
- Facilities. The costs to modify and activate existing launch base facilities for service with the Shuttle/Agena program.
- GSE. The cost to design and build new GSE hardware, to modify existing GSE, to activate the GSE on site, and to generate Shuttle/Agena peculiar ground checkout software.
- Vehicle Test. Costs for testing conducted at a total vehicle level, such as that performed with the PTV and the QTV. This item covers both the fabrication of test hardware and the actual test operations (including propellants and gases as required).
- Flight Operations (DoD and NASA). For the DDT&E phase, these entries cover only the generation of software to support Shuttle/Agena operations. Two types of software are included: (1) vehicle software to operate the onboard guidance and data management systems, and (2) mission control software to permit ground control of the Shuttle/Agena in flight. Vehicle software is charged to NASA Flight Operations because the first Shuttle/Agena flights are NASA missions.

For greater visibility into the DDT&E costs, a breakdown to WBS level 7 of the vehicle main stage costs is presented in Fig. 3.5-10. This figure identifies the costs for development of the Shuttle/Agena vehicle subsystems and the Orbiter Interface Equipment.

If the Shuttle/Agena Upper Stage is developed by the Air Force, then the nonrecurring costs to NASA for first use of this system are estimated as follows:

Mission Control Software	$1.030 M
Mission Control Crew Training	$0.115 M
	$1.145 M

All of these costs are already incorporated into the DDT&E cost estimate quoted above.

The funding requirements of the DDT&E program are displayed in Fig. 3.5-11. The peak funding for both the Augmented and Nominal concepts is just under $20 million in fiscal year 1978; the DDT&E phase funding requirement extends through fiscal year 1983 because of one-time activation costs at WTR.

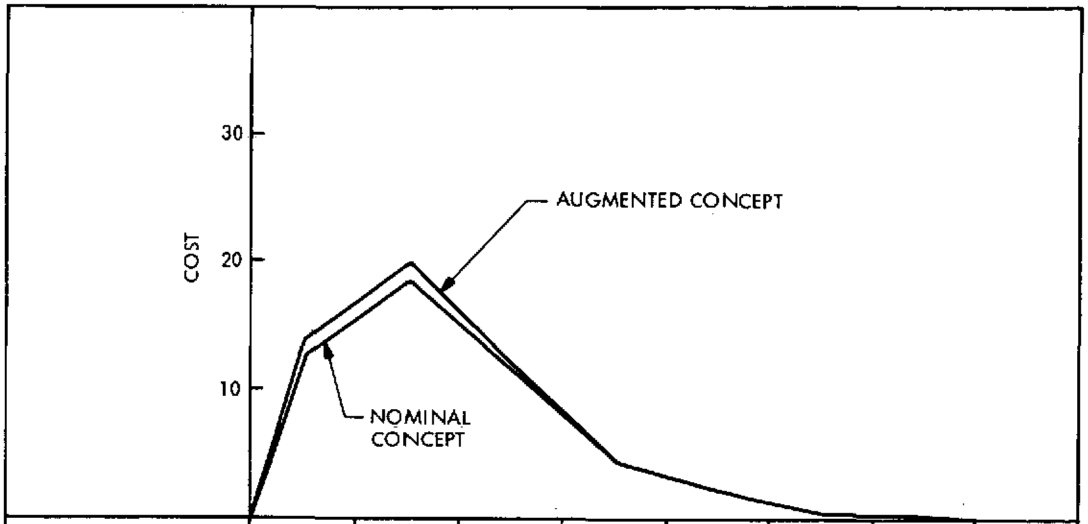
VEHICLE MAIN STAGE

26.895
(24.629)

STRUCTURES (CORE)	THERMAL CONTROL	AVIONICS		PROPULSION	ORBITER INTERFACE	AUXILIARY TANKS	FINAL ASSY/ CHECKOUT
2.042 (1.643)	0.302	10.718 (9.469)		8.558 (7.940)	2.490	2.683	0.102
Tankage 0.342 (0.171) Body Structure 0.174 Thrust Structure 0.338 Subsystem Engrg. 0.601 Structures Test (Subsystem Level) 0.485 (0.339) Structures Tooling 0.102 (0.020)	Subsystem Engrg 0.227 Thermal Control Test 0.075	Data Management Command Data Processor 0.209 Computer 0.515 Computer Interface Unit 0.557 System Engrg. 0.067 Test 1.862 Tooling/STE 0.097 Guidance/Navigation Inertial Meas. Unit 0.412 Controls Electronics Assy 0.446 Horizon Sensor 0.515 (0.0) Star Tracker 0.361 BUSS Electronics Assy 0.0 (0.175) Sys. Engrg 0.081 Test 2.651 (1.595) Tooling/STE 0.138	Communications Transponder 0.103 Sys. Engrg. 0.119 Test 0.471 (0.365) Tooling/STE 0.021 Instrumentation 0.110 Electrical Power Type 1902 Battery 0.103 Power Distribution/ Control Power Dist J-Box 0.124 Aft Control/ Instrum. J-Box 0.275 Elec. Harness 0.294 BUSS J-Box 0.0 (0.175) Sys. Engrg 0.094 Test 0.311 (0.389) Tooling/STE 0.152 Subsystem Engrg 0.194 Subsystem Lev Test 0.136	Main Engine 5.500 Main Engine Support Vent Valves 0.046 Helium Sphere 0.824 Helium Valve 0.052 Helium Regulator 0.283 ACPS Engines Low Mode Thrusters 0.618 (0.000) High Mode Thrusters 0.309 ACPS Engine Support Propellant Tank 0.031 Subsystem Engrg 0.854 Subsystem Level Test 0.041	Structures 0.465 Interface Panels 0.290 Test 0.036 Tooling/STE 0.799	Structures 0.345 Thermal Control 0.419 Propellant Support System 0.831 Test 0.390 Tooling 0.692	Assembly Tooling 0.102

NOTE: Nominal – Concept Costs in Parentheses

Fig. 3.5-10 Vehicle DDT&E Cost Details
($ Millions)



FISCAL YEAR		77	78	79	80	81	82	83	84
COST	AUGMENTED CONCEPT	13.8	19.7	11.9	4.4	2.1	.5	.1	
	NOMINAL CONCEPT	12.7	18.4	11.6	4.3	2.1	.5	.1	

Fig. 3.5-11 DDT&E Funding Requirements by Year ($ Millions)

3.5.5.3 Production Costs. The production (investment) phase costs are estimated at $57.8 million for the Augmented concept and $53.3 million for the Nominal concept. A breakdown of these sums is presented in Fig. 3.5-12. The average unit cost for a Shuttle/Agena Upper Stage vehicle, exclusive of Orbiter Interface hardware, is roughly $7 million.

Major elements that make up the production costs are as follows:

- Project Management. Costs to sustain a project office for the duration of the production phase.
- Systems Engineering/Integration. Costs for sustaining engineering at the vehicle system level; for quality and reliability record keeping; for configuration management during the production phase; and for test and manufacturing planning.
- Vehicle Main Stage. The costs to build a fleet of six Shuttle/Agena vehicles and four sets of Orbiter interface equipment.
- Logistics. The costs for spares provisioning and inventory control during the acquisition of initial spares for the Shuttle/Agena fleet.
- Spares (Vehicle and GSE). The costs for acquisition of spares sufficient to support Shuttle/Agena operation during the first year; the value of these initial spares is calculated as one-quarter of the total four-year spares.

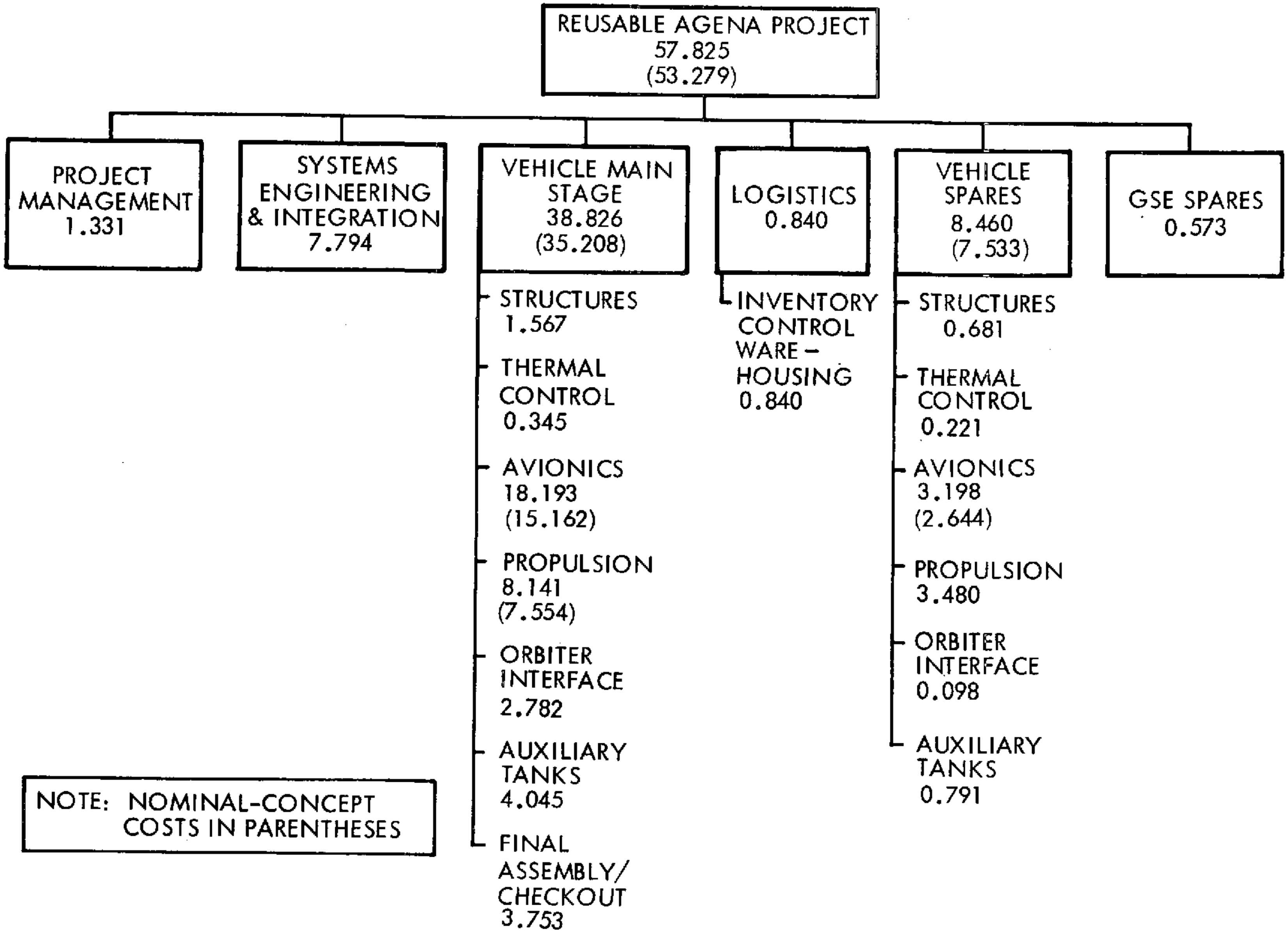


Fig. 3.5-12 Production (Investment) Cost Breakdown ($ Millions)

- REUSABLE AGENA VEHICLE 7.349 (6.762)
  - PROJECT MANAGEMENT 0.222
  - SYSTEMS ENGINEERING/INTEGRATION 1.135
  - VEHICLE MAIN STAGE 5.992 (5.405)
    - STRUCTURES 0.261
      - Propellant Tank (Core) 0.084
      - Body Structure 0.101
      - Thrust Structure 0.048
      - Subsystem Engrg. 0.028
    - THERMAL CONTROL 0.058
    - AVIONICS 3.032 (2.527)
      - Data Management
        - Command Data Processors 0.154
        - Computer 0.515
        - Computer Interface Unit 0.125
        - System Engrg. 0.108
      - Guidance/Navigation
        - IMU 0.618 (0.309)
        - Controls Electronics Assy. 0.071
        - Horizon Sensor 0.206 (0.0)
        - Star Tracker 0.257
        - BUSS Electronics Assy 0.0 (0.034)
        - Magnetometer 0.0 (0.014)
        - Rate Gyros 0.0 (0.042)
        - System Engrg. 0.145
      - Communications
        - Transponders 0.227
        - Antennas 0.114 (0.008)
        - Signal Control Equipment 0.023
        - System Engrg. 0.067
      - Instrumentation 0.110
      - Electrical Power
        - Type 1902 Battery 0.019
        - Type IVB Battery 0.006
      - Power Distribution and Control
        - Pwr Dist. J-Box 0.025
        - Aft Control/Instrum. J-Box 0.011
        - BUSS J-Box 0.0 (0.026)
        - Electrical Harness 0.104
        - System Engrg. 0.073
      - Subsystem Engrg. 0.054
    - PROPULSION 1.341 (1.259)
      - Main Engine 0.482
      - Main Engine Support
        - Feed/Fill/Drain/Pressurization 0.344
        - Hydraulic TVC 0.046
      - ACPS Engines
        - Low Mode Thrusters 0.082 (0.0)
        - High Mode Thrusters 0.130
      - ACPS Engine Support 0.074
      - Installation/Assembly/Checkout 0.049
      - Subsystem Engrg. 0.134
    - AUXILIARY TANKS 0.674
      - Structures 0.252
      - Thermal Control 0.069
      - Propellant Support System 0.314
      - Installation/Assy/Checkout 0.039
    - FINAL ASSEMBLY AND CHECKOUT 0.626
      - Final Assembly 0.250
      - Acceptance Test 0.375

NOTE: Nominal-Concept Costs in Parentheses

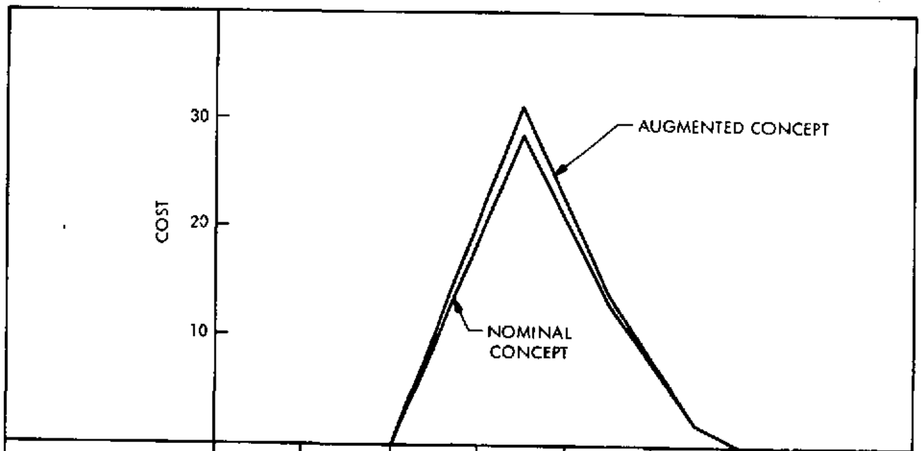
Fig. 3.5-13 Average Vehicle Cost Breakdown
($ Millions)

For greater visibility into the production costs, a WBS level 7 breakdown of average Shuttle/Agena vehicle unit costs is presented in Fig. 3.5-13. The quoted costs are for one unit from a block buy of six vehicles. The costs exclude Orbiter interface equipment. These costs are more than 50 percent higher than current Ascent Agena costs; the increase is due to stage-recovery avionics and the strap-on-tank system.

A funding requirements distribution for the production phase is presented as Fig. 3.5.14. These costs peak at about $30 million in fiscal year 1980.

3.5.5.4 Operations Costs. The cost for four calendar years of operation with the Shuttle/Agena system (93 flights 1980-1983) is $84.1 million with the Augmented concept and $81.3 million with the Nominal concept. All flights from WTR use the core stage alone; strap-on tanks are used at ETR. A breakdown of these costs is presented in Fig. 3.5-15. Major elements making up the operations costs are as follows:

- Program Management. The costs to maintain a project office at the home plant of the contractor during the operations phase.
- Systems Engineering/Integration. Home plant costs for sustaining engineering at the vehicle system level, and for quality/reliability record keeping during the operations phase.
- Vehicle Main Stage. Costs for home plant sustaining engineering at the subsystem level over the operations phase.



FISCAL YEAR		77	78	79	80	81	82	83	84
COST	AUGMENTED CONCEPT			10.7	31.2	13.9	2.0		
	NOMINAL CONCEPT			9.9	28.7	12.8	1.9		

Fig. 3.5-14 Production Funding Requirements by Year ($ Millions)

- Logistics. Home plant costs for inventory control and warehousing of the operations-phase spares.
- Ground Support Equipment. Launch base costs for maintenance of GSE during the operations phase.
- Launch Operations (ETR and WTR). The costs to prepare and launch a refurbished Shuttle/Agena vehicle. This entry includes all prelaunch mating and checkout activities, propellants and gases, and countdown activities of the Shuttle/Agena crew. It also includes post flight safing and all launch base management/administrative support services. It specifically excludes costs for Shuttle launch operations activities.
- Flight Operations (NASA and DoD). The costs for ground based operation of the Shuttle/Agena in orbit. This item includes flight control crew preparation, mission control activities, and post-flight evaluation. It also includes the generation of flight-to-flight software including vehicle guidance equations and mission-control software. It excludes costs for flight control of the Shuttle and first-of-a-kind charges for new missions with the Shuttle/Agena.
- Refurbishment and Integration (ETR and WTR). Costs for scheduled and unscheduled maintenance of the returned Agena vehicle, and for post-maintenance checkout, payload mating, and refurbishment planning. This entry also includes depot level maintenance, discussed subsequently.
- Spares (Vehicle and GSE). The spares required to support the Shuttle/Agena system for scheduled and unscheduled maintenance.

The manpower loadings, at each base, that support these costs are presented in Table 3.8.1-4, paragraph 3.8.1. This paragraph also discusses the underlying maintenance/refurbishment philosophy.

Important assumptions that were made in developing the operations costs concern depot-level maintenance and spares provisioning. The approach to calculating depot-level maintenance costs was as follows:

- Only high-value components were selected for depot-level servicing major (i.e., major avionics, main engine);
- It was assumed that each unit could be serviced just once and that, after maintenance, the extra lifetime in a component would be equal to its original design value (for example the main engine, with a design life of 3 flights, could be used on 3 additional missions after depot maintenance – for a total lifetime of 6 flights);
- The assumed cost to refurbish any component was 25 percent of its average unit price. This is consistent with payload refurbishment study results.

The spares requirements were calculated using the following expression:

$$\text{Total Spares } \$ = \sum_{i=1}^{n} \left(\frac{C_i}{L_i}\right) N_f$$

where

C_i = average unit production cost of the ith Shuttle/Agena component

L_i = average number of flights between scheduled replacement of the ith component

N_f = total number of applicable flights in the mission model.

The above expression calculates a level of spares that is higher than scheduled-maintenance requirements (by the lifetime of hardware on the initial vehicle fleet). This margin of conservatism is more than adequate to allow for any spares required as a result of unscheduled maintenance.

The total-spares dollar value calculated above was allocated between the investment (production) and operations phases. The investment phase was charged with spares to support the first year operation; the remainder of the spares were charged to the operations phase.

For greater visibility into the operations costs, the cost-per-flight of the Shuttle/Agena system was calculated in the NASA-specified reporting format (Table 3.5-6). The values in this table represent an average across 93 flights in the nominal 4-year mission model. This average is undifferentiated with respect to ETR versus WTR or NASA versus DoD missions. The average cost per flight of roughly $900,000 is consistent with current Agena expence when extrapolated to the high launch rates of the Shuttle era (i.e., greater than 20 flights/year).

The funding requirements for the Shuttle/Agena system are displayed in Fig. 3.5-16. The operations costs peak just over $25 million in fiscal years 1982 and 1983.

Table 3.5-6

AVERAGE COST PER FLIGHT
(ETR AND WTR)

MODE: SHUTTLE/AGENA UPPER STAGE VEHICLE ONLY – RETURNED FOR REUSE

Launch Operations		$133,063
Agena Upper Stage/Shuttle mating/checkout	$ 15,871	
Agena Upper Stage/Payload mating and checkout	4,365	
Prelaunch checkout	15,860	
Countdown	7,925	
Propellant and gases	59,225	
Post flight safing	2,710	
Site services and support	27,107	
Maintenance and Refurbishment		$420,470
Scheduled maintenance and refurb	$ 74,531	
Unscheduled maint. and refurb.	14,774	
Agena Upper stage spares	212,665	
Engine maint. and refurb.	1,683	
Engine spares	60,247	
Post maintenance checkout	13,097	
Refurb. requirements planning	3,538	
Depot maintenance	39,935	
TOTAL GROUND OPERATIONS (Launch and Maintenance/Refurbishment)		$553,533
Flight Operations		$150,891
Mission planning	$ 3,613	
Flight control	39,817	
Flight evaluation	5,430	
Flight software	102,031	
Operations Support		$199,504
GSE maintenance (including spares)	27,537	
Sustaining engineering	125,784	
Program management	15,753	
Transportation and handling	3,333	
Inventory control and warehousing	27,097	
Facilities maintenance	–	
TOTAL AVERAGE PER FLIGHT COST		$903,928*

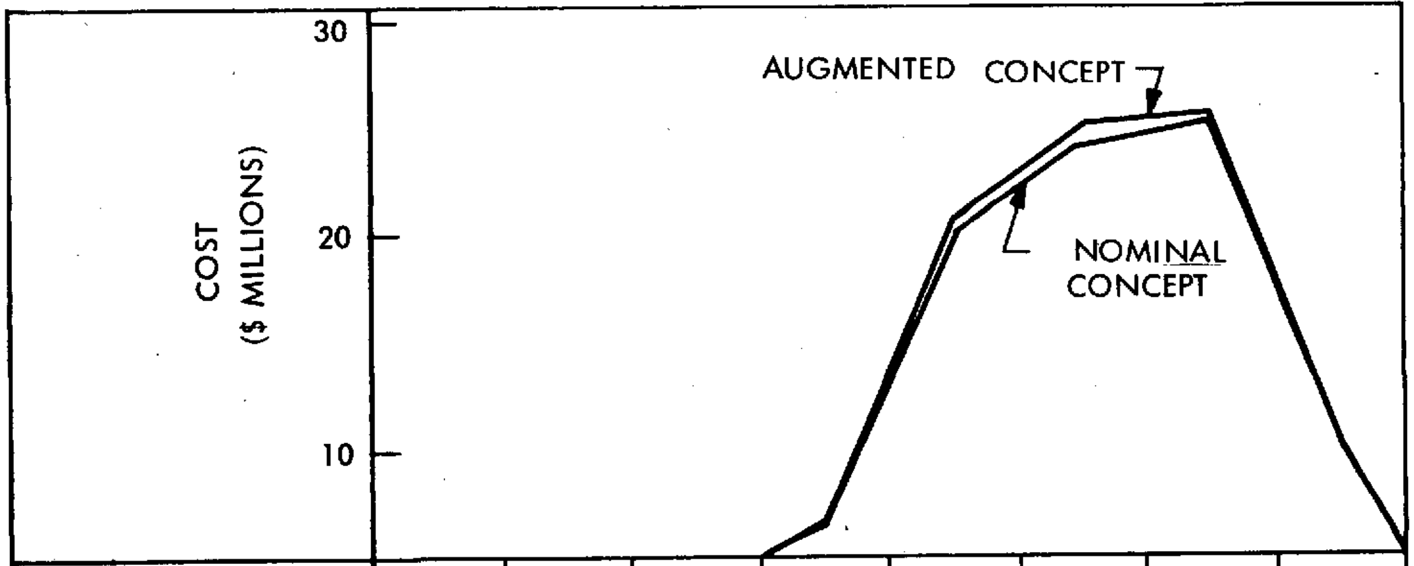
*Augmented concept; Nominal concept cost/flight is $874,170

SHUTTLE/AGENA PROJECT
84.066
(81.289)

PROJECT MANAGEMENT	SYSTEM ENGINEERING/ INTEGRATION	VEHICLE MAIN STAGE	LOGISTICS	GROUND SUPPORT EQUIPMENT	LAUNCH OPERATIONS, WTR	LAUNCH OPERATIONS, ETR	FLIGHT OPERATIONS, DOD	FLIGHT OPERATIONS, NASA	REFURBISHMENT & INTEGRATION, ETR	REFURBISHMENT & INTEGRATION, WTR	SPARES, MAIN STAGE	SPARES, GSE
1.465	5.033	6.665	2.830	0.267	1.385	10.584	5.871	8.162	11.683	2.446	25.381 (22.604)	2.294
		Structures 0.538 Thermal Control 0.266 Avionics 2.664 Propulsion 1.332 Orbiter Interface 0.799 Auxiliary Tanks 1.066			Launch Site Services/Spt. 0.454 Tug/Shuttle Mate & C/O 0.247 Prelaunch Checkout 0.247 Countdown 0.123 Propellants and Gases 0.272 Post-Flight Safing 0.042	Launch Site Services/Spt. 2.067 Tug/Shuttle Mate & C/O 1.228 Prelaunch Checkout 1.229 Countdown 0.614 Propellants and Gases 5.236 Post-Flight Safing 0.210	Mission Planning 0.140 Flight Control 1.543 Flight Evaluation 0.210 Flight Spt. Software 3.978 Vehicle Software 3.768 Mission Control Software 0.210	Mission Planning 0.196 Flight Control 2.160 Flight Evaluation 0.295 Flight Spt Software 5.511 Vehicle Software 5.217 Mission Control Software 0.294	Scheduled Maint/Refurb 5.856 Unscheduled Maint/Refurb 1.138 Post-Maint. Checkout 1.006 Tug/Payload Mate & C/O 0.335 Refurb. Planning 0.273 Depot Maint. 3.075	Scheduled Maint/Refurb 1.232 Unscheduled Maint/Refurb 0.236 Post-Maint Checkout 0.212 Tug/Payload Mate & C/O 0.071 Refurb. Planning 0.056 Depot Maint. 0.639	Spares, Structures 2.043 Spares, Thermal Cont. 0.663 Spares, Avionics 9.566 (7.933) Spares, Propulsion 10.440 (9.296) Spares, Orbiter I/F 0.295 Spares, Aux. Tks. 2.374	

NOTE: Nominal-Concept Costs in Parentheses

Fig. 3.5-15 Operations Cost Breakdown
($ Millions)



FISCAL YEAR		77	78	79	80	81	82	83	84
COST	AUGMENTED CONCEPT				2.2	21.0	26.7	27.5	6.7
	NOMINAL CONCEPT				2.2	20.1	25.7	26.6	6.7

Fig. 3.5-16 Shuttle/Agena Upper Stage Operations Funding Requirements By Year

3.6 SAFETY AND EMERGENCY DUMP

3.6.1 Safety

3.6.1.1 Scope and Approach. Safety was an area of constant attention throughout the Shuttle/Agena Upper Stage study. Design changes and operational changes were identified and implemented as the study progressed to preclude hazards to manned safety. The resulting configurations and operational sequences were subjected to a safety analysis as indicated in Fig. 3.6.1-1.

The analysis approach was to:

1. Develop or accept event sequences for all normal operations and for Shuttle abort.
2. Identify critical areas of concern and develop failure mode diagrams.
3. Analyze each step in each sequence of events to identify potential hazards, identify the probable effects of each hazard, and develop preventive and corrective/remedial measures.
4. Analyze safety of contingency operations and of potential nonoperational events, identify potential hazards, describe the potential effects of such hazards, and develop preventive and corrective remedial measures.

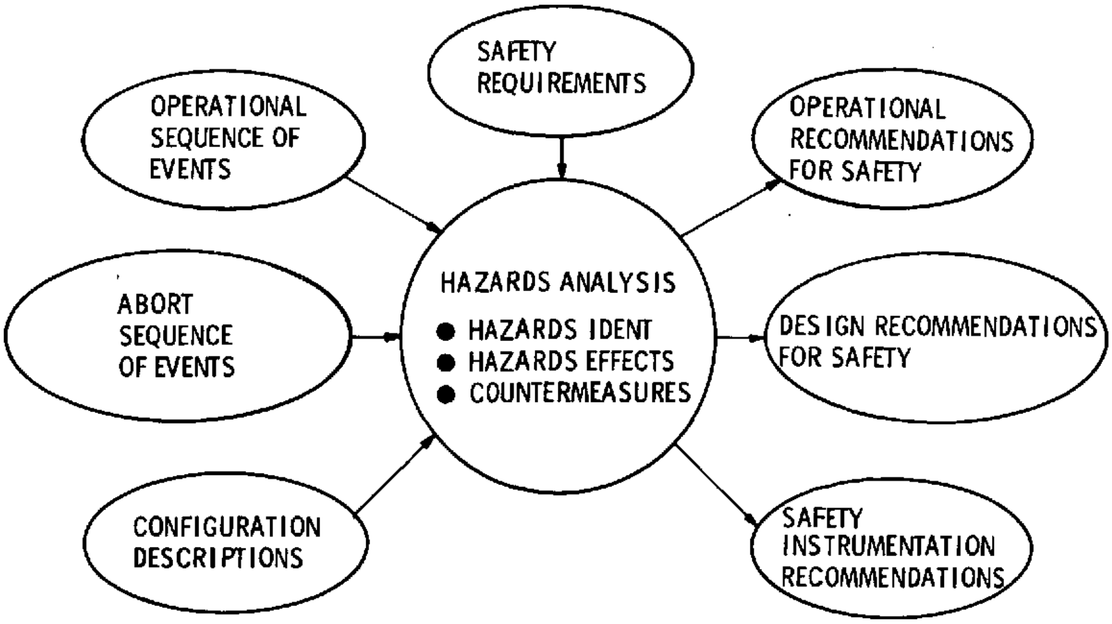


Fig. 3.6.1-1 Safety Analysis Approach

5. Identify the impact of significant safety requirements on Agena, support system, and Orbiter interface
6. Establish safety instrumentation, warning devices, and monitoring procedures.

The principal safety concerns addressed by the study were:

1. The presence and handling of high energy, toxic, corrosive, hypergolic propellants.
2. Presence of high pressure helium gas.
3. Large masses being maneuvered and transported.
4. Verification of system integrity between uses.

The system safety criteria observed for the study were as presented in ref 3-9.

3.6.1.2 Hazard Diagrams and Analyses. The general areas of concern are fire, explosion, collision, contamination, and toxicity. These areas are displayed in hazard diagrams in Fig. 3.6.1-2 (Fire/Explosion), 3.6.1-3 (Collision), and 3.6.1-4 (Contamination/Toxicity).

Results of analyses of the hazard diagrams are presented in Tables 3.6.1-1, 3.6.1-2, and 3.6.1-3. A description of each potential hazard and proposed counteraction is included in the tables.

3.6.1.3 Normal Sequence of Events Hazards Analyses. The sequence of events for normal operations on the ground, during deployment, during Agena operation on orbit, and during retrieval are presented in Tables 3.6.1-4, 3.6.1-5, 3.6.1-6, and 3.6.1-7 respectively. Accompanying the description of each event as an identification of potential hazards and a description of proposed counteraction to eliminate or cope with the hazard.

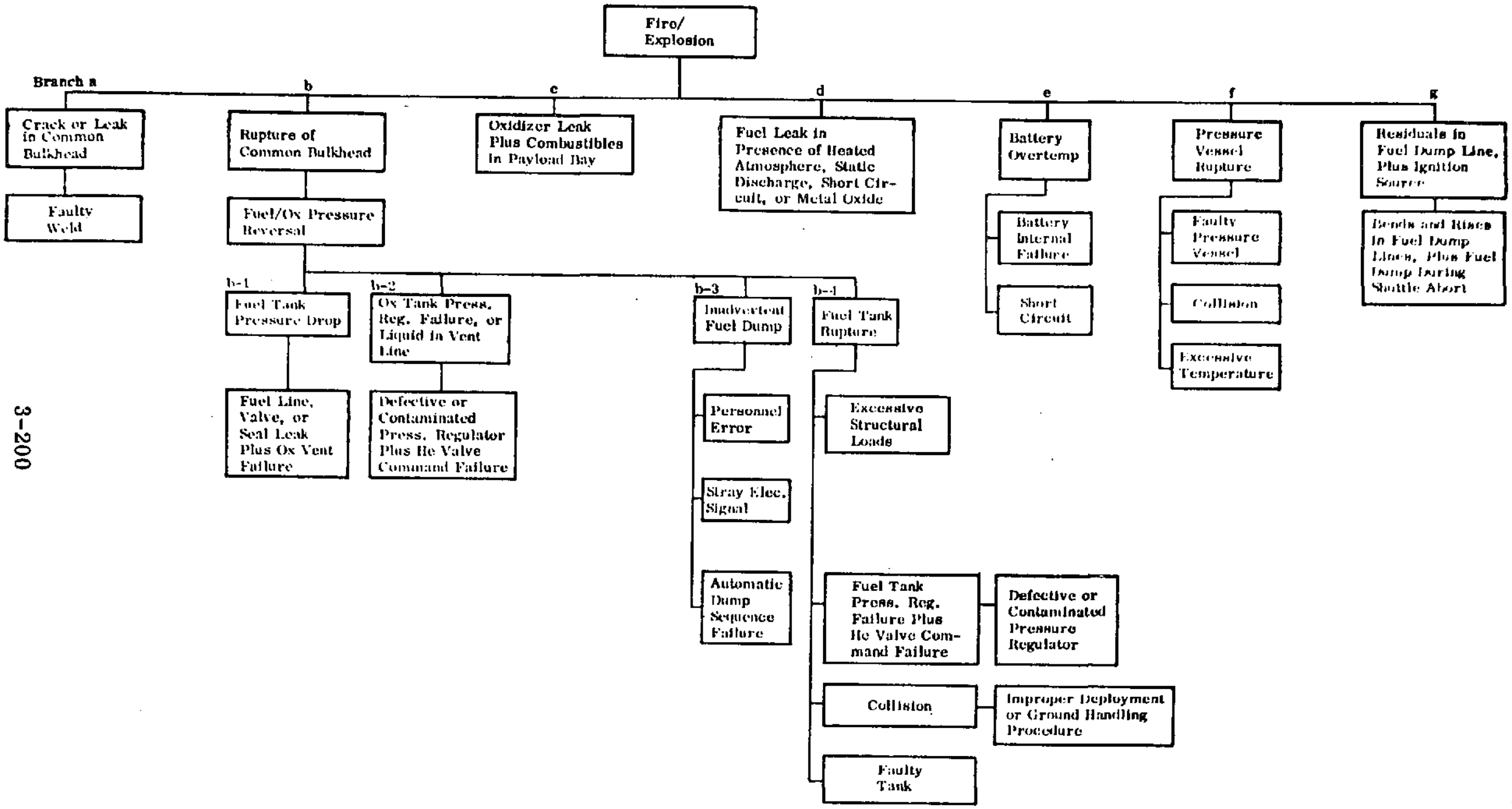


Fig. 3.6.1-2 Fire/Explosion Hazard Diagram

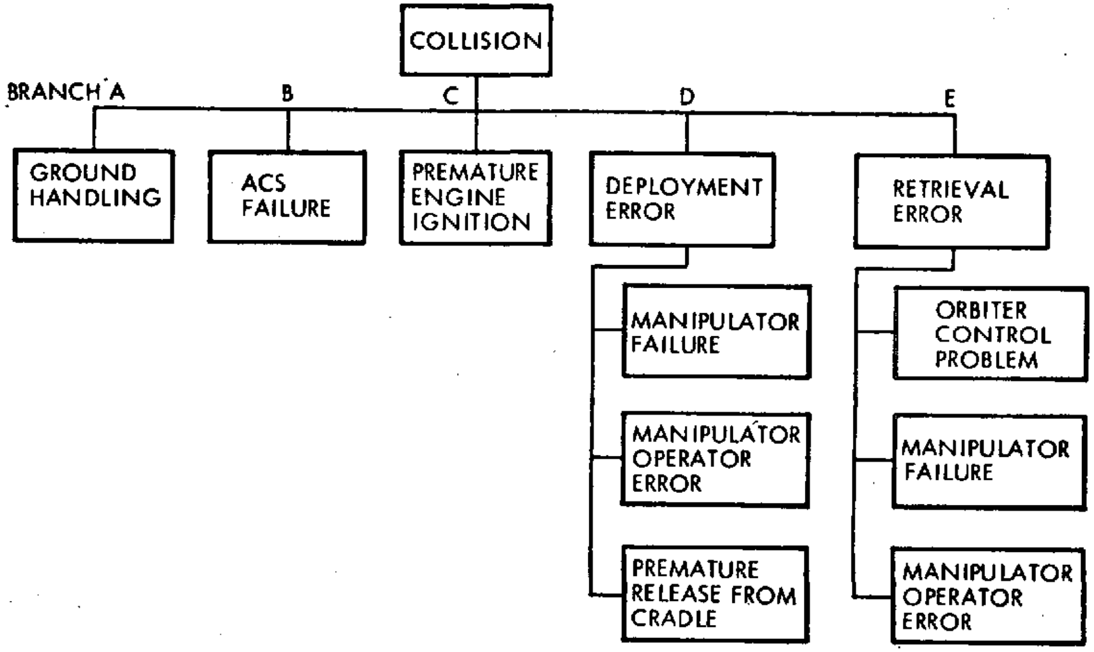


Fig. 3.6.1-3 Collision Hazard Diagram

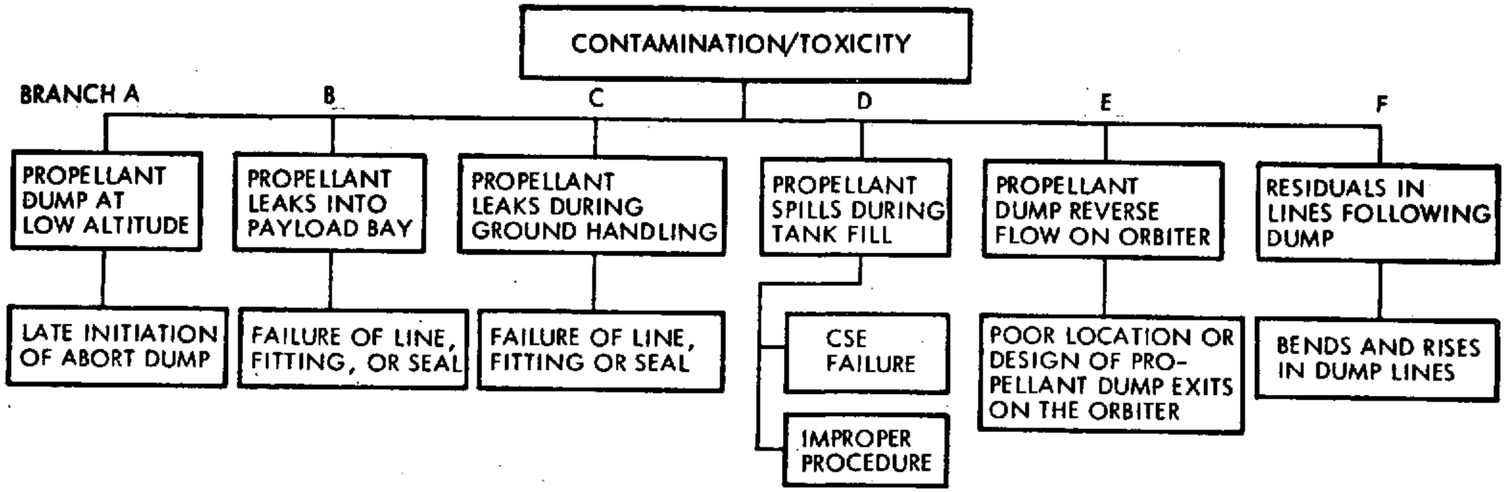


Fig. 3.6.1-4 Contamination/Toxicity Hazard Diagram

Table 3.6.1-1

HAZARD ANALYSIS FOR FIRE/EXPLOSION HAZARD DIAGRAM

Hazard Branch	Hazard Analysis	Counteraction
a	A crack or leak in the common bulkhead would permit commingling of hypergolic propellants and might lead to rapid tank pressure rise, tank rupture, and fire.	1. Apply manufacturing, testing, and inspection techniques used successfully on Agena for many years to ensure a sound bulkhead 2. Maintain tank ΔP within specified limits
b-1	Fuel pressure leak plus oxidizer vent failure could result in rupture of common bulkhead and fire. Dual failure required before fire can occur.	1. Component qualification and inspection 2. Safety monitor can increase fuel tank pressure by command
b-2	Failed open ox. press. regulator, plus ox. vent failure, plus He valve command failure could result in bulkhead failure and fire. Triple failure required before fire can occur	1. Component qualification, inspection, and test
b-3	Inadvertant fuel dump could cause bulkhead failure and fire. System can be designed fail-safe Personnel "error" would have to be deliberate action.	1. Prevented by fail-safe system design and by personnel training
b-4	Fuel tank rupture could result in fire. No hazard from loads or accelerations unless design spec values are exceeded. Dual failure required before tank is overpressurized. Collision unlikely with adequate equipment, procedures, and training.	1. Control acceleration 2. Dump propellant before landing 3. Component qual, inspection, and test 4. Fail-safe procedures and equipment
c	Oxidizer combined with organic material may spontaneously ignite. Demonstrated absence of leaks in Agena, plus payload bay free of organic materials, should preclude fire	1. Provide leak-tight propellant system 2. Keep combustible materials out of payload bay 3. Dump oxidizer if large leak does occur

Table 3.6.1-1 (Cont)

Hazard Branch	Hazard Analysis	Counteraction
d	Fuel combined with atmosphere and ignition source may burn. Demonstrated absence of leaks in Agena, plus elimination of metal oxides from payload bay should preclude fire	1. Provide leak-tight propellant system 2. Keep metal oxides out of payload bay 3. Purge payload bay with inert gas while on the ground 4. Control payload bay temperature 5. Eliminate ignition sources from payload bay 6. Dump propellant if large leak occurs
e	Overheated batteries can explode. Overload devices protect batteries from short circuit. Internal failure of battery precluded by design, qualification, inspection, and test	1. Use current practices to prevent battery explosion 2. Consider use of debris shield enclosing the battery
f	Pressure vessel rupture could be quite hazardous, damaging propellant tanks, equipment and shuttle, and injuring personnel	1. Control payload bay temperature 2. Depressurize tanks before landing 3. Certify tanks by design, test, and inspection to preclude faults 4. Maintain 2.0 factor of safety ultimate 5. Protect tanks from impact or collision 6. Consider use of debris shields
g	Fuel trapped in an open dump line following abort could present an explosion hazard if an ignition source were introduced	1. Design dump lines for gravity drain following landing 2. Consider covering dump line exit immediately following landing 3. Keep all ignition sources well away from the Orbiter 4. Purge dump lines as soon as feasible following landing

Table 3.6.1-2

HAZARD ANALYSIS FOR COLLISION HAZARD DIAGRAM

Hazard Branch	Hazard Analysis	Counteraction
a	Ground handling errors could lead to collision and damage to Agena, equipment, and personnel	1. Develop fail-safe ground handling equipment and procedures and train personnel to avoid ground handling errors
b	ACS failure when Agena is activated following deployment in orbit could lead to collision with the Orbiter	1. Establish adequate separation between Orbiter andAgena before activating Agena ACS 2. Redundant ACS components prevent loss of control
c	Premature engine ignition could lead to collision of Agena with the Orbiter	1. Inhibit engine firing until arm command is given following adequate separation between Orbiter and Agena
d	Manipulator failure, operator error, or premature release of Agena from the support cradle could lead to collision of Agena with the Orbiter	1. Design Agena cradle so that mission specialist must command release 2. Manipulator failure and operator error are the responsibility of the Space Shuttle contractor and beyond the scope of this study, but guides, aids, and protective devices should be a subject for further study.

Table 3.6.1-3

HAZARD ANALYSIS FOR CONTAMINATION/TOXICITY HAZARD DIAGRAM

Hazard Branch	Hazard Analysis	Counteraction
a.	Late initiation of propellant dump could result in propellants reaching the ground in toxic concentrations during approach and landing	1. Mission specialist must be trained to initiate propellant dump at the proper time 2. Propellant dump is specified to be complete above 70,000 ft altitude.
b	Propellant leaks into the payload bay could result in a toxic environment and contamination	1. Provide a leak-tight propellant system 2. Purge payload bay with inert gas while on the ground, and vent while in flight
c	Propellant leaks during ground handling could result in a toxic environment and in contamination of Agena, GSE, and facilities	1. Provide a leak-tight propellant system 2. Provide ground handling equipment and procedures to avoid damage to lines, fittings, and seals 3. Provide propellant leak detectors and monitors
d	Propellant spills during tank fill could result in a toxic environment and in contamination of Agena, GSE, and facilities	1. Use fail-safe equipment and procedures 2. Provide large quantities of water to dilute and wash away any spilled propellant 3. Observe current safety practices during fill 4. Use properly trained personnel
e	Reverse flow at the Orbiter base during propellant dump could result in contamination of the aft end of the Orbiter	1. Provide safe dump exit design and location through development and test, and dump only under specified flight conditions
f	Residuals in dump lines could result in a toxic environment at line exits, or at disconnects if lines are not purged	1. Design dump lines for gravity drain following landing 2. Cover dump exits until line purge can be accomplished 3. Purge lines before disconnecting or working around dump exits

Table 3.6.1-4

GROUND OPERATIONS SEQUENCE OF EVENTS AND HAZARDS ANALYSIS

Event No.	Event
	POST LANDING
1.	Tow Orbiter to safing area. No significant hazard.
2.	Connect fuel and oxidizer vent lines to GSE and reduce tank pressures to slightly above atmospheric. Purge all dump and vent lines. Disconnect dump lines and electrical umbilical at Orbiter interface and release support cradle from Orbiter tiedown. Possibility of toxic propellant vapors exists. Use trained personnel wearing protective clothing and breathing equipment.
3.	Remove Agena and cradle from payload bay and install in transporter. Potential impact or collision while hoisting or moving. Use fail-safe constraints, developed procedures, and trained personnel. (NOTE: This potential hazard and proposed counteraction also applies to events 5, 7, 9, 11, 13, 15, 16, 18, 19, and 26.)
4.	Transport to propellant flushing/refurbishment facility. No significant hazard.
	FLUSHING/REFURBISHMENT
5.	Remove Agena/cradle from transporter and load on work dolly.
6.	Remove IMU and star sensor assembly and deliver to test facility No significant hazard.
7.	Install Agena/cradle in flushing stand.
8.	Flush/purge/clean tanks and engine No significant hazard.
9.	Remove Agena from cradle and flushing stand, install in work dolly, and move to refurbishment area.
10.	Inspect, and refurnish as required. No significant hazard.
11.	Move to pressure test area.
	PRESSURE TEST
12.	Install in support cradle and move to maintenance and checkout facility, alignment area.

Table 3.6.1-4 (Cont)

Event No.	Events
13.	Install in support cradle and move to maintenance and checkout facility, alignment area.
	ALIGNMENT
14.	Perform alignment checks and verification. No significant hazard.
15.	Install Agena/cradle on transporter and move to system test area.
	SYSTEM TEST
16.	Remove Agena/cradle from transporter and install on dolly.
17.	Perform checkout and conditioning operations and correct discrepancies. No significant hazard.
18.	Install Agena/cradle on transporter and transport to spacecraft facility.
	PAYLOAD MATING
19.	Mate Spacecraft to Agena, transport to launch complex, remove Agena/spacecraft/cradle from transporter, and install in clean room.
	PROPELLANT LOADING
20.	Connect fuel and oxidizer flex fill lines to cradle dump lines, flex vent lines to Agena GSE vent valves, and He flex fill line to Agena. No significant hazard.
21.	Calibrate propellant and gas loading equipment. No significant hazard.
22.	Load 10 percent propellants, load He to half flight pressure, and verify no propellant leaks via leak detectors. No significant hazard with remote loading.
23.	Visually check for propellant or gas leaks. Propellant leaks could generate toxic vapors. Wear protective clothing and breathing equipment. Repair leaks. Dump propellant if leak is excessive.
24.	Load Propellants to flight requirements. No significant hazard with remote loading.
25.	Purge and remove fuel and oxidizer flex fill lines and remove He flex fill line. Propellant leakage could generate toxic vapors. Wear protective clothing and breathing equipment.

Table 3.6.1-4 (Cont)

Event No.	Events
	ORBITER MATING
26.	Move Agena/spacecraft/cradle into payload bay.
27.	Connect Orbiter propellant dump/vent lines, He fill line, and electrical umbilical to Agena/cradle. Propellant leakage could generate toxic vapors. Wear protective clothing and breathing equipment.
28.	Witness Orbiter/Agena checkout and verification sequence. No significant hazard.
29.	Load He to flight pressure. No significant hazard with remote loading.
30.	Verify Agena flight readiness. No significant hazard.

Table 3.6.1-5

DEPLOYMENT SEQUENCE OF EVENTS AND HAZARDS ANALYSIS

Event No.	Event
	PREDEPLOYMENT ON ORBIT
1.	Verify all systems GO. No hazard.
2.	Transfer from Orbiter to internal Agena power. Negligible hazard.
3.	Attach manipulator arm to Agena and verify. Improper handling of manipulator arm might result in impact and damage to Agena. This is basically a Shuttle responsibility, but guides, aids, and protective devices should be a subject for further study.
	DEPLOYMENT
4.	Disconnect umbilicals for electrical power and propellant dump/vent at Agena/cradle interface, retract lines, and verify. Umbilicals fail to disconnect, with all connections still intact, prevents completion of the mission. Manually disconnect umbilicals via EVA, or abort and return Orbiter and Agena to ground. Partial disconnect of umbilicals could result in a condition wherein Agena could not be deployed and propellant could not be dumped for abort or vented. Manually disconnect or reconnect umbilicals via EVA. Propellant in dump lines at time of disconnect could result in contamination or fire. (Small amounts of propellant in lines will be evacuated by the space environment). The condition of dump lines should be known through monitoring of safety instrumentation. If leakage is excessive, initiate an abort and return Orbiter and Agena to ground.
5.	Disengage Agena stowage retention devices, open clamshell doors, and verify. With umbilicals disconnected, if Agena fails to release from the cradle the vehicle cannot be deployed and propellant can be neither dumped for abort nor vented. Safe return of Orbiter to ground is jeopardized. Counteraction includes provision of redundant release mechanisms plus options to manually release Agena from the cradle via EVA or to reconnect umbilicals and abort the mission.

Table 3.6.1-5 (Cont)

Event No.	Event
6.	Deploy Agena/spacecraft with manipulator. Faulty design or handling of the manipulator could result in collision of Agena with the Orbiter. This is basically a Shuttle responsibility, but guides, aids, and protective devices should be a subject for further study.
7.	Command Agena telemetry ON via RF command link, and check RF link, and telemetry, are GO. No hazard if RF link and telemetry are not GO. May require abort of mission.
8.	Release and withdraw manipulator from Agena. Failure of manipulator arm to release the Agena following deployment creates a condition in which the Orbiter could not re-enter for landing. This is a Shuttle responsibility.
	SEPARATION
9.	Move Orbiter away from Agena 1500 to 2000 ft. Failure or improper handling of the Orbiter as it moves away from the released Agena could result in a collision. This is a Shuttle responsibility.
10.	Activate Agena attitude control system by command, and verify. No hazard.
11.	Arm Agena propulsion system by command, and start computer-controlled operational sequence. Negligible hazard if Orbiter is stationed at the specified distance or greater.
	SUPPORT CRADLE STOWAGE
12.	Close support cradle clamshell doors of SOT option if Orbiter is not expected to retrieve Agena. Support cradle doors fail to close. Doors for SOT option project beyond Orbiter envelope and would prevent closure of cargo bay doors. Counteraction includes provision of redundant means for closing SOT cradle doors, and backup capability to close SOT cradle doors manually via EVA.

Table 3.6.1-6

MAIN PROPULSION SYSTEM ON-ORBIT SEQUENCE OF EVENTS AND HAZARDS ANALYSIS

Initial Condition – All transfer line valves open – SV07, SV08, SV09, SV10, SV11, SV12, SV13, SV14 (see Fig. 3.6.1-5). Agena is stabilized and oriented and the Orbiter is located a safe distance away.

Event No.	Event
	ORBIT OPERATIONS
1.	Open SV01-03, SV02-04. Regulators PR01 and PR02 control pressure. One He isolation valve fails to open. No hazard since valves are parallel redundant. A pressure regulator fails open. Pressure and/or ΔP measurement leads to automatic closure, and subsequent modulation, of the appropriate pressurant supply valves. Vent valves are opened if pressures reach vent limits.
2.	Open SV23 and SV24 (PIV vent line shut off valves). Propellant isolation valve vent line shutoff valve fails to open. No immediate hazard, but engine starts after No. 1 may be jeopardized. Accept risk, or install parallel-redundant vent line shutoff valves.
3.	Open PIVs SV17and SV18 and start engine. PIV fails to open and engine will not start. This risk is acceptable.
4.	Engine shutdown – Close helium valves SV01-03, SV02-04, engine valves, and SV17 and SV18. One He isolation valve fails to close. Regulator will control tank pressure. PIV SV17 or SV18 fails to close. Subsequent engine start may be jeopardized. This risk is acceptable.
5.	Close SV09, SV10. SV11, SV12, SV14. One SOT transfer valve fails to close. A small amount of propellant may migrate between SOT and core tank changing CG and balance an insignificant amount. No hazard prior to retrieval (see event 21).
6.	Following coast, open SV01-03, SV02-04, SV09, SV10, SV11, SV12, SV13, SV14 for second burn. One SOT tansfer valve fails to open. Propellant from that tank cannot be used. This risk is acceptable. One He isolation valve fails to open. No hazard since valves are parallel redundant.

Table 3.6.1-6 (Cont)

Event No.	Event
7.	Open PIVs SV17 and SV18 and start engine. Same comments as event No. 3.
8.	Engine shutdown – Same comments as event 4.
9.	SOTs are empty. Close SV09, SV10, SV11, SV12, SV13, SV14. Same comments as event 5.
10.	Close SV07 and SV08 to isolate SOTs.
11.	Open SV05 and SV06. SV05 or SV06 fails to open. Corresponding core tank cannot be supplied with pressurant. Reopen SV07 and SV08 as appropriate, and reopen one corresponding SOT transfer valve to feed pressurant via SOT.
12.	Following coast open He valves SV01-03, SV02-04. No hazard.
13.	Open PIVs SV17 and SV18 and start engine. Same comments as event No. 3.
14.	Engine Shutdown. Same comments as event 4.
15. through 20.	Twice repeat of events 12 though 14.
21.	Now back in orbit with the Orbiter, coasting, open SV20 and SV22 to initiate oxidizer dump. Dump valve SV20 or SV22 fails to open. Residual oxidizer will not dump. No hazard is created. Close dump valves and terminate residuals dump. Vent core tanks to reduce pressure. Continue retrieval sequence at event No. 26. Orbiter may be contaminated by approaching Agena too closely while propellants are being dumped. Orbiter should maintain safe distance of (TBD) while propellants are being dumped. One SOT transfer valve has failed to close. SOT pressurant will be lost during residual dump and tanks will not be pressurized as required to prevent implosion on landing. Several alternative counteractions exist: ● Retrieve Agena with tanks depressurized, then vent to atmosphere for landing.

Table 3.6.1-6 (Cont)

Event No.	Event
	• Carry sufficient pressurant to repressurize tanks for landing.
	• Leave SOT and core tank pressurant lines interconnected during residual dump, and close the residual dump valves when tank pressure reaches a preset minimum value suitable for landing.
	• Retrieve Agena without dumping residuals, and land with residuals still on board.
22.	Open fuel residual dump valves SV19 and SV21. Dump valve SV19 or SV21 fails to open. Residual fuel will not dump. No hazard is created. Close dump valves, and terminate residuals dump. Vent core tank to reduce pressure. Continue retrieval sequence at event No. 26.
23.	Close fuel residuals dump valves SV19 and SV21. SV19 or SV21 fails to close. No problem, since valves are series redundant.
24.	Close oxidizer tank residuals dump valves SV20 and SV22. SV20 or SV22 fails to close. No problem, since valves are series redundant.
25.	Close engine vent valves SV23 and SV24. SV23 or SV24 fails to close. No hazard is created.
26.	Open SV07 to equalize pressure in SOT and core fuel tanks. SV07 fails to open. Open SV09, or SV11, or SV13 to equalize pressure.
27.	Open SV08 to equalize pressure in SOT and core oxidizer tanks. SV08 fails to open. Open SV10, or SV12, or SV14 to equalize pressure.
28.	Safe propulsion system by disarming engine valves, plus SV17, SV18, SV19, SV20, SV21, SV22, SV23, SV24. If the propulsion system fails to safe, an inadvertant signal to start the engine could result in flow of gas through the engine with possible contamination of the Orbiter cargo bay. Continuation of retrieval is recommended, since risk and likelihood of occurrence is very low.

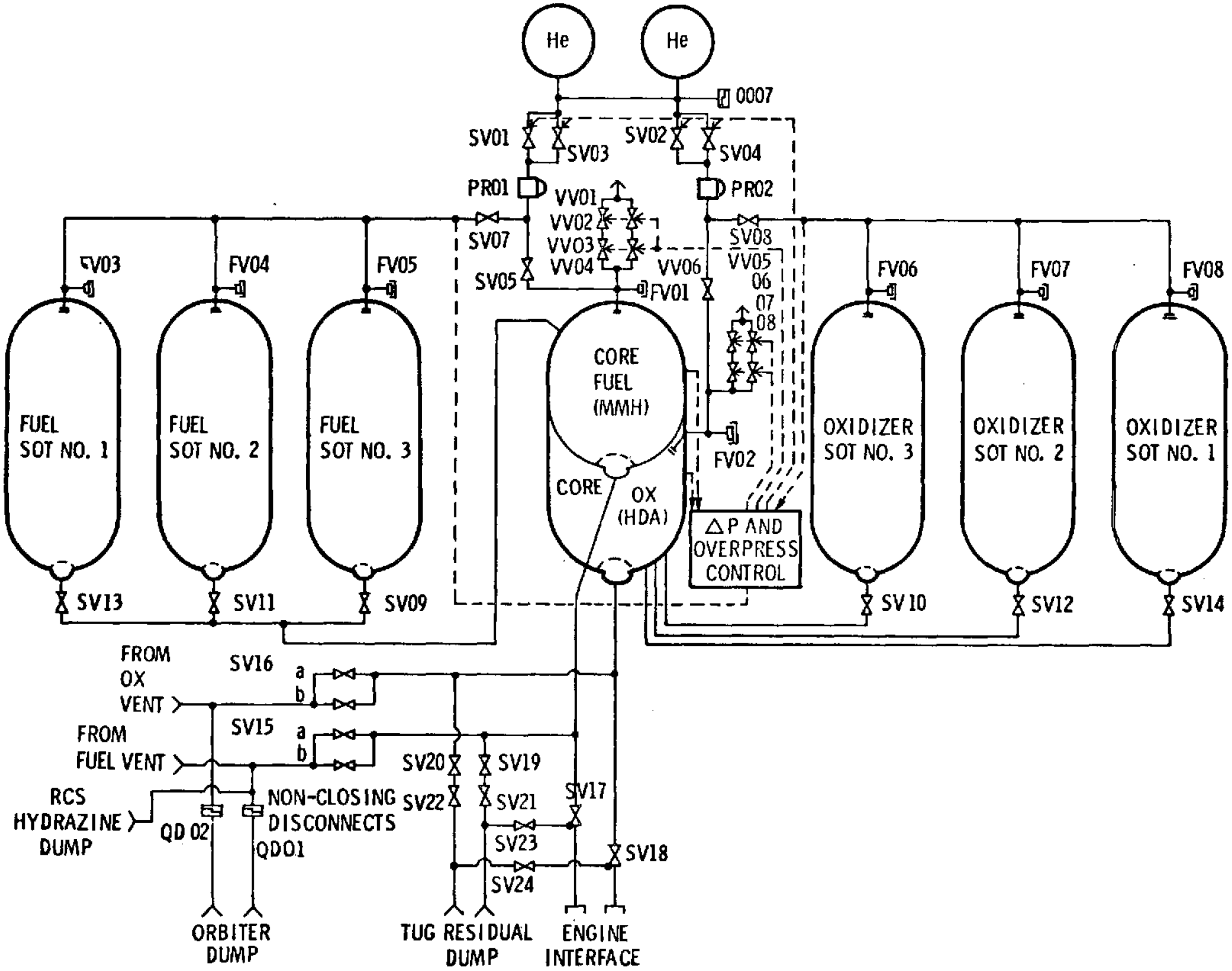


Fig. 3.6.1-5 Main Propellant/Pressurization System

Table 3.6.1-7

RETRIEVAL SEQUENCE OF EVENTS AND HAZARDS ANALYSIS

Initial Condtion – The retrieval sequence is assumed to start with the Agena returned to the Orbiter orbit, with the Orbiter stationed 1500 to 2000 ft away, with ACS maintaining the desired orientation. Propellant tanks are empty. All valves are closed except SV05, SV06, SV07, and SV08 (see Fig. 3.6.1-5). Oxidizer tank pressure has been established at about 22 psi and fuel tank pressure at about 27 psi.

Event No.	Event
1.	Assess all safety related status information and verify GO.
2.	Command retraction or separation of any deployed devices or appendages that would interfere with retrieval and remating with the Orbiter and verify. If appendages fail to retract or separate, Agena cannot be retrieved. No hazard is created. Agena must then be prepared for retrieval via EVA or abandoned.
3.	Command deactivation and safing of all safety critical systems except command, and confirm all systems safed and Agena ready for retrieval. If Agena is found unsafe for retrieval, correct or abandon.
4.	Orbiter moves in to rendezvous and visual inspection and verify safe for retrieval. Improper handling of the Orbiter could result in collison. This is a Shuttle responsibility.
5.	Agena ACS is deactivated and safed. Orbiter captures Agena by attaching manipulator arm and verifies attachment integrity. Agena could be damaged by faulty handling of the manipulator. This is basically a Shuttle responsibility, but guides, aids, and protective devices should be a subject for further study.
6.	Agena is maneuvered into the cargo bay and support cradle by the manipulator. Agena and Orbiter could be damaged by collision through faulty handling of the manipulator. This is basically a Shuttle responsibility, but guides, aids, and protective devices should be a subject for further study.
7.	Agena/cradle attachments are made and clamshell doors closed and verified. If Agena/cradle attachments are not secure and doors closed, the Orbiter cannot safely re-enter. Attachments and door closure must be accomplished via EVA or Agena must be redeployed and abandoned.

Table 3.6.1-7 (Cont)

Event No.	Event
8.	Reconnect electrical, fluid, and vent umbilicals and verify. If umbilicals cannot be reconnected, safety during reentry, landing, and post landing is degraded. Alternative counteraction includes: • Connect umbilicals via EVA • Accept degraded safety • Redeploy Agena and abandon it in orbit.
9.	Transfer from internal Agena to Orbiter power and verify. If power does not transfer, no hazard is created. Continue on internal Agena power.
10.	Withdraw manipulator arm. Faulty handling of manipulator arm could damage Agena. This is a Shuttle responsibility.
11.	Verify all systems safed and all safety status instrumentation within safe limits. If systems are not verified safe, corrective action is situation dependent. If potential hazard cannot be corrected, jettison Agena in orbit.

3.6.1.4 Hazards Analysis Summary. The more significant hazards identified and analyzed in the preceding paragraphs are summarized in this section. Table 3.6.1-8 identifies the hazards, describes possible effects of the hazards, and proposes preventive and corrective/remedial actions.

3.6.1.5 Residual Hazards. Residual hazards, where a single point failure could lead to loss of personnel or system, are identified in four areas. These are as follows:

1. Crack or leak in propellant tank common bulkhead
2. Defective propellant tank
3. Defective pressure vessel
4. Defective propellant line or fitting

All four of these hazards are considered acceptable risks in view of the Agena record of well over 300 flights without such a failure. The common bulkhead is further protected by fail-safe ΔP control.

The propellant tanks are protected by operating within a factor of safety of 1.4 limit to ultimate for all normal operations, and to ultimate for crash landing.

The propellant lines and pressure vessels are protected by operating within a factor of safety of 2.0 limit to ultimate.

3.6.1.6 Agena Safety Features. Shuttle/Agena Upper Stage safety features are identified in the areas of design, operations, and instrumentation. These areas are discussed in the following paragraphs.

Design Features for Safety

Design features are incorporated to meet specified safety criteria and to eliminate hazards from single-point failures, except for propellant tanks, pressure vessels, and general structure.

Table 3.6.1-8

GENERAL HAZARDS ANALYSIS SUMMARY

Hazard Identification			Hazard Effects				Control Actions	
Error, Malfunction; Undesired Event	Potentially Hazardous Condition	Cause	Potential Consequences	Hazard Class	Likelihood of Occurrence		Preventive Actions	Corrective/ Remedial Actions
					Condition	Consequences		
Fuel pressure leak and oxidizer vent failure	Common bulkhead rupture	Faulty components	Fire	a	Unlikely. Dual equipment failure required	Certain	High reliability parts	Open fuel tank He valve to maintain tank pressure
Inadvertent fuel dump	Common bulkhead rupture	Personnel error	Fire	a	Prevented by design	Possible	System design requiring deliberate action to arm, open He valves, and open dump valves, plus fuel dump inhibit if ox dump valve is not open	Command dump valve closed
Oxidizer leak	Oxidizer in payload bay	Faulty seal	Fire, contamination	a	Unlikely, based on Agena history	Possible	Redundant seals, high rel parts, inspection, careful handling, absence of organic materials in payload bay	Inert purge of payload bay while on the ground. Dump oxidizer.
Fuel leak	Fuel in payload bay	Faulty seal	Fire, contamination	a	Unlikely, based on Agena history	Possible	Redundant seals, high rel parts, inspection, careful handling, absence of metal oxides in payload bay	Inert purge of payload bay while on the ground. Dump propellants.
Battery explosion	Propellant tank penetrated by debris	Internal failure or short circuit	Explosion and fire	a	Unlikely	Unlikely	Fail-safe battery design. Qual test. Short circuit protection. Debris shields.	–
Pressure vessel rupture	Propellant tank penetrated by debris	Faulty pressurant tank	Fire, contamination, toxicity	a	Unlikely	Possible	Flight qual., factor of safety 2.0, inspection	–
Propellant tank rupture	Propellant released	Faulty propellant tank	Fire, contamination, toxicity	a	Unlikely	Possible	Flight qual, inspection, factor of safety 1.4	Water deluge if pre-launch
Crack in common bulkhead	Commingling of fuel and oxidizer	Faulty tank	Fire	a	Unlikely	Certain	Manufacturing, testing, and inspection techniques currently used on Agena. Maintain ΔP within specs.	–

Table 3.6.1-8 (Cont)

Hazard Identification			Hazard Effects				Control Actions	
Error, Malfunction; Undesired Event	Cause	Potentially Hazardous Condition	Potential Consequences	Hazard Class	Likelihood of Occurrence		Preventive Actions	Corrective/ Remedial Actions
					Condition	Consequences		
Dump lines wet during disconnect in orbit	Propellant dump valve leak or propellant vent	Propellant released onto payload bay	Fire contamination corrosion	a	Possible	Possible	Purge lines before disconnect. Check valves on cradle side of line interface activated by disconnect.	
Unsuccessful deployment in orbit	Equipment failure or handling error	Agena partially disconnected or deployed, or damaged	Orbiter cannot safely reenter	a	Unlikely	Possible	Redundant release mechanisms and fail safe restraints	EVA to release or reconnect
Unsuccessful retrieval in Orbit	Equipment failure or handling error	Agena damaged or umbilical or tiedowns not reconnected	Orbiter cannot safely reenter	a	Possible	Possible	Care in movement of Agena. Fail-safe design of umbilicals and tiedowns	EVA to secure or release Agena Abandon Agena in Orbit
Cradle doors for SOT option fail to close on orbit	Actuator failure	Orbiter cannot close cargo bay doors	Orbiter cannot safely reenter	a	Possible	Possible	Fail—safe design of cradle door actuators and latches	EVA to close and latch doors
Propellant leak during visual check or line disconnect on ground	Fitting leak or inadequate line purge	Presence of toxic propellant	Toxicity	b	Unlikely	Unlikely	Wear protective clothing and breathing equipment	Repair leaks. Dump propellants if leak is excessive
Impact or collision during handling or transport	Equipment failure or human error	Personal injury. Propellant tank rupture.	Personal injury Fire, toxicity, contamination	b a	Unlikely Unlikely	Possible Possible	Fail-safe handling equipment, safe procedures, trained personnel	Medical aid Remove personnel plus water deluge
Residuals remain in fuel dump line following abort	Dump line rises and bends, inadequate purge	Explosive mixture in dump line	Explosion, if ignition source is present	a	Possible	Possible	Eliminate bends and rises in dump line, provide reliable purge with inert gas	Keep ignition sources away from fuel dump exit. Cover exits following landling until lines are purged

Design features for safety include:

1. Propellant dump capability on the pad, in orbit, and during powered Shuttle abort. Propellant dump for abort with the SOT option is completed in 280 seconds.
2. Pressure vessels, tanks, and structures are designed to meet factor or safety requirements of MSFC-Hdbk-505.
3. Automatic pressure relief and common bulkhead ΔP control is provided.
4. Critical command and control circuitry is fail op-fail safe.
5. Command override of safety critical functions is provided to the Orbiter.
6. Redundant components or alternative paths are provided for fail-safe operation in the presence of Shuttle or men.
7. No pyrotechnic devices are used.

Operational Features for Safety

Agena operations are planned and developed to be fail-safe. Specific operational safety features include:

1. All propellants are dumped to accommodate Shuttle abort.
2. All propellants are consumed or dumped before retrieving Agena.
3. Command override is provided for all safety critical functions.
4. The Orbiter crew is provided fail op-fail safe control.
5. Safety status information is provided to the Orbiter.
6. Propellant tank pressures are reduced for launch and landing.

Safety Instrumentation

Safety instrumentation associated with transport of an Agena in the cargo bay of a Space Shuttle should provide information concerning potential hazards. The parameters to be monitored are listed in Table 3.6.1-9.

3.6.2 Emergency Propellant Dump

3.6.2.1 Abort Profile. During a launch abort it is required that all Agena propellants be dumped while the Shuttle is performing a powered return-to-launch-site (RTLS).

Table 3.6.1-9

SAFETY INSTRUMENTATION

Measurement	Location	Instrument Range	Accept. Readings	Action Required if Reading Out of Range
Fuel tank pressure	In ullage control line	0 to 100 psi	5 to 45 psig	Reduce fuel temp, or dump, if high. Open He pressurization valve, if low
Ox. tank pressure	In ullage control line	0 to 100 psi	0 to 40 psig	Reduce ox. temp, vent, or dump
Fuel tank temp	Exterior tank skin	30° to 130°F	≤ 75°F	Depends on temperature
Ox. tank temp	Exterior tank skin	30° to 130°F	≤ 75°F	Depends on temperature
Ox. fuel differential pressure	Computed from individual ox. and fuel pressures	±10 psi	Fuel minus ox. ≥ 0 psi	Cool, vent, dump oxidizer, or increase fuel tank pressure
ACS fuel tank pressure	In pressurant	0 to 500 psi	0 to 350 psi	Reduce temp, vent, or dump
ACS fuel tank temperature	Exterior tank skin	30° to 130°F	≤ 75°F	Depends on temperature
Cargo bay temp	Shuttle cargo bay	TBD	TBD	Shuttle responsibility
Presence of fuel or oxidizer	Near dump valves. In dump lines on support cradle	TBD	Negative	Assess leak rate, and if out of acceptable range either deploy or remove Agena or dump propellant, as appropriate
He tank pressure	He fill line	0 to 4000 psi	≤ 3600 psi	Cool or vent
Valve position Dump valves Pressurant valves Vent valves Isolation valves	At each valve	Open to closed	As required	Situation dependent
Voltage and current	Main bus and pyro bus	TBD	TBD	TBD
Battery temp	Battery	TBD	TBD	TBD
Umbilical positions	At each umbilical	Connected to retracted	As required	Situation dependent
Support cradle door positions	At actuators	Open to closed	As required	Situation dependent
Support cradle latch positions	At latches	Latched or unlatched	As required	Situation dependent
Orbiter accelerations	At orbiter c.g.	±1g	As required to ensure propellant is settled	Delay propellant dump

The most critical condition in terms of time available in which to dump propellants occurs for Mission 3A, powered RTLS abort at T = 253 seconds from liftoff.

This abort profile is illustrated in Fig. 3.6.2-1. The abort is initiated at an altitude of about 350,000 ft. The Shuttle is pitched to a retro thrust attitude with the X axis directed toward the launch site. Retro acceleration increases from about 1 g to 3 g at burnout while changing velocity from up and away from the launch site to down and toward the launch site. Burnout occurs at about 200,000 ft altitude.

Agena propellants dumped through fins on the Orbiter sides at the aft end, with exits pointing aft, will have an exit velocity of about 30 ft/sec. In addition, the Shuttle will be accelerating away from the dumped propellants. During the period when the propellant dump exits are aimed within ±30 deg of the Orbiter direction of flight (≃100 seconds), the altitude is between 300,000 and 400,000 ft. Under these conditions, the dynamic pressure is very low, and the propellant dispersion is predicted to be insignificantly different from that for dump on orbit.

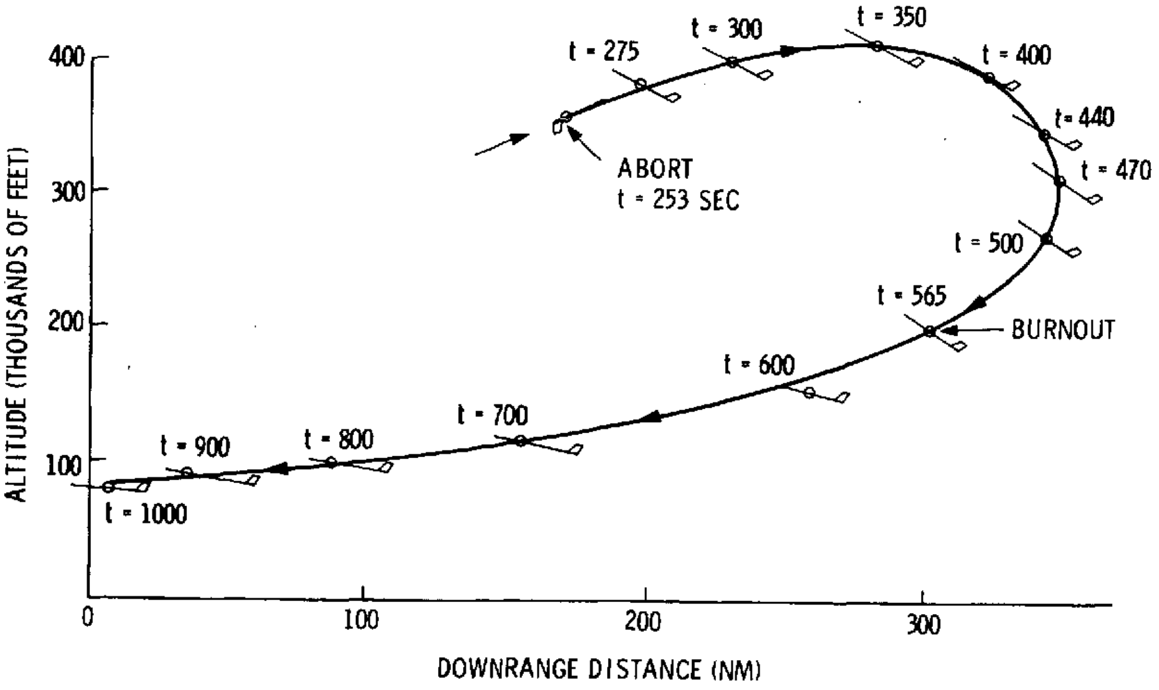


Fig. 3.6.2-1 Abort Profile – Powered RTLS

3.6.2.2 Abort Dump Time. The Agena with SOT option can dump all of its propellant while it is in the Orbiter, via Orbiter/cradle connectors and Orbiter dump lines. For the critical abort profile shown in Fig. 3.6.2-1, 310 seconds are available for propellant dump. Propellant settling accelerations during this period increase from one g to 3 g. Under these conditions, Agena fuel and oxidizer can be dumped simultaneously in 280 seconds, including a delay in start of fuel dump calculated to permit oxidizer pressure to decay for about 20 seconds before fuel depletion occurs. The resulting propellant flow rate profile is shown in Fig. 3.6.2-2.

The combination of the tank pressure of 30 psia (ox) and 35 psia (fuel) and the acceleration head (head height of approximately 30 ft) provides high flow rates. The propellant is discharged from the aft end of the Agena core after it is cascaded into the core tank from the three parallel flow strap-on tanks.

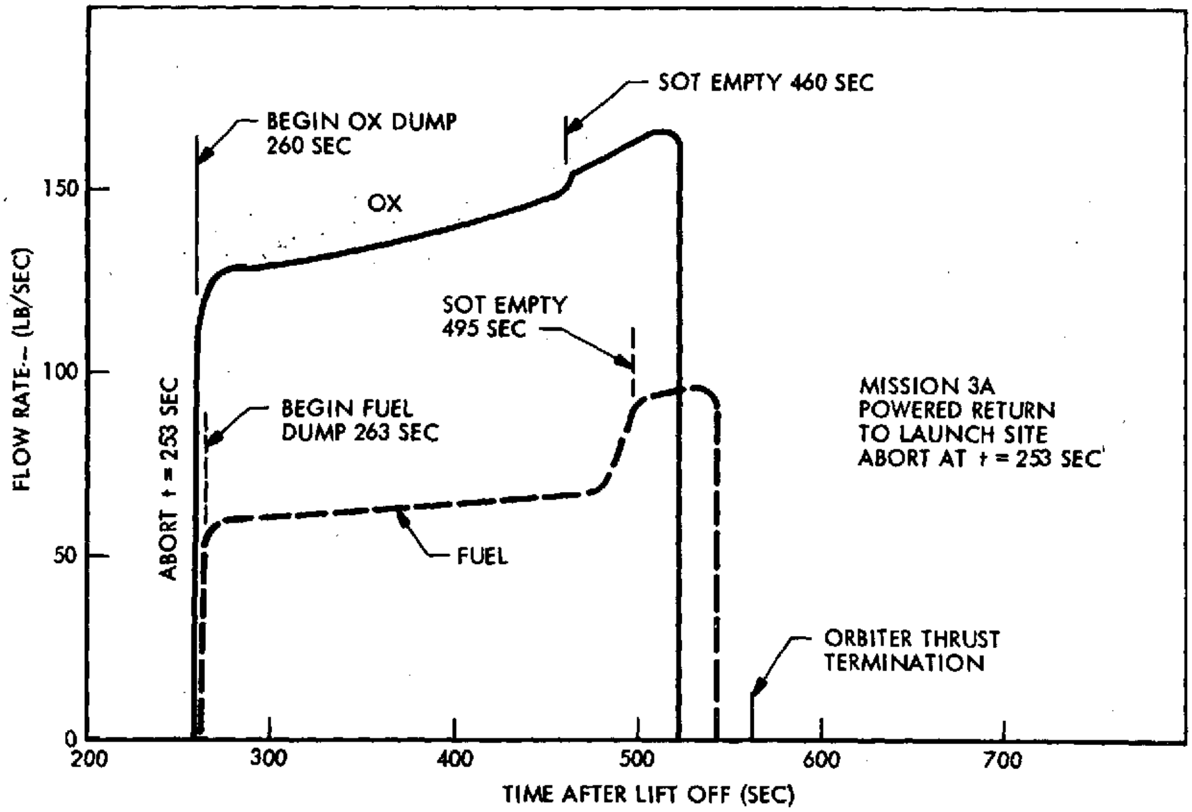


Fig. 3.6.2-2 Abort Dump Flow Profile

The flow rates are based on a 2.5 inch feed line in the oxidizer SOT and a 2.0 inch line in the fuel SOT and 3 inch fuel standpipe. The valves in these lines are low loss with 2.4 inch diameter openings. The core sumps and lines are the standard Agena system except the feed and fill lines are larger (2.5-inch) and are routed above the existing propellant isolation valves.

The lines in the Orbiter are assumed to be 3.25 inch diameter, routed aft to dump fins on both sides of the Orbiter near the base. Adequate connections, bends, and bellows were provided to account for flow losses.

Propellant can be dumped with this system when the Orbiter and Agena are in orbit, if the Orbiter provides a small (≃ 0.001 g) longitudinal acceleration. Simultaneous dump of ox and fuel can be completed in 390 seconds, while sequential dump will require 715 seconds. A detailed assessment of propellant dump time is presented in ref 3-8.

3.6.2.3 On-Pad Dump Time. Agena propellant dump while on the launch pad is assumed to be simultaneous into closed receivers. Under this condition, using the basic dump system with He supplied through the pressure regulators and the assistance of 1 g acceleration, dump is calculated to be complete in 365 seconds.

3.6.2.4 Abort Sequence of Events and Hazards Analysis. During a Shuttle ascent abort, all Agena propellant must be dumped while the Shuttle is performing a powered return-to-launch-site (RTLS). The sequence of events and hazard analysis for this emergency operation is presented in Table 3.6.2-1.

Table 3.6.2-1

ABORT SEQUENCE OF EVENTS AND HAZARD ANALYSIS

Abort sequence with simultaneous propellant dump during powered RTLS. (See Fig. 3.6.1-5)

Initial Configuration – All valves closed except SV07, SV08, SV09, SV10, SV11, SV12, SV13, SV14. Fuel tanks pressurized to 30 psia and oxidizer tanks pressurized to 22 psia.

Event No.	Event
	ABORT
1.	When a Mode III abort is initiated, an Orbiter crewman arms the abort system for propellant dump and depresses the abort button to initiate the following programmed events.
2.	Open primary He control valves SV01, SV02, SV03, SV04 to fuel and oxidizer tanks. If fuel or oxidizer pressure regulator fails open, the pressure controller modulates the corresponding fuel or oxidizer pressurant control valve.
3.	Open dump valves SV16a and SV16b for oxidizer tank. If one oxidizer dump valve fails to open, parallel redundant valves prevent single point failure.
4.	After a programmed delay of 3 seconds, open dump valves SV15a and SV15b for fuel tank. If one fuel dump valve fails to open, parallel redundant valves prevent single point failure.
5.	Open dump valve for RCS propellant. If one RCS propellant dump valve fails to open, parallel redundant valves prevent single point failure.
6.	When pressure in the core oxidizer tank drops to (TBD) psi, close He control valves SV02, SV04, and SV08, and transfer valves SV10, SV12, and SV14. If He control valve SV02, SV04, and SV08, fails to close, no hazard with single failure. If oxidizer transfer valve fails to close, no hazard.
7.	When pressure in the core fuel tank drops to (TBD) psi, close He control valves SV01, SV03, and SV07, and transfer valves SV09, SV11, and SV13 and dump valves SV15a and SV15b. If He control valve SV01, SV03, or SV07 fails to close, no hazard with single failure.

Table 3.6.2-1 (Cont)

Event No.	Event
	If fuel transfer valve fails to close, no hazard. If fuel dump valve SV15a or SV15b fails to close, core fuel tank drops to atmospheric and oxidizer tank must not be repressurized. Inhibit oxidizer dump valves from closing when a fuel dump valve is open. Manually command all transfer valves open to vent SOT to atmosphere, and land with dump valves SV15a, SV15b, SV16a, and SV16b open.
8.	Open valves SV05 and SV07 to equalize pressures among all fuel tanks. If SV05 or SV07 fails to open, command SV09, SV11, SV13 open to equalize pressures.
9.	Close oxidizer dump valves SV16a and SV16b. If one oxidizer dump valve fails to close, command SOT transfer valves SV10, SV12, and SV14 open and land with oxidizer tanks vented to atmosphere.
10.	Open valves SV06 and SV08 to equalize pressure between all oxidizer tanks. If SV06 and SV08 fails to open, command SV10, SV12, and SV14 open to equalize oxidizer tank pressures.
11.	Orbiter lands. No load hazard on normal landing. Propellant may be trapped in dump lines. Keep ignition sources away from fuel dump exit following landing. Cover fuel dump exit until line is purged.
	POST LANDING
12.	Cover fuel dump line exit on orbiter until line is purged. Fuel vapors in the dump line are toxic and can present a fire hazard. Keep ignition sources away. Use caution to prevent personnel exposure to fuel vapor if exit cover is manually installed.
13.	Connect fuel and ox vent lines to GSE and reduce tank pressures to slightly above atmospheric. A possibility of exposure to toxic vapors or liquids exists when connecting GSE. Use trained personnel wearing protective clothing.
14.	Purge all dump and vent lines. Toxic materials may be released. Careless handling of propellant systems after landing could expose personnel to toxic propellants. Use adequate procedures, equipment, training, and protective clothing.

Table 3.6.2-1 (Cont)

Event No.	Event
15.	Disconnect dump lines and electrical umbilical at Orbiter interface and release support cradle from Orbiter tiedowns. No hazard in disconnecting umbilicals if dump lines properly purged and tanks vented in previous step.
16.	Remove Agena/payload and cradle from cargo bay, install in transporter, and move to fill/drain or disposal facility. Collision or impact may occur if removal and transport is not properly handled. Use adequate procedures, fail-safe equipment, and training. Use extra care if some propellant remains in tanks.
17.	Connect facility drain lines and drain and purge propellant tanks and lines. Possibility of toxicity, contamination, fire if tank and line drain and purge are not handled properly. Use adequate procedures, fail-safe equipment, and trained personnel.
18.	Transport to refurbishment facility. No hazard if transport is properly handled. Collision with careless handling. Use adequate procedures, fail-safe equipment, and trained personnel.

3.7 PERFORMANCE AND MISSION ACCOMPLISHMENT

The performance characteristics for the various Agena configurations are presented in this paragraph. Since the greatest number of payload placements is for the synchronous equatorial mission, detailed data will be presented for this mission. The guidelines used in the generation of the performance data are:

- 160 nm (296 km) initial parking orbit
- 170 nm (314.8 km) final parking orbit
- Shuttle performs final rendezvous
- Both 1.0% and 1.7% ΔV considered for flight performance reserves
- Payload placement only
- Propellants will be off-loaded if required
- Optimum kick motor (I_{sp} = 295, $\lambda = 0.94$) sized to perform the apogee circularization burn for the synchronous equatorial mission

The mission accomplishment analyses will include single and multiple placements with launches from both ETR and WTR, and alternatively with all missions being launched from ETR. Determination of the least number of required vehicles and flights is the paramount objective of these analyses.

3.7.1 Shuttle/Agena Upper Stage Performance Capability

An augmented Shuttle/Agena Upper Stage has been defined along with a nominal concept. The performance capabilities are presented for each of these concepts, with variations in the weight contingency and flight performance reserve. Each of these stages can be configured with six strap-on-tanks (SOTs) and/or a kick motor specifically sized for the geosynchronous mission.

3.7.1.1 Synchronous Equatorial Mission Sequence. The mission profile and sequence presented in Fig. 3.7-1 and Table 3.7-1 are applicable to operation with the Shuttle/Agena SOT option. Five burns of the main propulsion engine are required. Analysis of par. 3.3.3 substantiates that no midcourse correction is needed on either ascent or return transfer. It is assumed that the Shuttle/Agena SOT option remains within

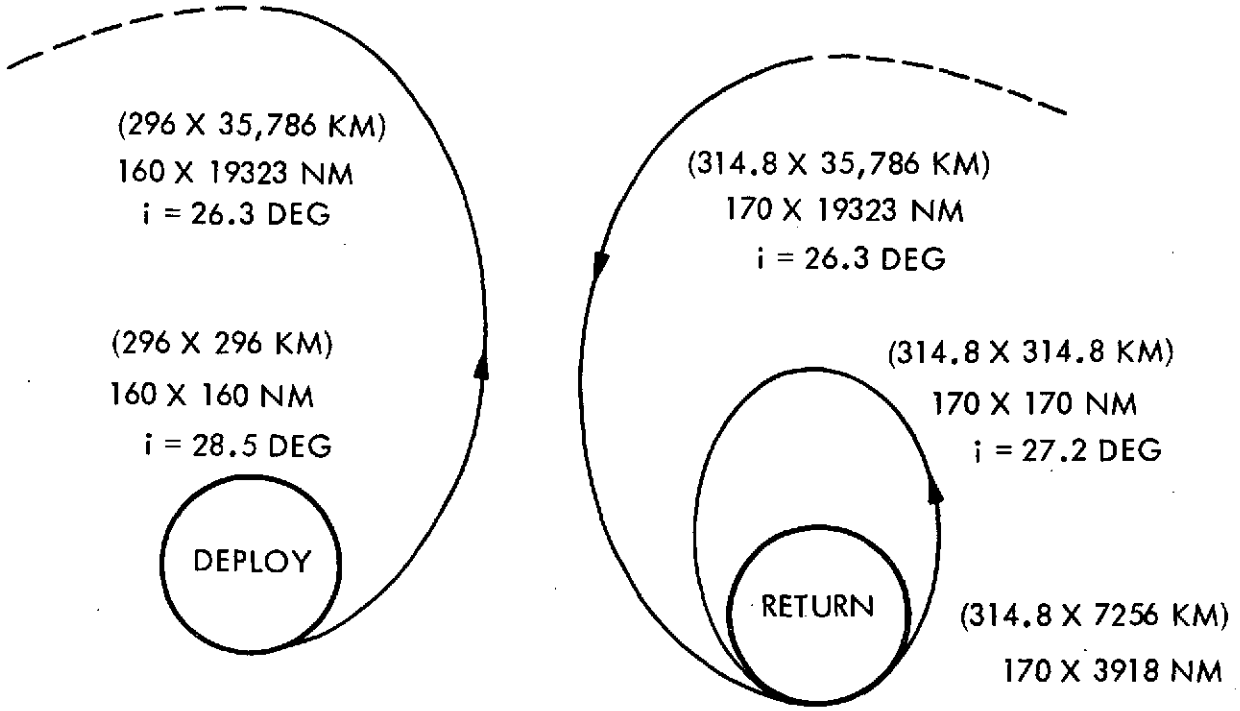


Fig. 3.7-1 Synchronous Equatorial Mission Profile

the Shuttle cargo bay until some desired node location can be acquired for the ascent portion of the mission. The Agena sequence is modified when the kick motor option is used.

3.7.1.2 Payload Capability. Tables 3.7-2 and 3.7-3 present the Agena capability with the strap-on tanks and/or apogee kick motor (AKM) options for the synchronous equatorial mission. The Agena with AKM and the Agena SOT configurations can deliver sizable payloads. The addition of an AKM to the Agena SOT vehicle further enhances its capability. The payload for this configuration is presented as an indication of potential and is not meant to imply that such a payload exists. The 300 pound (136 kg) adapter weight is considered as a spin table type of hardware, separated from the Agena, but jettisoned prior to kick motor ignition.

Table 3.7-1

SYNCHRONOUS EQUATORIAL MISSION SEQUENCE

Sequence Number	Time or (Duration) Hours or Seconds	Event or Mission Segment	Incl - Deg Hp Ha	 nm (km) nm (km)	Delta Vel. ft/sec (m/sec)	Alt - nm (km) Vel FPS (m/s) FPA Deg	
1	(4 sec)	Start Transient	28.5 160 160	 (296) (296)	0	160 25,367 0	(296) (7732)
2	(690 sec)	Main Engine Burn for Transfer Injection (Δi = 2.2°)	26.3 160 19,323	 (296) (35,786)	8046 (2452)	160 33,335.9 0	(296) (10,160.8)
3	(2 sec)	Shutdown Transient	26.3 160 19,323	 (296) (35,786)	0	160 33,335.9 0	(296) (10,160.8)
3-4	(5.27)	Coast to Apogee	26.3 160 19,323	 (296) (35,786)			
4	(1 sec)	Start Transient	26.3 160 19,323	 (296) (35,786)	0	19,323 5271.3 0	(35,786) (1606.7)
5	(250 sec)	Main Engine Burn for Synchronous Injection (Δi = 26.3)	0 19,323 19,323	 (35,786) (35,786)	5849 (1782.8)	19,323 10,008.3 0	(35,786) (3074.9)
6	(2 sec)	Shutdown Transient	0 19,323 19,323	 (35,786) (35,786)	0	19,323 10,088.3 0	(35,786) (1606.9)
6-7	(11.5)	Coast at Synchronous Altitude and Deploy Payload	0 19,323 19,323	 (35,786) (35,786)			
7	(1 sec)	Start Transient	0 19,323 19,323	 (35,786) (35,786)	0	19,323 10,088.3 0	(35,786 (1606.9)
8	(108 sec)	Main Engine Burn for Return Transfer (Δi = 26.3°)	26.3 170 19,323	 (314.8) (35,786)	5849 (1782.8)	19,323 5276.9 0	(35,786) (1608.4)
9	(2 sec)	Shutdown Transient	26.3 170 19,323	 (314.8) (35,786)	0	19,323 5276.9 0	(35,786) (1608.4)
9-10	(5.27)	Coast to Perigee	26.3 170 19,323	 (314.8) (35,786)			
10	(1 sec)	Start Transient	26.3 170 19,323	 (314.8) (35,786)	0	170 33,283.5 0	(314.8) (10,144.8)
11	(45 sec)	Main Engine Burn for Phase Orbit Injection (Δi = 0.92°)	27.22 170 3918	 (314.8) (7,256)	3972 (1210.7)	170 29,343.3 0	(314.8) (8943.8)
12	(2 sec)	Shutdown Transient	27.22 170 3918	 (314.8) (7256)	0	170 29,343.3 0	(314.8) (8943.8)
12-13	(2.8)	Coast One Revolution	27.22 170 3918	 (314.8) (7256)			
13	(1 sec)	Start Transient	27.22 170 3918	 (314.8) (7256)	0	170 29,343.3 0	(314.8) (8943.8)
14	(31 sec)	Main Engine Burn for Park Orbit Injection (Δi = 1.28)	28.5 170 170	 (314.8) (314.8)	4056.8 (1236.5)	170 25,332.6 0	(314.8) (7721.4)
15	(2 sec)	Shutdown Transient	28.5 170 170	 (314.8) (314.8)	0	170 25,332.6 0	(314.8) (7721.4)

The Agena general performance characteristics are presented in Figs. 3.7-2 through 3.7-5. The Agena is capable of placing heavy payloads in low to medium altitude earth orbits efficiently from either ETR or WTR and, as shown, the Agena with SOT configuration performs well for the geosynchronous and other high altitude missions. Flexibility can be obtained for planetary missions by the addition of a kick motor to the Agena or the Agena with SOTs. With this addition the Agena capability can be extended to place large payloads into the intermediate to high energy escape missions.

Table 3.7-2

AUGMENTED SHUTTLE/AGENA UPPER STAGE SYNCHRONOUS
(HDA/MMH PROPELLANTS – I_{SP} = 324 SEC)

Configuration	Payload lb (kg)			
	2/10% Weight Contingency 1.0% ΔV FPR		10% Weight Contingency 1.7% ΔV FPR	
Agena	N/A		N/A	
Agena/AKM	2,880(5)	(1306)	2,700(7)	(1226)
Agena SOT	3,560	(1615)	2,980	(1352)
Agena SOT/AKM	10,763(6)	(4881)	10,610(8)	(4813)
Expendable Agena SOT	13,200	(5987)	13,065	(5926)
Expendable Agena SOT/AKM	12,950(6)	(5874)	12,895(8)	(5849)

AKM Sizes

	(5)	(6)	(7)	(8)
Specific Impulse – sec	295	295	295	295
Propellant Weight – lb (kg)	2,702 (1225)	10,083(4573)	2,534(1149)	9,939 (4508)
Case Weight – lb (kg)	172 (78)	643(291)	162(73)	635 (288)
Adapter Weight – lb (kg)	300 (136)	300 (136)	300 (136)	300 (136)

Table 3.7-3

NOMINAL SHUTTLE/AGENA UPPER STAGE SYNCHRONOUS EQUATORIAL PAYLOAD CAPABILITY (HDA/MMH PROPELLANTS – I_{SP} = 324 SEC)

Configuration	Payload lb (kg)			
	2/10% Weight Contingency 1.0% ΔV FPR		10% Weight Contingency 1.7% ΔV FPR	
Agena	N/A		N/A	
Agena/AKM	2,885(1)	(1311)	2,710(3)	(1229)
Agena SOT	3,895	(1768)	3,362	(1525)
Agena SOT/AKM	10,930(2)	(4957)	10,838(4)	(4916)
Expendable Agena SOT	13,384	(6071)	13,305	(6035)
Expendable Agena SOT/AKM	13,109(2)	(5946)	13,075(4)	(5931)

AKM Sizes

	(1)	(2)	(3)	(4)
Specific Impulse – sec	295	295	295	275
Propellant Weight – lb (kg)	2,704 (1226)	10,241 (4645)	2,537 (1151)	10,154 (1606)
Case Weight – lb (kg)	173 (78)	654 (297)	162 (73)	648 (294)
Adapter Weight – lb (kg)	300 (136)	300 (136)	300 (136)	300 (136)

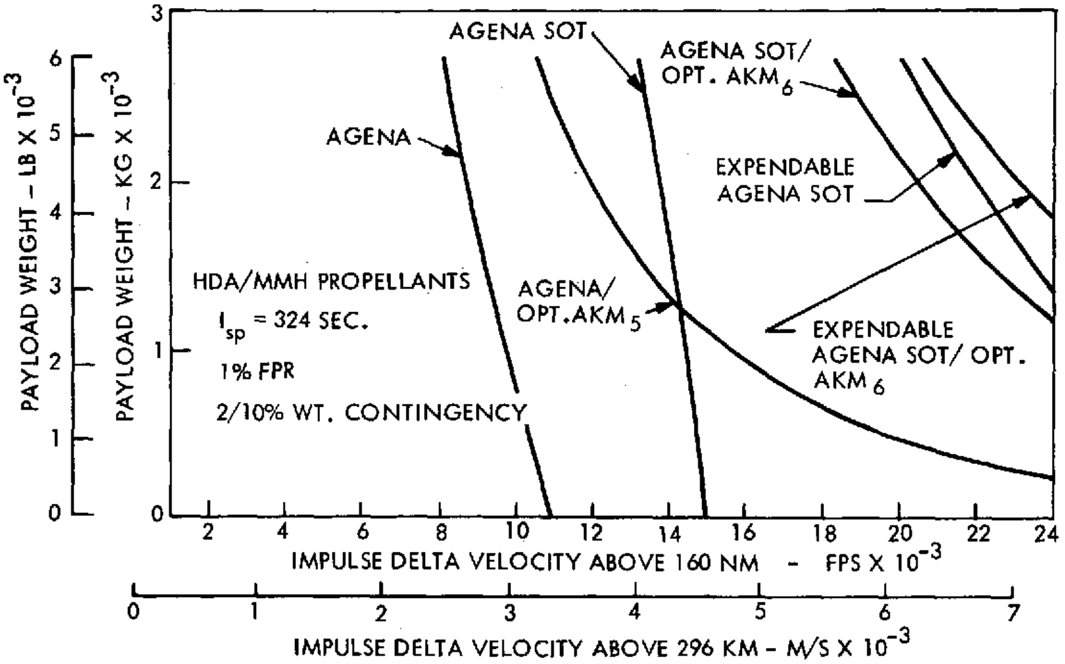


Fig. 3.7-2 Nominal Shuttle/Agena Upper Stage Payload Capability HDA/MMH Propellants – I_{sp} = 324 Sec – 1% FPR 2/10% Contingency

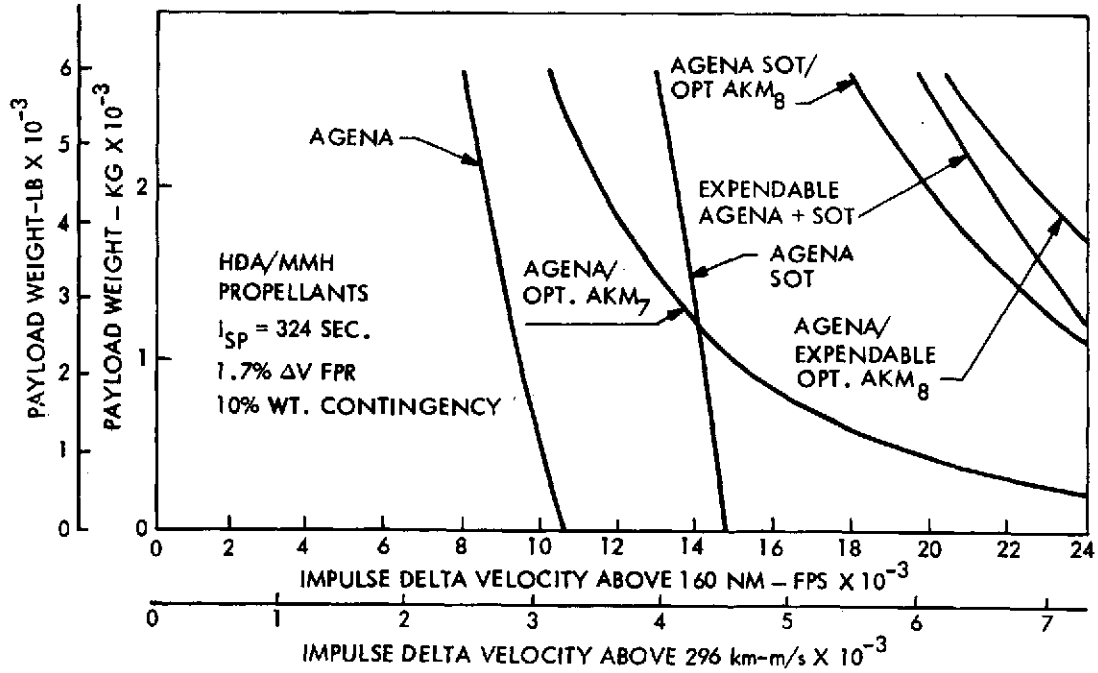


Fig. 3.7-3 Nominal Shuttle/Agena Upper Stage Payload Capability HDA/MMH Propellants – I_{sp} = 324 Sec – 1.7% ΔV FPR 10% Weight Contingency

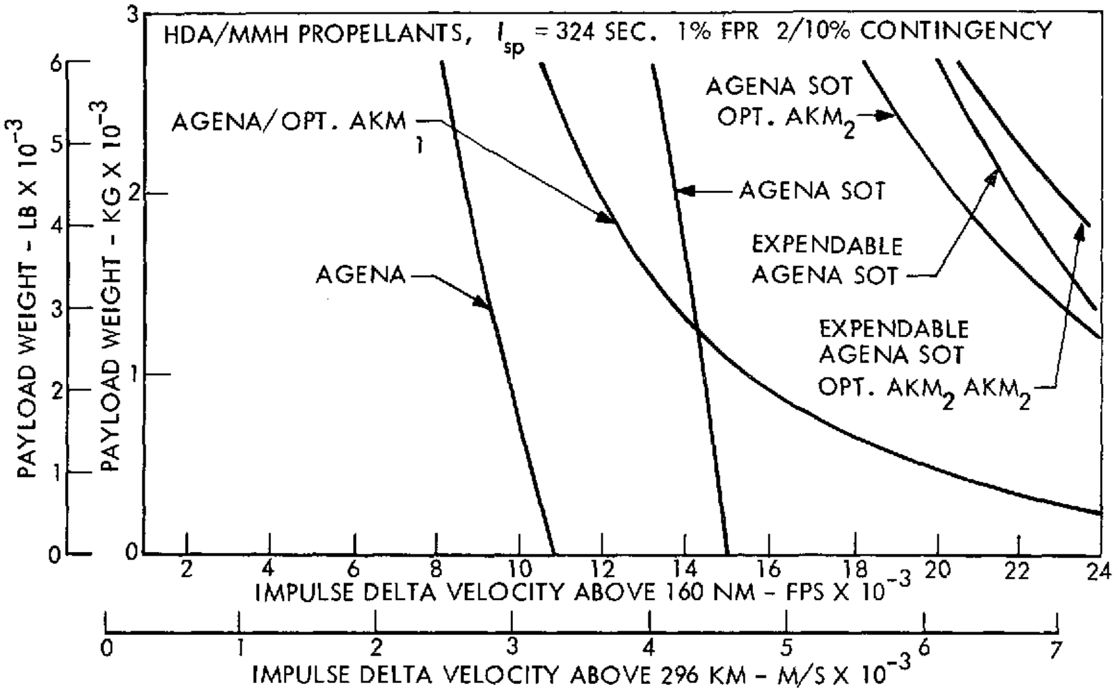
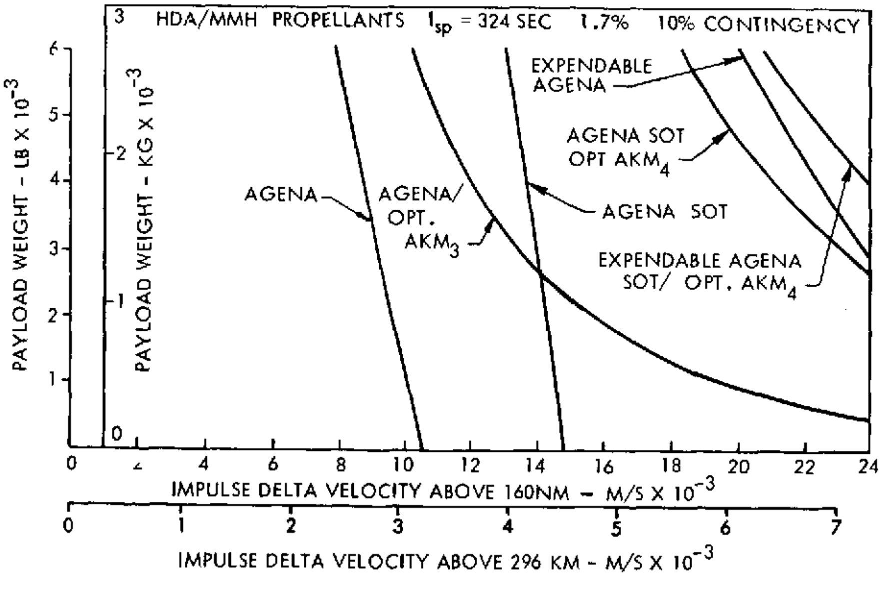


Fig. 3.7-4 Augmented Shuttle/Agena Upper Stage Payload Capability HDA/MMH Propellants – I_{sp} = 324 Sec, 1% FPR 2/10% Contingency



ALTERNATIVE SHUTTLE/AGENA UPPER STAGE PAYLOAD CAPABILITY

Fig. 3-7-5 Augmented Shuttle/Agena Upper Stage Payload Capability HDA/MMH Propellants – I_{sp} = 324 Sec, 1.7% FPR 10% Contingency

3.7.2 N_2O_4/MMH Agena Configuration Performance

Performance data for Agena configurations which use N_2O_4/MMH propellants are presented in Table 3.7-4 and Fig. 3.7-6 and 3.7-7. The Full Growth Agena is able to deliver large payloads to earth orbital missions. This configuration is capable of performing planetary missions when an existing kick motor (TE-364-19) is used. The expendable mode of operation is used when large payloads are required for the high energy missions.

The 5-ft (1.52 m) Shuttle/Agena is a flexible design because the core can be used for intermediate altitude missions, and when configured with strap-on tanks high altitude missions can be performed. If certain missions require additional capability, the SOT can be jettisoned, in pairs, thus extending the performance envelope as shown in Fig. 3.7-7. Existing kick motors such as the TE-364-19 can assist this configuration in delivering moderate sized payloads to interplanetary missions.

Table 3.7-4

SYNCHRONOUS-EQUATORIAL PAYLOAD CAPABILITY
FOR N_2O_4/MMH CONFIGURATIONS

I_{sp} = 326 Sec

Configuration	Payload	
	lb	(kg)
• 10 ft Full Growth Agena (N_2O_4/MMH)	3,340	(1,515)
• 5 ft Diameter Reusable Agena (N_2O_4/MMH)		
• With TE-M-364-19 Kick Motor	1,870*	(848)
• With 3 Strap-on Tank Kits	1,680	(762)
• 1 Ejectable Kit	3,005	(1,363)
• 2 Ejectable Kits	4,120	(1,869)
• 3 Ejectable Kits	5,240	(2,377)

*Increases to 2300 lb (1043 kg) with orbiter parking orbit of 600 nm (1111 km)

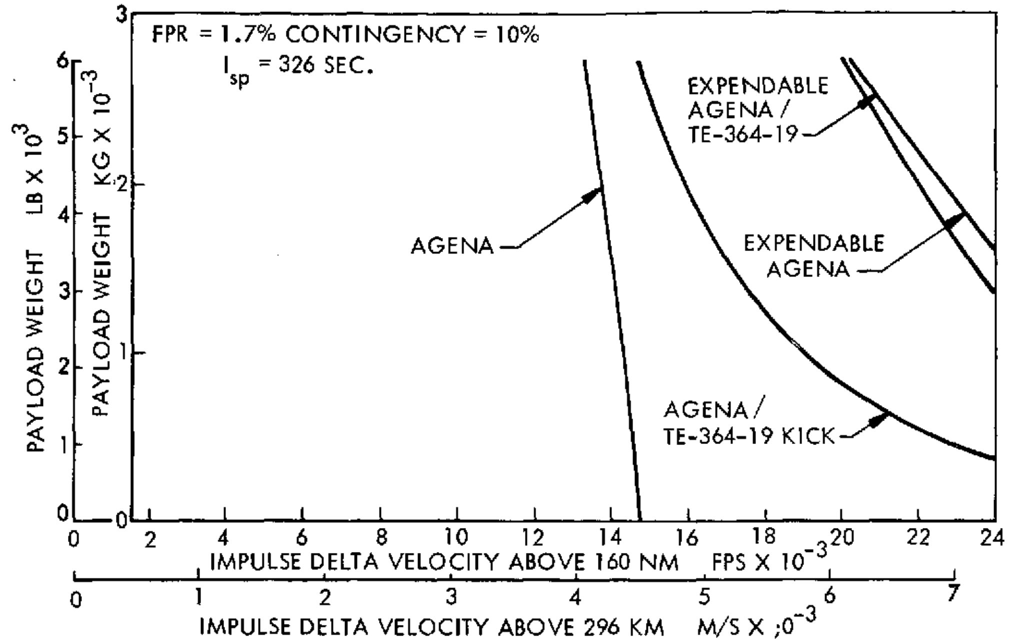


Fig. 3.7-6 Performance Capability – 10 Ft (3.04 m) Dia Full Growth Agena N_2O_4/MMH (FPR = 1.7%, Contingency = 10%, I_{sp} = 326 Sec.

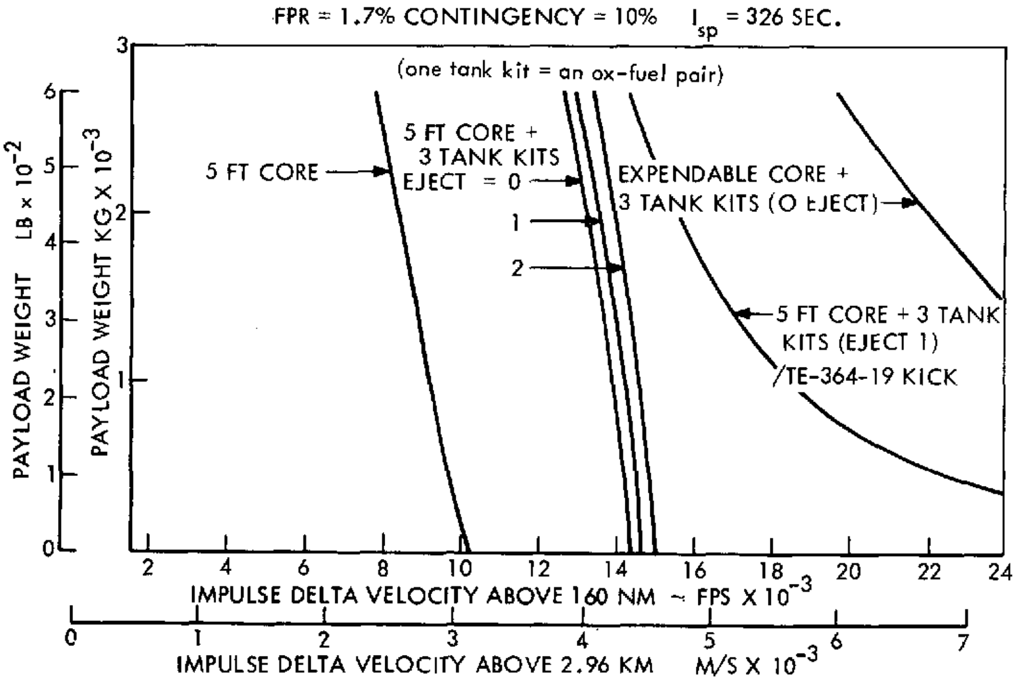


Fig. 3.7-7 Performance Capability – 5 Ft (1.52 m) Dia Reusable Agena (N_2O_4/MMH) – Strap-on/Drop Kits (FPR = 1.7%, Contingency = 10%, I_{sp} = 326 Sec

3.7.3 Mission Accomplishment

Mission model, vehicle concept, and placement mode are considered in mission capture analyses. The nominal mission model spans 11 years (1980-1990), has current design payloads only, and assumes that WTR is either operational in 1983 or not at all. Agena vehicles are considered with and without the SOT, with alternative propellants and with alternative weight contingencies. The weight contingencies are: (1) 10 percent on all dry weight and (2) 2 percent on existing hardware and 10 percent on new hardware (2/10 percent contingency). Nominally each mission is accomplished using one Agena flight (and one Shuttle flight) per payload, with no on-orbit assembly.

The objective is use of the Shuttle/Agena Upper Stage for optimum mission accomplishment for each set of conditions assumed. Optimum mission accomplishment means maximum percentage of missions captured at minimum transportation cost. This cost consists of operations costs and amortized investment cost for each flight.

Vehicle concepts possible, in order of increasing transportation cost, (not necessarily increasing performance) are:

R = Reusable Agena
RT = Reusable Agena + SOT
R/K_1 = Reusable Agena + optimum kick motor
RT/K_2 = Reusable Agena + SOT + optimum kick motor
E = Expendable Agena
ET = Expendable Agena + SOT
E/K_1 = Expendable Agena + optimum kick motor
ET/K_2 = Expendable Agena + SOT + optimum kick motor

The two kick motors are sized for maximum performance to synchronous equatorial orbit while augmenting the Agena in the reusable mode. Number one is sized for Agena alone, while number two is sized for Agena + SOT option.

For a particular mission, the first configuration in the order of increasing transportation cost which can accomplish the mission is the one chosen.

C-4

3.7.3.1 Mission Model. The basic mission model is essentially the Space Tug Study Traffic Model/Option 1 of August 10, 1973. Only current design payloads are assumed. Some payload placements have been eliminated from 1980 and 1981 because of a constraint which reduced Shuttle flights in those years to 3 and 21 respectively. Also, WTR does not become operational until 1983. Under these constraints the total numbers of payload placements are 93, 161, and 336 for the 4-, 6-, and 11-year models respectively. Payload placement breakdown by year and mission is presented in Table 3.7-5. When multi-payload placements are assumed, the number of payloads placed within the 3 and 21 shuttle flight constraint increases. Under the constraint that all flights must be launched from ETR, pre-1983 WTR flights which had been cancelled become available and the number of payload placements increases. These increases are shown in Table 3.7-6.

3.7.3.2 Mission Capture – Nominal HDA/MMH Concepts (Fig. 3.7-8). Significantly, both the 2/10 percent and 10 percent contingency versions of the Shuttle/Agena/Upper Stage capture 100 percent of the missions in the 11-year mission model. Of these, over 97 percent are performed in the reusable mode (Agena returns to the Shuttle). The 10 percent contingency case requires 21 percent Agena core stage only flights (R), 53 percent Agena + SOT flights (RT), 23 percent reusable flights augmented with a kick motor (R/K and RT/K), and less than 3 percent expendable Agena + SOT (ET) flights. The larger payload capability of the lighter 2/10 percent Agena results in a reduction in kick augmented flights to 11 percent and expendable flights to 1.2 percent. When WTR is closed, the polar missions launched from ETR require significantly more energy for accomplishment because of ETR launch azimuth constraints. Where previously all of the WTR missions had required an Agena core stage only, they now require RT, R/K, or RT/K configurations for mission capture. The result is a reduction to 2 percent R flights and increases to 5 percent, 8 percent and 7 percent respectively in RT, R/K, and RT/K flights. When WTR is closed, the only mission still captured using R only is the flexible sortie mission to low earth orbit.

Table 3.7-5

NOMINAL MISSION MODEL – SINGLE P/L FLIGHTS; ETR & WTR AVAILABLE

Mission No.	PAYLOAD CHARACTERISTICS						MISSION CHARACTERISTICS								PAYLOAD DELIVERY SCHEDULE (P/L Placements/Retrievals)											
	L		D		WT		HP		HAP		i		Velocity (Total)		– Year –											
	ft	(m)	ft	(m)	lb	(kg)	nm	(km)	nm	(km)	Deg	(rad)	FPS	(m/sec)	80	81	82	83	84	85	86	87	88	89	90	Total
1	6	(1.8)	5	(1.5)	500	(227)	19,323	(35,781)	19,323	(35,784)	0	(0)	27,903	(8,505)	2	2	2	1	2	1	1	1	2	1	2	17
2	8	(2.4)	5	(1.5)	800	(363)	19,323	(35,781)	19,323	(35,784)	0	(0)	27,903	(8,505)	1	2		1		1		1		1		7
3	10	(3.0)	6	(1.8)	1,100	(499)	19,323	(35,781)	19,323	(35,784)	0	(0)	27,903	(8,505)		7	3	3	1	5	5	6	7	2	3	42
4	22	(6.7)	9	(2.7)	1,500	(680)	19,323	(35,781)	19,323	(35,784)	0	(0)	27,903	(8,505)		1		2	1	1		2	1			8
5	17	(5.2)	10	(3.0)	1,800	(816)	19,323	(35,781)	19,323	(35,784)	0	(0)	27,903	(8,505)				3						3		6
6	12	(3.7)	8	(2.4)	2,600	(1,179)	19,323	(35,781)	19,323	(35,784)	0	(0)	27,903	(8,505)			1			1		1			2	5
7	20	(6.1)	10	(3.0)	3,000	(1,361)	19,323	(35,781)	19,323	(35,784)	0	(0)	27,903	(8,505)		1	2	2	1	2		2	1	1		12
8	25	(7.6)	14	(4.3)	3,500	(1,588)	19,323	(35,781)	19,323	(35,784)	0	(0)	27,903	(8,505)		1	1	2	2	2	2	2	2	2	2	18
9	7	(2.1)	5	(1.5)	750	(340)			1 AU ESCAPE				28,090	(8,562)			1		1		2		1		2	7
10	12	(3.7)	8	(2.1)	6,000	(2,722)	6,900	(12,778)	6,900	(12,778)	55	(0.95)	19,508	(5,946)		1			1			1			1	4
11	8	(2.4)	5	(1.5)	800	(363)	16,000	(29,631)	30,000	(55,557)	29	(0.50)	24,509	(7,470)		1		1		1		1		1		5
12	8	(2.4)	4	(1.2)	1,200	(544)	180	(333)	1,800	(3,333)	90	(1.57)	4,568	(1,392)				1		1		1		1		4
13	8	(2.4)	5	(1.5)	650	(295)	1,000	(1,852)	20,000	(37,038)	90	(1.57)	17,119	(5,218)				1		1		1		1		4
14	7	(2.1)	3	(0.9)	400	(181)	300	(555)	3,000	(5,556)	90	(1.57)	7,124	(2,171)				1	1	1	1	1	1	1	1	8
15	6	(1.8)	5	(1.5)	1,000	(454)	700	(1,296)	700	(1,296)	100	(1.74)	3,420	(1,042)				1	1	1	1	1	1	1	1	8
16	12	(3.7)	6	(1.8)	2,600	(1,179	500	(926)	500	(926)	99.2	(1.73)	2,238	(682)				4		4				6		14
17	12	(3.7)	10	(3.0)	1,000	(454)			ESCAPE				26,043	(7,938)										2		2
18	12	(3.7)	10	(3.0)	2,000	(907)			ESCAPE				26,043	(7,938)					2							2
19	20	(6.1)	12	(3.7)	5,500	(2,495)			ESCAPE				33,102	(10,089)							1	2				3
20	17	(5.2)	10	(3.0)	900	(408)			ESCAPE				46,298	(14,112)			2		2							4
22	16	(4.9)	12	(3.7)	2,500	(1,134)			ESCAPE				48,309	(14,725)							1	1		1	1	4
23	17	(5.2)	12	(3.7)	5,000	(2,268)			ESCAPE				36,971	(11,269)							2					2
24	17	(5.2)	12	(3.7)	3,300	(1,497)			ESCAPE				44,288	(13,498)					2						2	4
25	12	(3.7)	5	(1.5)	690	(313)	19,323	(35,784)	19,323	(35,784)	0	(0)	27,903	(8,505)		2	2	2	2	2	2	2	2	2	2	2
26	15	(4.6)	5	(1.5)	1,570	(712)	19,323	(35,784)	19,323	(35,784)	0	(0)	27,903	(8,505)			1	1	1		1	1	1		1	7
27	16	(4.9)	10	(3.0)	1,970	(894)	19,323	(35,784)	19,323	(35,784)	0	(0)	27,903	(8,505)			1	1	1	1	1	1	1	1	1	8
28	12	(3.7)	10	(3.0)	2,220	(1,007)	19,323	(35,784)	19,323	(35,784)	0	(0)	27,903	(8,505)				2	2		1		1	1	1	8
30	20	(6.1)	9	(2.7)	3,480	(1,579)	19,323	(35,784)	19,323	(35,784)	0	(0)	27,903	(8,505)						2		1		1		4
31	25	(7.6)	15	(4.6)	3,480	(1,579)	19,323	(35,784)	19,323	(35,784)	0	(0)	27,903	(8,505)					2			2			2	6
32	15	(4.6)	5	(1.5)	1,570	(712)	13,630	(25,242)	25,020	(46,335)	60	(1.04)	28,873	(8,800)			4	4	4		4	4	4		4	28
33	25	(7.6)	15	(4.6)	3,480	(1,579)	850	(1,574)	20,960	(38,816)	634	(1.10)	22,459	(6,846)			2	1		2	1		2	1		9
34	24	(7.3)	9	(2.7)	2,745	(1,245)	400	(741)	21,410	(39,649)	634	(1.10)	22,043	(6,719)		1		1								2
35	25	(7.6)	12.7	(3.9)	2,430	(1,102)	1,000	(1,852)	20,810	(38,518)	634	(1.10)	22,593	(6,886)		2	2	2	2	2	2	2	2	2	2	20
39	3	(0.9)	5	(1.5)	735	(333)	750	(1,389)	750	(1,389)	99	(1.72)	3,702	(1,128)				3	3		3	3		3	3	18
40	14.5	(4.4)	6.7	(2.0)	2,610	(1,184)	400	(741)	400	(741)	98.3	(1.71)	1,610	(491)				4		2	2		2	2		12
41	20	(6.1)	10	(3.0)	6,000	(2,722)	160-300	(296-555)	160-300	(296-555)	0-140	(0-2.44)	–	–				1/1		1/1		1/1		1/1		4/4
													TOTALS		3	21	24	45/1	34	34/1	32	41/1	31	40/1	31	336/4
															4 Yr Total			93/1								
																		6 Yr Total 161/2								

Table 3.7-6

PAYLOAD PLACEMENT TOTALS

P/L Placement Mode	Available Launch Site	Mission 4	Model Time 6	Span (Yr) 11
Single	ETR & WTR	93	161	336
Single	ETR Only	95	163	338
Multi	ETR & WTR	100	168	343
Multi	ETR Only	113	181	356

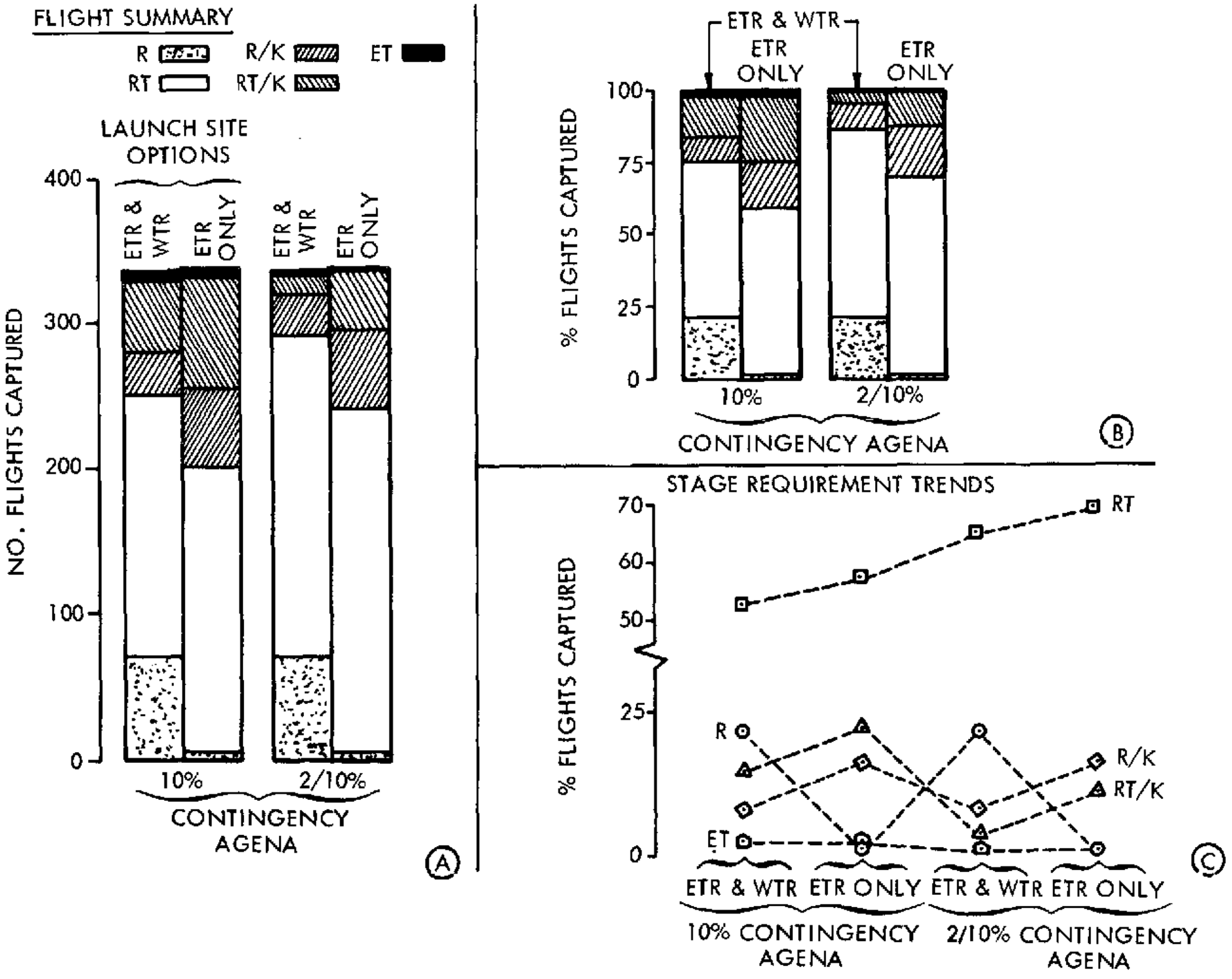
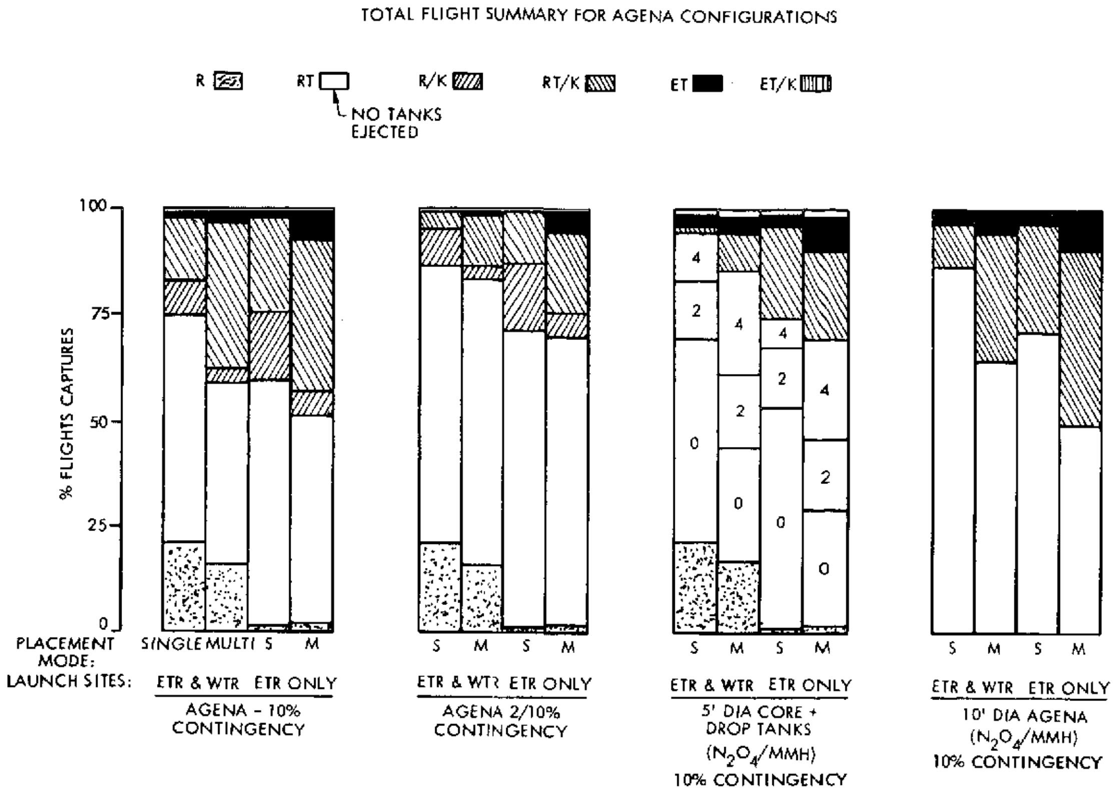


Fig. 3.7-8 Mission Capture Analysis

3.7.3.3 Mission Capture – Alternative Propellants and Concepts. In addition to the nominal mission capture configurations, alternative concepts and conditions are presented. These are: (1) mission model time spans of 4 years (1980-1983) and 6 years (1980-1985); (2) multi-placement of payloads on one Agena flight; (3) multi-placement of Agena during one Shuttle flight; and (4) two N_2O_4/MMH vehicle concepts. Multi-payload placement assumes that, under Shuttle cargo weight and dimension constraints, several payloads can be carried in the cargo bay and flown to their respective orbits on the Agena. The ground rules imposed on this operation are: (1) not more than three payloads within the cargo bay; (2) no multiple interplanetary flights; (3) DoD missions are not mixed on the same Agena flight; (4) only one Shuttle flight to support each multiple-placement Agena flight. The multi-Agena concept assumes the same ground rules as for the multi-placement configuration.

Figure 3.7-9 presents mission capture data for HDA/MMH concepts, N_2O_4/MMH concepts, the two launch site options, and two payload placement options (single and multiple). The two N_2O_4/MMH Agenas were discussed in par. 3.7.2. Their performance and mission capture capability is shown in Fig. 3.7-9 for comparison purposes. The multi-payload placement configuration significantly reduces the number of Agena flights required to capture 100 percent of the mission model. The greatest cost benefit is in the corresponding reduction of Shuttle flights. Shuttle and upper stage flights are reduced by approximately 33 percent for all vehicles. This great reduction shows the sizable benefits gained by utilizing a multi-payload delivery. While 100 percent of the mission model is captured for all configurations, the multi-payload mode requires greater percentages of kick motor augmentation and expendable Agena flights. This results because the Shuttle cost reduction in using higher performance modes of payload delivery (thereby delivering more payloads per flight) greatly offsets the cost increases of the kick motors and expendable flights.

Figure 3.7-10 shows the effects of mission model time span and multi-Agena Shuttle flights. The basic difference between the 4-, 6-, and 11-year models is the number of payload placements, not the type of payloads placed. By 1983, 78 percent of the missions will have had scheduled flights, including all but two of the synchronous equatorial missions. As the model time span lengthens, most of the additional missions are interplanetary. Therefore, there is no significant change in the percentage



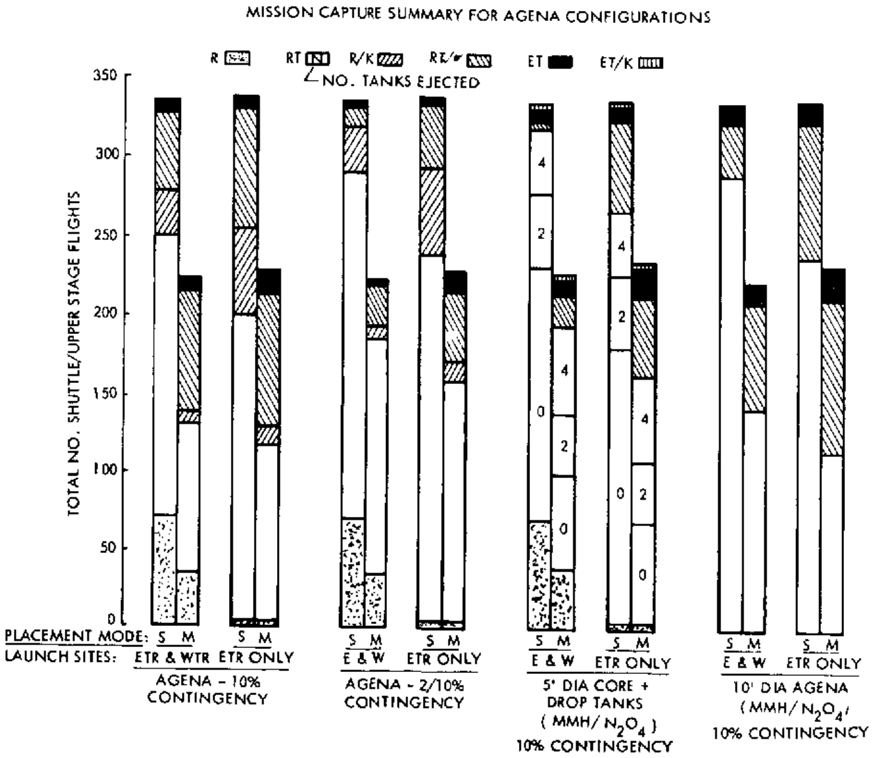
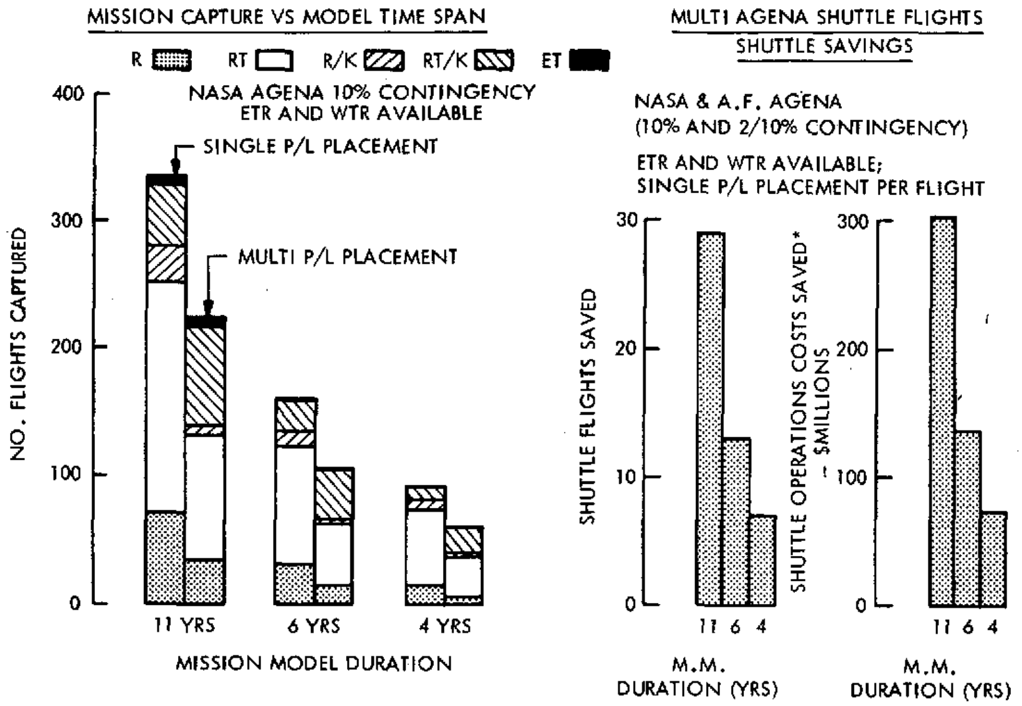


Fig. 3.7-9 1980 – 1990 Mission Capture Analysis



*BASED ON $10.5M
PER SHUTTLE LAUNCH

Fig. 3.7-10 Mission Capture Analysis for Agena Configurations

breakdown of Agena flights by type. For all three time spans, there are approximately 20 percent R flights, 55 percent RT flights and 25 percent expendable or kick augmented flights. Most of the additional expendable and kick augmented flights on the 11-year model are for interplanetary missions.

The effect of several Agenas delivered to the parking orbit by a single Shuttle flight is to reduce the total number of Shuttle flights. Because of weight and diameter constraints only, the Agena without SOT can be placed in the cargo bay in a multiple configuration. The multi-Agena shuttle flights therefore are proposed only for polar missions launched from WTR. The resultant Shuttle flight reduction is as high as 29 for the 11-year model, or about 8 percent. Assuming a $10.5 million Shuttle operations cost per flight, this results in a $304.5 million cost savings.

3.7.3.4 Conclusions. The basic Shuttle/Agena Upper Stage has the capability of providing 100 percent mission accomplishment for the 11-year mission model using over 97 percent reusable flights. Kick motor augmentation is required on 23 percent of the reusable flights for the 10 percent contingency vehicle and 15 percent for the 2/10 percent contingency vehicle. Closure of WTR loses no missions but does increase kick augmentation requirements. Multi-payload placement results in a 33 percent reduction of total Agena and Shuttle flights while capturing 100 percent of the missions. Shuttle operations cost of $300 million can be saved using the multi-Agena concept in the nominal configuration. No significant change in Agena configuration requirements is seen for different mission model time spans other than total number of flights.

3.8 OPERATIONS

This section presents the significant functional requirements and identifies supporting requirements for the ground processing cycle and the sequence of flight operations for the Shuttle/Agena Upper Stage concept.

3.8.1 Ground Operations

A plan for ground processing of the Shuttle/Agena Upper Stage at KSC is presented in this paragraph. The plan can also apply to WTR when those specifics of Orbiter and payload integration are better defined. The facility and equipment requirements are applicable to both KSC and WTR.

Ground rules and assumptions

a. The Space Tug Ground Operation Plan defined in the MSFC Space Tug System Study Data Package April 1973 was used as a guide to define the overall ground processing sequence of operations for the Agena.
b. The KSC Space Shuttle Processing Study dated March 6, 1973 was used to identify the Spacecraft and Orbiter integrating times for the prelaunch ground operational sequence.
c. After installation in the Orbiter cargo bay, all primary monitor and control for Agena health status and checkout will be by the Orbiter.
d. All test and checkout activities of Agena external to the Orbiter vehicle during Agena turnaround refurbishment and checkout will be controlled and evaluated by Agena peculiar automatic control and data evaluation equipment.

Ground Processing Plan. Ground processing of the Agena vehicle involves post landing retrieval, maintenance and refurbishment, and assembly and prelaunch. During both post landing recovery and prelaunch preparation, the Agena is integrated with other operational elements of the Shuttle system to perform the required operations. This study has concentrated on the maintenance and refurbishment phase which is peculiar to the needs of the Agena. The ground operations functional sequence is shown in Fig. 3.8.1-1.

Refurbishment. The Agena and its CBSS will be refurbished on a flight-to-flight basis for a next flight by performing maintenance and service on selected vehicle equipment and by demonstrating the performance capability of each system element through functional tests.

Maintenance. At the launch bases, maintenance activities will be conducted directly on the vehicle (Level I) or on equipment removed from the vehicle for performing bench-level servicing or calibrations (Level II). All repairs or rework of equipment that has been removed for replacement will be conducted at other contractor or government facilities (Level III ; i.e., depot level).

Scheduled maintenance tasks for the Agena will include the replacement of equipment at flight intervals as shown in Table 3.8.1-1. These replacement time intervals were established by assessing the equipment design life qualification capabilities versus the required mission duty cycles. The Agena design facilitates flight-to-flight servicing

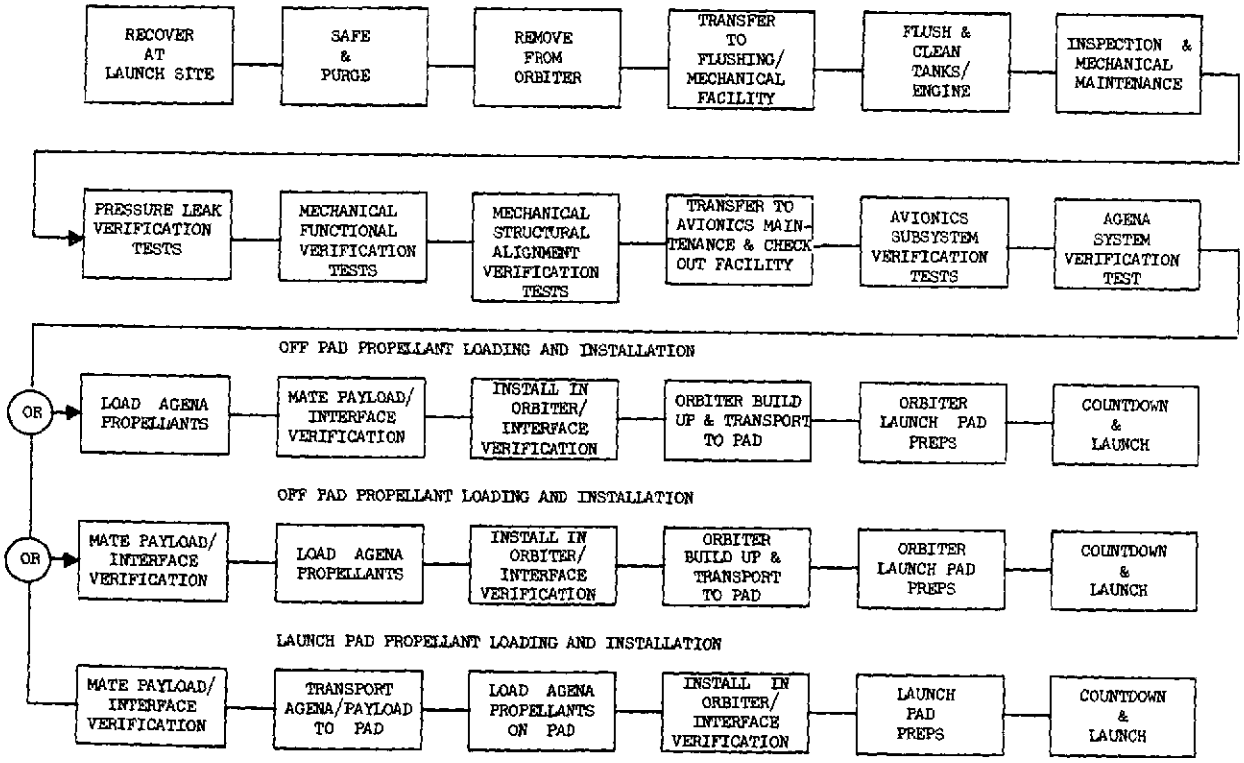


Fig. 3.8.1-1 Agena Ground Operations Sequence

Table 3.8.1-1

AGENA SCHEDULED EQUIPMENT REPLACEMENT

ASSEMBLY/EQUIPMENT		AFTER FLIGHT NUMBER																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
STRUCTURE											> 20										
CORE TANK				●			●			●			●			●			●		
STRAP-ON TANKS											> 20										
CBSS											> 20										
ENGINE (8096L)				●			●			●			●			●			●		
START SYSTEM				●			●			●			●			●			●		
EXH DUCT SHIELD						●					●					●					
PRESSURIZATION																					
He TANK											> 20										
VALVES (FILL/VENT)																●					
REGULATORS											●										
VENT DISCONNECTS											●										
FILL DISCONNECTS	FUEL				●				●				●				●				
	OX			●			●			●			●			●			●		
TVC																					
HYD POWER PKG								●							●						
SERVO ACTUATORS								●							●						
FEED/FILL/DUMP																					
PIVs	FUEL				●				●				●				●				
	OX			●			●			●			●			●			●		
DUMP VALVES																●					
SUMP/RETENTION DEVICE											●										
BELLOWS	FEED								●								●				
	FILL					●					●					●					
FILL DISCONNECT	FUEL				●				●				●				●				
	OX			●			●			●			●			●			●		
RCS/BUSS																					
HYDRAZINE TANKS																●					
VALVES, CPLGS, FILTERS																●					
HIGH MODE THRUSTERS											●										
LOW MODE THRUSTERS						●					●					●					●
THERMAL CONTROL MLI							●						●						●		
GN&C	IMU										●										
	CEA, HSA										> 20										
DM&I	COMPUTER										> 20										
	SERVICE CONSOLE										> 20										
EPS&D	BATTERY	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		
	DISTRIB BOXES										> 20										
	HARNESS										> 20										

and removal and replacement of equipment without disassembly of the vehicle except for the core tank and engine assemblies. For these replacements the vehicle will be disassembled and reassembled at designed assembly joints.

The core tank replacement has been programmed on a conservative basis to coincide with the hard time replacement interval of the engine (after each third flight). In practice it is anticipated that the replacement of the core tanks will be established on a flight-to-flight basis by visual and non-destructive test (NDT) assessment of tank structure and critical weld joints.

Unscheduled maintenance tasks will be determined after each flight by assessment of flight performance data and as the result of visual and NDT inspections and functional tests. This unscheduled corrective maintenance will be accomplished primarily through removal and replacement of the deficient component and/or in-place adjustment/calibration as appropriate. General flight-to-flight servicing will include the following:

Vehicle

- Flushing and cleaning of propellant tanks, engine assembly, and plumbing lines and disconnects
- Flushing and cleaning of hydraulic system
- Flushing and cleaning of RCS/BUSS system propellant tanks and plumbing
- Removal and reinstallation of MLI thermal blankets
- Removal and reinstallation of new batteries
- Removal and reinstallation of tape recorder tape
- Visual and NDT inspection of all structural elements and weld joints

Cargo Bay Support Structure (CBSS)

- Flushing and cleaning of propellant plumbing lines and disconnects

Avionics components will be refurbished on condition basis only. Evaluation of flight performance records will be used to identify components for replacement. Visual inspection of the avionics assemblies will be used to verify the integrity of all wiring connectors and harnesses.

After every third flight, in addition to the activities already identified, the core tank assembly will be replaced. The strap-on tanks will be removed and serviced. The Agena will be disassembled by removing the aft equipment rack/engine assembly and the forward equipment rack from the core tank assembly. The core tank will be replaced with a new tank to which the forward equipment rack and aft equipment rack/engine assembly will be reinstalled. After servicing activities, the propulsion, pressurization, and engine systems will be certified through performance of pressure, leak and functional tests. The structural assembly will be certified by mechanical alignments using theodolites.

Agena Verification Testing. During each turnaround cycle, maintenance activities are planned to ensure that all vehicle systems are restored to their original performance levels and both subsystem functional tests and avionics integrated systems tests will be made. Significant test requirements are shown in Table 3.8.1-2.

Table 3.8.1-2

AGENA GROUND OPERATIONS TESTING

Test Category	Test Requirements
Visual Inspection	• Structural – Interfaces, mechanical elements, equipment installations, pressure vessels, tank walls, weld joints • Avionics – Wire harnesses, connectors • Thermal – Insulation covering, paint
NDT	• Weld joints x-ray • Surface emissivity
Cleanliness Contamination	• Propellant tank flushing and cleaning • Hydraulic system fluid filtering • Gaseous system purging, filtering
Mechanical Alignment	• IMU and star sensors • Horizon sensor to guidance module • Engine gimbal axis • Attitude control thrusters
Functional Subsystems	• Propulsion pressurization valves and regulator functional and leak • Engine control valves functional and leak • Propellant and gaseous tanks leakage and pressure • Mechanical docking and separation system functional • Guidance inertial measurement unit and star sensor calibration and drift • Engine TVC gimbal response • Horizon sensor targeting response • Power system functional • Communication data management and instrumentation functional
Functional Systems	• Agena integrated – Interface simulation and mission sequence • Spacecraft/Agena integrated – Functional interfaces • Orbiter/Agena integrated – Functional interfaces
Status Checks Critical Safety and Health Functions Monitoring	• Ground launch readiness – Electrical power, propellant/gas tank Press temp Engine control valves Separation and docking systems Guidance and control – Computer self check

Propellant and gas tanks and plumbing will be leak pressure tested and all moving parts activated and sequenced. Tests will be individually controlled and monitored using test equipment such as the engine and the hydraulic test carts.

The test philosophy for avionics is to maintain a hands-off policy and to verify performance at the systems level. One exception to this will be a rate table calibration test of the module assembled IMU and star sensor assembly to ensure alignment and sensitivity characteristics. Required avionics subsystem testing will be determined by analyses of telemetry flight records and on-board recorded data. The refurbishment cycle will be completed with an integrated systems test of the Agena, using simulators for payload and orbiter interfaces.

The avionics integrated system checkout will be accomplished using the vehicle guidance computer (GC) with the vehicle telemetry system acting as the primary monitoring medium. The GC is controlled and monitored using the guidance system test support equipment. Agena system readiness will be verified as shown in Fig. 3.8.1-2.

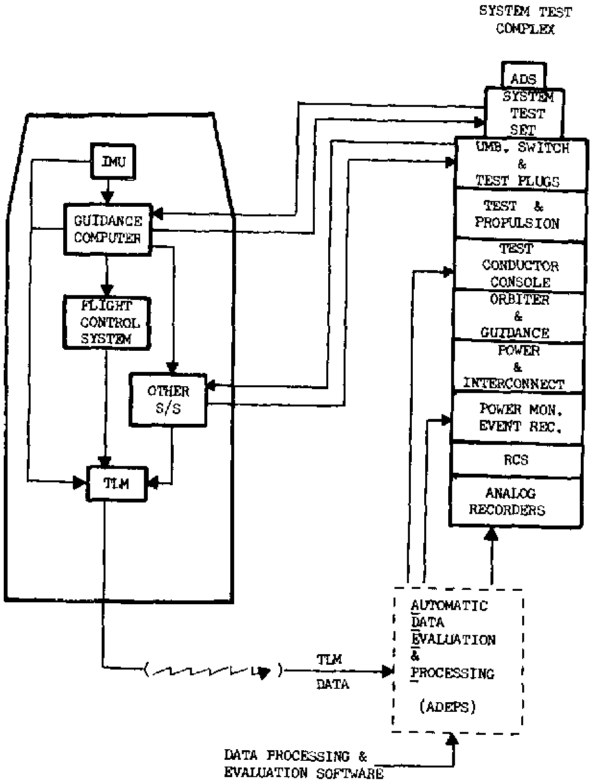


Figure 3.8.1-2 Ground Test Interfaces

The hardline data points are to be provided principally by the vehicle main electrical umbilical (MEU). A system test complex with a computer test set to control the vehicle computer supported by an automated computer-controlled data evaluation and processing system (ADEPS) will be used at the launch bases and in the factory for conducting evaluation of vehicle performance during system test operation. Figure 3.8.1-3 shows the interface between the vehicle and the ADEPS during conduct of system tests.

No specific requirements exist for direct interface with the proposed Shuttle Launch Processing System (LPS). It would be possible, however, to provide status and performance data on a real time or post test basis to the LPS through special input/output interface equipment with ADEPS.

Agena/Spacecraft Integration Testing. By groundrules of this study, functional interface with the spacecraft was not considered. After assembly of the spacecraft to the Agena, therefore, testing will consist of visual inspection of mating surfaces and verification of structural alignments and center of gravity. No functional system level testing will be required. For any spacecraft control and data monitor lines which may be carried through theAgena, an end-to-end continuity type test will be performed of the wire harness and connectors.

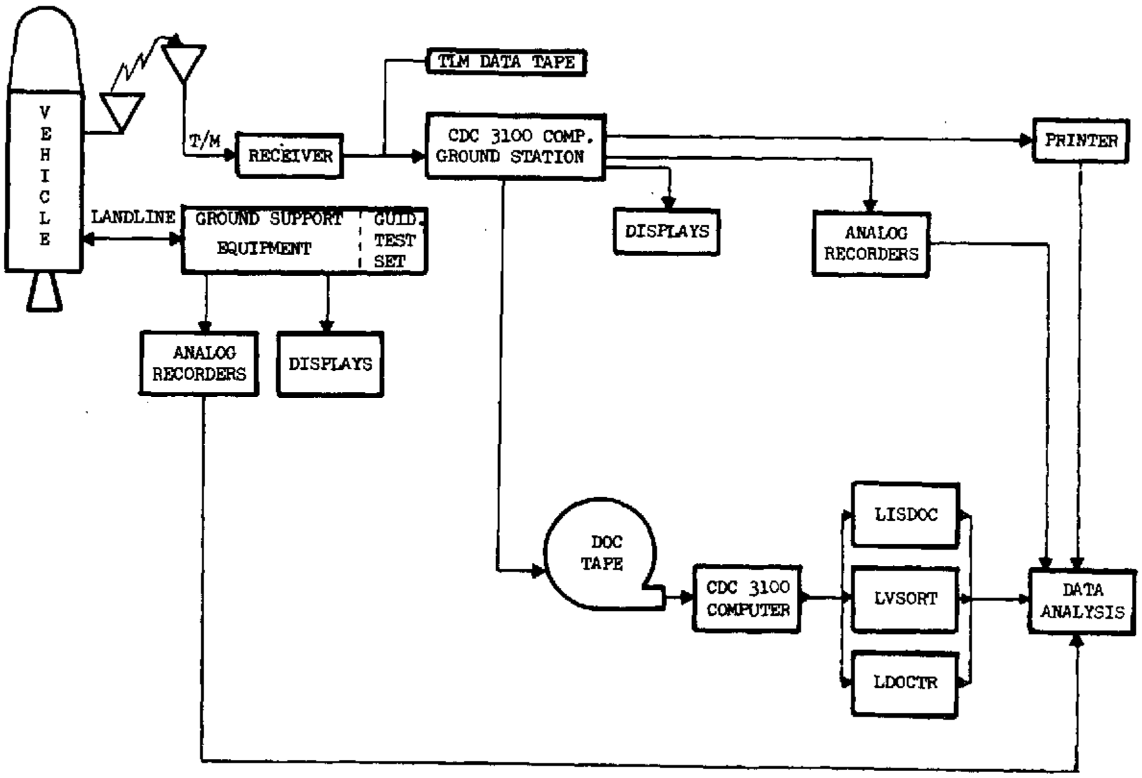


Fig. 3.8.1-3 Ground Test Data Interfaces

Agena/Orbiter Integration Testing. Primary control and monitor of the Agena after installation in the orbiter will be directly through the Agena service console. Test and checkout operation will be programmed and monitored through this console by the Orbiter data management system. Agena telemetry data will be transmitted by RF-link to the ADEPS in the Agena maintenance facility to provide a backup monitor and evaluation source during integrated Orbiter/Agena testing in the Orbiter assembly area or during launch pad operations. It is assumed that these operations will be under direct control of the Shuttle LPS.

Ground Test Software. Two major categories of ground test software will be required for the Agena. They are the vehicle guidance computer test software, and the data evaluation and processing software.

The vehicle GC test software will provide control inputs to the vehicle computer for direction of test sequence and functions for all vehicle systems actions. The test software will incorporate routines applicable to verify memory readouts and compare values, perform simulated flight, perform navigation, check alignment, check flight controls through end-to-end checks, check all discrete functions, and check all interface functions.

Data processing software will provide instructions to the ADEPS computer to process and evaluate vehicle performance data. The software programs will incorporate routines to enable the ground computer to scan the telemetry data automatically, determine which measurements have violated a limit or aperture value, and print out the results on a CRT or printer display.

Assembly and Pre-Launch Sequencing Options. The Agena configuration can meet the assembly and prelaunch requirements for ground processing in accordance with the three propellant/gas loading options as shown in Fig. 3.8.1-1.

The results of trade-off analysis involving functional and operational interfaces are indicated in Table 3.8.1-3.

Table 3.8.1-3

AGENA PROPELLANT/GAS LOADING OPTIONS

OPTION	PROCEDURE SEQUENCE	SAFETY	HANDLING/MATING/TRANSPORT	FACILITY/EQUIPMENT	TIME LINE
1 Off Pad Loading - before mating spacecraft	°Load propellant/gas in Agena °Mate spacecraft °Transport to orbiter facility °Install in orbiter	°Agena only during loading °Mating inside orbiter during shuttle assy	°Vertical spacecraft mate °Vertical transport loaded °Vertical orbiter installation	°Propellant/gas loading facility °Overhead hoist °Vertical stand °Propellant/gas transfer equipment °Fixed installation	°To launch 174 hours °Agena turnaround 404 hours
2 Off Pad Loading - after mating spacecraft	°Mate spacecraft °Load propellant/gas in Agena °Transport to orbiter facility °Install in orbiter	°Agena and spacecraft during propellant/gas loading °Mated inside orbiter during shuttle assy	°Horizontal/vertical S/C mate °Horizontal/vertical transport before loading °Vertical transport loaded °Vertical orbiter installation	°Same as Option 1	°To launch 150 hours °Agena turnaround 404 hours
3 Pad Loading - after mating spacecraft	°Mate spacecraft °Transport to pad °Load propellants on pad °Install in orbiter	°Controlled access °Pad environment °Installed in orbiter after assembly and pad interface	°Horizontal/vertical S/C mate °Horizontal/vertical transport °Vertical orbiter installation °Controlled mechanized mating	°Pad payload change-out shelter °Installation/removal device °Propellant/gas transfer equipment	°To launch 54 hours °Agena turnaround 336 hours

There is very little discrimination between Option 1 and Option 2. The selection between loading the Agena before mating the spacecraft rather than after mating would probably be governed by the spacecraft configuration and handling requirements. Option 1 results in the maximum time from propellant loading to launch for the Agena of 174 hours. The Agena turnaround time for either option is 404 hours. Option 3 delays the time for installation of the Agena/spacecraft until the later phases of the Shuttle schedule and thereby reduces the Agena ground processing span by 68 hours from Option 1 or 2. This option further delays the loading of Agena propellant/gases until 54hours prior to launch.

Turnaround Schedule. Agena turnaround begins after removal of the vehicle from the Orbiter and delivery to the Agena maintenance area for scheduled maintenance operations.

The turnaround schedule shown in Fig. 3.8.1-4 was developed by analysis of the tasks required to refurbish the Agena vehicle and to integrate with other elements of the Shuttle system. Mechanical maintenance and servicing takes place in a propellant flushing facility and requires 110 hours; electronic systems maintenance and checkout takes place in a maintenance and checkout facility and requires 120 hours, culminating with an integrated systems test to verify the Agena readiness for flight.

Assembly and prelaunch activities can be performed in either of two optional sequences, an On-Pad Integration Sequence and an Off-Pad Integration Sequence. The Pad Integration Sequence assumes the conduct of Agena propellant/gas loading on the launch complex and subsequent installation and integration with the Orbiter vehicle. This sequence requires 106 hours. For this optional sequence, the turnaround schedule for the Agena is 336 hours. On a two-shift working basis this equals approximately 21 working days (about 30 calendar days).

The off-pad integration sequence assumes the conduct of Agena propellant/gas loading at an off-pad facility and subsequent installation and integration with the Orbiter vehicle in the Orbiter assembly area before transfer to the launch complex. This sequence requires 174 hours. For this option, the Agena turnaround schedule is 404 hours. This is equivalent to approximately 26 working days (about 36 calendar days).

Agena Operating Cycle. Typical Agena operating cycles are shown in Fig. 3.8.1-5 for both ETR and WTR launch operations. The mission model used in this study has an average launch rate of 24 launches per year from ETR and 12 launches per year from WTR.

Turnaround maintenance for the Agena requires 230 hours. The maximum assembly and pre-launch integration time span requires 174 hours for off site propellant loading and Agena/payload installation in the Orbiter maintenance facility. An ETR launch rate of 24 launches per year results in a fleet size requirement of 4 Agenas when an average mission of 5 days is assumed. A 17 calendar day maintenance contingency will exist for each vehicle processing sequence to provide assurance that an Agena will always be available to accommodate variations in the mission traffic model.

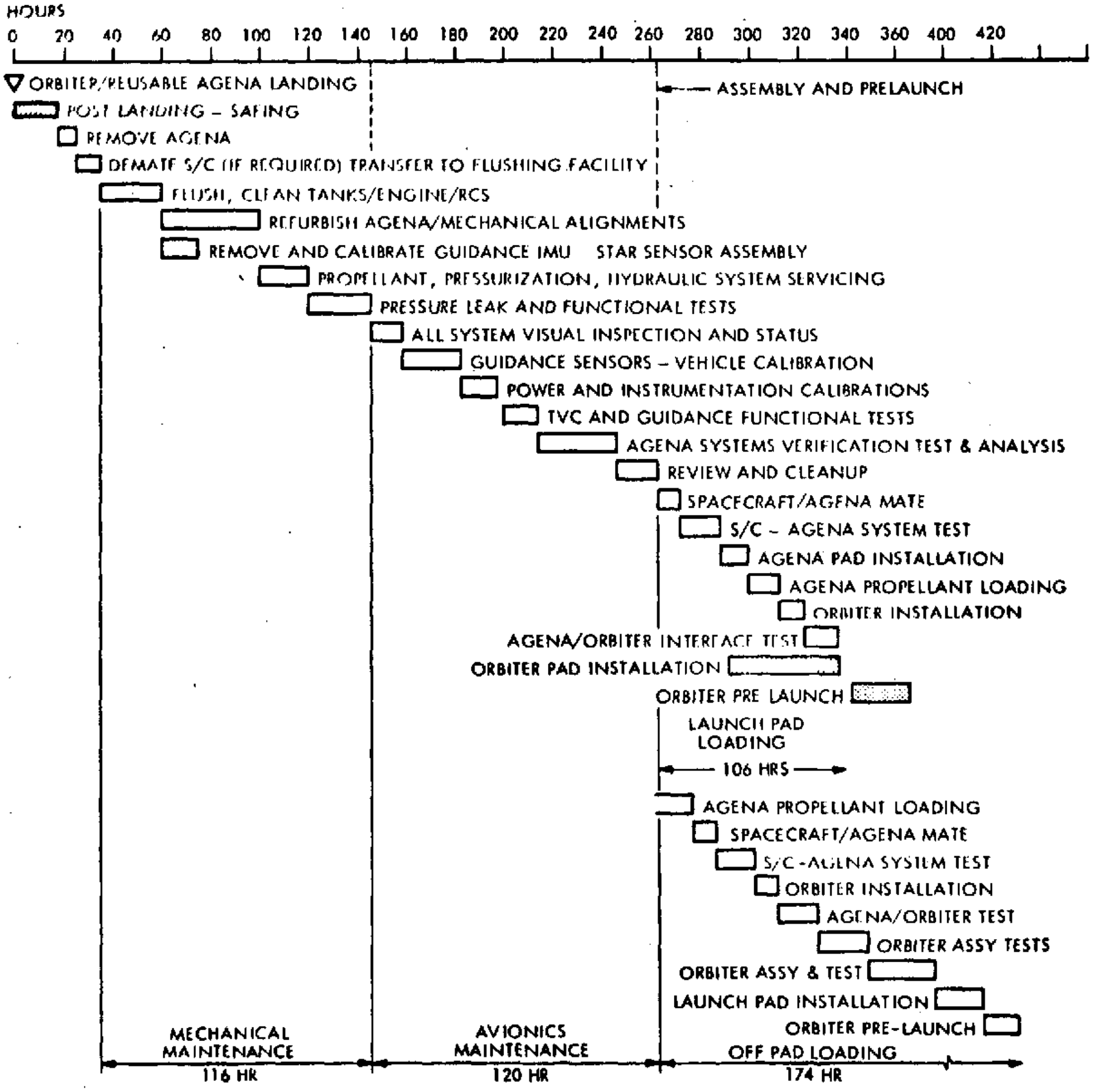


Fig. 3.8.1-4 Ground Turnaround Schedule

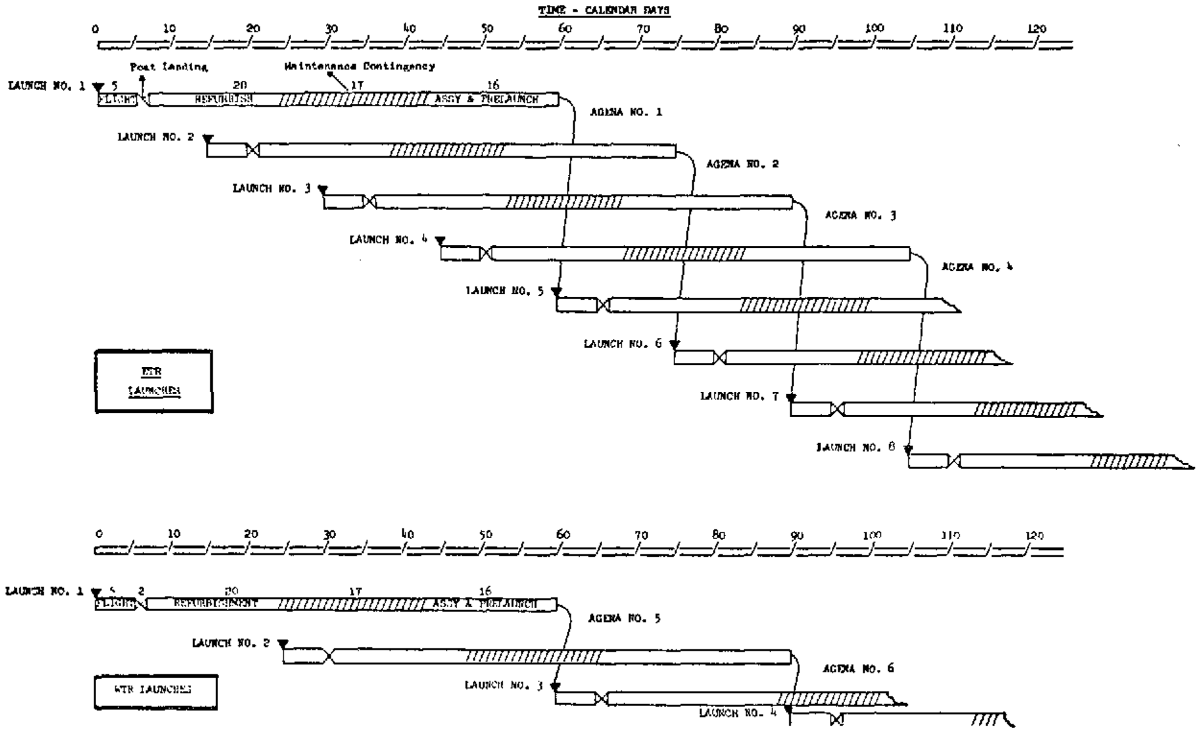


Fig. 3.8.1-5 Agena Fleet Operating Cycle

Where the average launch rate at WTR is 12 per year, two Agena vehicles will accommodate the traffic model. The total operating Agena fleet size would be six vehicles at any one time.

Manpower Requirements. The launch base manpower requirements were estimated from LMSC experience with Agena at both ETR and WTR. The results were adjusted to provide a headcount level, two-shift crew loading at ETR/WTR as shown in Table 3.8.1-4. This level will provide for level 2 maintenance support shop activity such as metal, electrical, paint, battery, and valve. The manpower levels shown will accommodate the mission model launch rate projected for ETR of one launch every two weeks and for WTR of one launch every month.

The manpower buildup to support IOC activities at the launch base is indicated below:

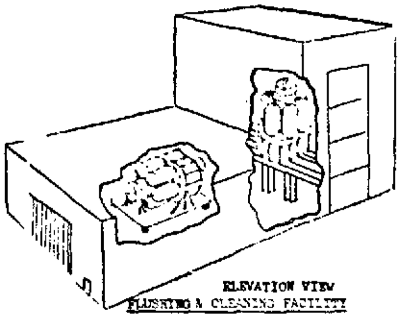
Table 3.8.1-4
LAUNCH BASE MANPOWER REQUIREMENTS

	CALENDAR YEAR												
	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
ETR	14	80	116	155	155	155	155	155	155	155	155	155	155
WTR				12	60	106	106	106	106	106	106	106	106

	ETR			WTR		
MANPOWER SKILLS / SHIFT	1	2	TOTAL REQ	1	2	TOTAL REQ
SUPPORT						
FINANCE & ACCOUNTING	2		2	2		2
PROCUREMENT	1		1	1		1
GOVERNMENT PROPERTY CONTROL	1		1	1		1
BLUEPRINT CONTROL	1	1	2	1	1	2
FACILITIES	1		1	1		1
PLANS & SCHEDULES	2		2	2		2
TECHNICAL DOCUMENTATION	1		1	1		1
SPARES & TOOLS	3	1	4	3	1	4
GSE DESIGN & MAINTENANCE	2		2	2		2
SAFETY	2	1	3	2	1	3
PRODUCT QUALITY						
INSPECTORS	7	3	10	4	2	6
RELIABILITY ENGINEER	2		2	1		1
QUALITY ENGINEER	1	1	2	1	1	2
TECHNICAL SUPPORT	2		2	2		2
OPERATIONS						
ELECTRICAL ENGINEERS	7	3	10	4	2	6
MECHANICAL ENGINEERS	7	3	10	4	2	6
SYSTEM ENGINEERS	3	1	4	2	1	3
OPERATIONS INTEGRATION	3	1	4	2	1	3
MECHANICAL TECHNICIANS	18	10	28	11	6	17
ELECTRICAL TECHNICIANS	18	10	28	11	6	17
TEST CONDUCTORS	3	1	4	2	1	3
DATA PROCESSING TECHNICIANS	2	2	4	2	1	3
DATA ANALYSIS & EVALUATION	8	4	12	6	2	8
MANAGEMENT & ADMINISTRATION						
MANAGERS & SUPERVISION	7	3	10	4	2	6
SECRETARY & TYPIST	5	1	6	3	1	4
TOTAL	109	46	155	75	31	106

Facility Requirements. Four facilities have been identified to support launch base ground processing of the Agena as shown in Fig. 3.8.1-6.

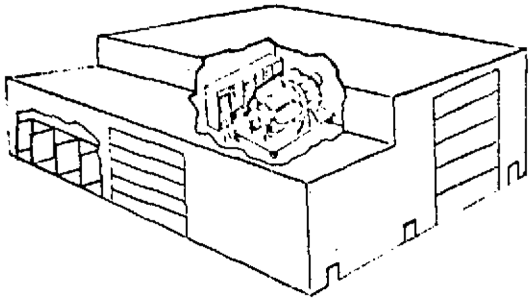
1. The Flushing and Cleaning Facility. Used for propellant tank and engine flushing and cleaning. In addition, all pressure tests, engine servicing, mechanical tests and alignments will be performed in this facility.



ELEVATION VIEW

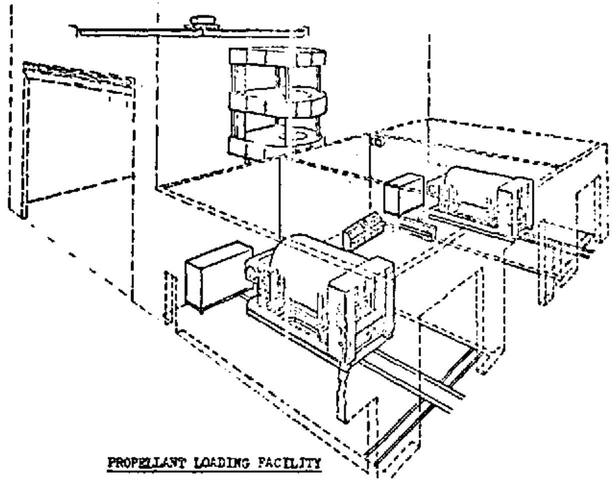
FLUSHING & CLEANING FACILITY

- 6400 SQUARE FEET FLOOR SPACE
- 60 FOOT HIGH BAY AREA
- 5 TON BRIDGE CRANE
- VERTICAL STANDS
- FLUID CONTAINMENT TRAILERS
- FLUID CONTROL EQUIPMENT & PLUMBING
- PRESSURIZATION SYSTEM
- PRESSURE TEST AREA
- WATER & LIQUID DRAINAGE SYSTEMS
- ENGINE SERVICE AREA



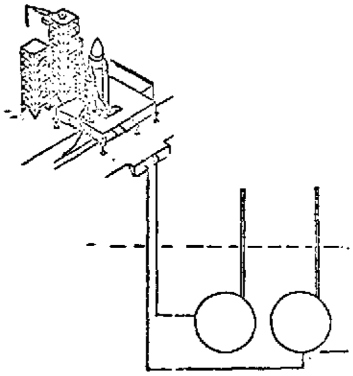
MAINTENANCE & CHECKOUT FACILITY

- 68000 SQUARE FEET FLOOR SPACE
- 50 FOOT HIGH BAY AREA
- 10 TON BRIDGE CRANE
- DATA EVALUATION & PROCESSING SYSTEM
- VEHICLE TEST STATION
- SIX SUPPORT SHOPS
- ENGINEER & ADMINISTRATIVE OFFICES
- CLASS 100,000 CLEANLINESS
- RECEIVING & SHIPPING DOCKS
- PARTS & STORAGE



PROPELLANT LOADING FACILITY

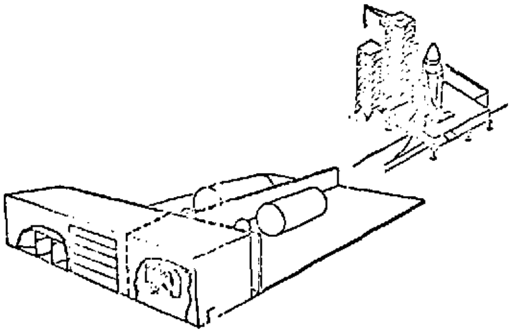
- 3800 SQUARE FEET FLOOR SPACE
- 80 FOOT HIGH BAY AREA
- 50 TON BRIDGE CRANE
- VERTICAL STAND
- PROPELLANT TRANSFER UNIT
- SPS SERVICE UNIT
- PROPELLANT & PNEUMATIC CONSOLE
- HIGH PRESSURE CONSOLE
- TV MONITORING



LAUNCH PAD

PROPELLANT OFF LOADING FACILITY

- STAINLESS STEEL TANKS 2 EACH (15 FEET BELOW GROUND)
- BURN STACK - EACH TANK
- PLUMBING LINES/INTERCONNECTS/CONTROL VALVES



LAUNCH PAD

PROPELLANT LOAD & DUMP FACILITY

- CONCRETE PAD 1400 SQUARE FEET
- REVETMENT WALL 660 SQUARE FEET
- PROPELLANT TANKS
- CONTROL BUILDING
- 10 HP PUMPS
- PROPELLANT LOADING CONSOLE
- GAS LOADING CONSOLE
- LIGHTING/POWER
- WATER DELUGE SYSTEM
- PLUMBING LINES/INTERCONNECTS/CONTROL VALVES

Fig. 3.8.1-6 Shuttle/Agena Upper Stage – Launch Base Facility Requirements

2. The Maintenance and Checkout Facility. Used for receiving/inspection, refurbishment/repairs, integrated tests and storage of the Agena vehicle. This facility will also house the necessary shops, administrative and engineering offices.
3. The Propellant Loading Facility. Used to load propellants and pressurize the gas systems of the vehicle.
4. The Launch Pad Propellant Off Loading Facility. Used to contain propellants from the Agena vehicle in the event of an abort condition requiring removal of the propellants from the vehicle at the launch pad.

Items 3 and 4 will support the Agena prelaunch processing sequence for off-pad propellant loading and Orbiter installation as identified in the functional flow sequence, Fig. 3.8.1-1. To accommodate the optional sequence for propellant loading and installation at the launch pad, the alternative facility indicated below would be used in lieu of items 3 and 4.

> Launch Pad Propellant Load and Dump Facility. Used to load propellants and gas systems of the vehicle while installed in the payload change out room on the launch pad. In addition, this facility will provide the capability for containment of dumped propellants from the Agena in the event of an abort operation.

Existing Facility Utilization. Because the Agena will use propellants that are compatible with the Orbiter OMS, the planned OMS propellant servicing facility may be adapted for servicing Agena propellant and pressurization systems. (Table 3.8.1-5). The low bay area in the VAB or the NASA Hangar S Building at CKAFS would serve as satisfactory alternatives for the maintenance and checkout facility and all facilities could be located in either the KSC or CKAFS areas at ETR.

Ground Support Equipment Requirements. The GSE for the Shuttle/Agena is essentially the same as that used on the Ascent Agena. GSE is categorized as servicing, handling, and checkout and test equipment as defined in this section.

Servicing Equipment. The servicing equipment supports the Agena during refurbishment and pre-launch activities, including flushing and cleaning, pressure testing, propellant and gas loading. This equipment is listed in Table 3.8.1-6.

Table 3.8.1-5
SHUTTLE AGENA UPPER STAGE FACILITY ALTERNATIVES

Facility Name	Functions	Alternate Sites		
		KSC	CKAFS	WTR
Flushing and Cleaning	• Flushing and Cleaning • Engine Servicing • Mechanical Maintenance • Mechanical Checkout	S/C Support Bldg M7-1210/12	Hanger E	Flush – Bldg. 1140 Mechanical – Bldg. 8310
Maintenance and Checkout	• Receiving and Storage • Shops and Engineering • Avionics Maintenance • Agena Integrated Systems Test	VAB – Low Bay	Hanger S	Bldg. 8310
Propellant Loading Off-Pad	• Propellant Loading • Gas Loading	S/C Support Bldg. M7-1210/12	Launch Complex 13	New
Launch Pad Propellant Off Loading	• Launch Pad Propellant Drain	Combine With Orbiter OMS Pad Pad Dump		Combine With Orbiter OMS Pad Dump
Launch Pad Propellant Load and Dump (Optional Facility)	• Propellant Loading • Gas Loading	New		New

Table 3.8.1-6
AGENA GSE REQUIREMENTS

SERVICING

NAME-DESCRIPTION	# REQ	
	WTR	ETR
FLUSHING TRAILERS	E	E
CHROMIC TRAILER	E	E
PROP. SYS FLUSH CART	E	E
PRESS. SYS CHECKOUT CART	E	E
HYD. PWR. SIM. CART	E	E
HYD. PWR. SIM. CONTROL CART	E	E
HYDRAULIC TEST PANEL	E	E
NITROGEN CART ASSEMBLY	E	E
NITROGEN HEATER ASSEMBLY	E	E
HYDRAULIC GROUND TEST UNIT	E	E
PANEL ASSY-HYDRAULIC FILTERING	E	E
PANEL ASSY-HYDRAULIC MOTOR GAUGE	E	E
NITROGEN CONTROL PANEL ASSY	E	E
FILTER CART	E	E
R2S BUSS CHECKOUT CART	E	E
PIV CHECKOUT BOX	E	E
GAS COMPRESSOR MODULE	E	E
TRAILER ASSY N_2 & He HI PRESS	E	E
SERVO ACTUATOR TEST ASSY	E	E
PRESS MONITORING FIXTURE	E	E
HELIUM LEAK DETECTOR	E	E
PROPELLANT TRANSFER UNIT	E	E
PNEUMATIC CONTROL CABINET	E	E
HIGH PRESSURE GAS PANEL	E	E
GUIDANCE GAS COMPRESSOR MODULE	E	E
PROPELLANT & PNEUMATIC CSL	E	E
LEAK DETECTOR - PROPELLANT	E	E

GROUND HANDLING

NAME-DESCRIPTION	# REQ	
	WTR	ETR
AGENA CORE HANDLING DOLLY	E	E
AGENA YOKE RINGS (2 PER SET)	E	E
AGENA SPRDR BEAMS (2 PER SET)	E	E
AGENA TRANSPORTER	E	E
AGENA TILT SLING	E	E
AGENA HORIZONTAL HOIST BEAM	E	E
AGENA RING REMOVAL SLING	E	E
AGENA FORWARD RACK DOLLY	2	4
AGENA FORWARD RACK SLING	1	2
AGENA TANK DOLLY	2	4
AGENA TANK SLING	1	2
AGENA ENGINE DOLLY	2	5
AGENA ENGINE SLING	1	2
AGENA - ASSEMBLY STAND	1	2
AGENA - FLUSHING STAND	1	2
AGENA - HOIST FRAME	2	4
AGENA - VERTICAL/TILT SLING	2	4
AGENA - HORIZONTAL SLING	2	4
AGENA - HRZNTL TRANSPORTER	1	2
AGENA - VERTICAL TRANSPORTER	1	2
AGENA - BALLAST WEIGHTS	1	3
AGENA - HANDLING DOLLY	3	6
STRAP-ON TANK HANDLING DOLLY	6	12
STRAP-ON TANK HOIST SLING	2	4
STRAP-ON TANK HOIST FIXTURE	3	6
STRAP-ON TANK AFT PIVOT	3	6
CARGO BAY SUPPORT CRADLE DOLLY	3	6
CARGO BAY SUPPORT CRADLE SLING	1	3
KICK STAGE HANDLING DOLLY	1	3
KICK STAGE HOIST TRUNNIONS	1	3
KICK STAGE HOIST SLING	1	2
PROTECTIVE COVERS (SET)	6	6

CHECKOUT & TEST EQUIP

NAME-DESCRIPTION	# REQ	
	WTR	ET
STRUCTURAL		
THEODOLITES/TARGETS	E	E
MASS SPECTRO LEAK DETECTORS	E	E
PROPULSION		
ENGINE TEST SET	E	E
THRUST CHAMBER ALIGN FIXTURE	2	2
GUIDANCE		
IMU POSITION RATE TABLE	1	1
HOLDING FIXTURE	1	1
CABLING	1	1
HYDRAULIC TEST CART	2	2
INTERFACE TEST UNIT	1	1
STAR SIMULATOR	1	1
HORIZON SENSOR TARGETS	1	1
SYSTEM		
AUTOMATIC DATA SET	1	1
SYSTEM TEST SET	1	1
POWER CONTROL CONSOLE	1	1
SYSTEM TEST CONTROL CONSOLE	1	1
INTERCONNECT CONSOLE	1	1
CRT DATA DISPLAY MONITOR	1	1
ORBITER SIMULATOR	1	1
PAYLOAD SIMULATOR	1	1
ADEPS		
DATA PROCESSING SET	E	1
ANTENNA SYSTEM	1	1
S-BAND RECEIVERS	E	1
S-BAND SIGNAL GENERATORS	E	1
TAPE RECORDERS	E	1
DISCRIMINATOR ASSEMBLY	E	1
VIDEO PATCH PANELS	E	1
OSCILLOSCOPE	E	1
DECOMMUTATOR/COMPRESSOR	E	1
PRINT RECORDERS	E	1
REMOTE CRT	E	1

E - EXISTING

Handling Equipment. The ground handling equipment required to support the Agena stage is listed in Table 3.8.1-6. This equipment will support the functional sequence defined in Fig. 3.8.1-1.

All required handling equipment for the Agena core tank optional concept exists. For support of the strap-on-tank concept, relatively unsophisticated new handling equipment is required. This new handling system will utilize the CBSS to provide primary structural support of the Agena during the ground processing operations. A handling frame type structure attached to the two trunnions on the Agena forward equipment rack and to the Orbiter interface attachment points on the CBSS will provide hoist points for horizontal and vertical support, hoisting, and rotational operations. Vertical work stands will provide for positioning of the Agena vehicle during mechanical maintenance and off-pad propellant/gas loading.

Appropriate handling dollys will be provided for localized moving and storage of the assembled Agena and its major structural subassemblies within the maintenance facilities.

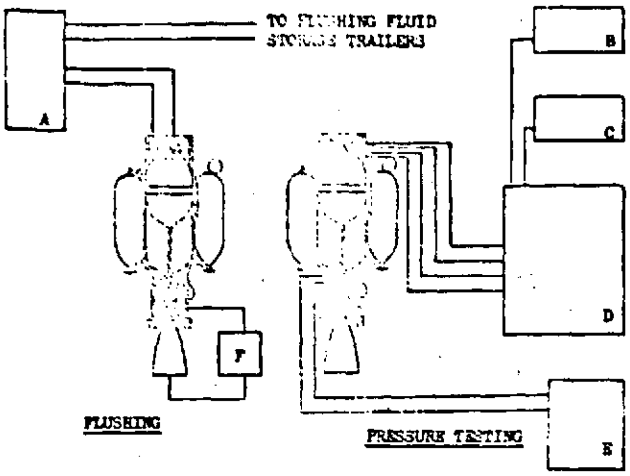
Over-the-road transport is by a vehicle which handles the completely assembled Agena/spacecraft combination. The Agena/spacecraft will be transported in a horizontal attitude and erected at the launch pad for the on-pad propellant loading and installation sequence. For the optional off-pad propellant loading and installation sequence, the Agena/spacecraft is transported in a vertical attitude to the Orbiter facility for mating with the Orbiter.

Checkout and Test Equipment. Checkout and test equipment used to establish subsystem and system level performance capability of the Agena during the ground refurbishment cycle is listed in Table 3.8.1-6.

Subsystem Test Equipment. Specific subsystem test equipment will be used to perform and verify mechanical alignment of vehicle structure, engine nozzle, RCS/BUSS thrusters and guidance sensors. Specialized test carts will be used to verify performance of the hydraulic system and engine nozzle actuators. Target simulators and a position-rate servo table will be used to calibrate the guidance system inertial measurement unit and star sensor assemblies. Subsystem test and servicing equipment functional interfaces are shown in Fig. 3.8.1-6.

System Test Equipment. A systems test complex will be used to verify performance of the guidance, navigation, and controls data management and instrumentation, and electrical systems of the vehicle. The test complex will be located in the maintenance and checkout facility and will directly interface through both landline and RF link with the ADEPS to provide an automated, computer-controlled testing complex. The test complex will contain the necessary consoles to perform systems tests of the Agena and integrated tests using spacecraft and Orbiter simulators. Major functional elements of the test complex are shown in Fig. 3.8.1-7. Except for the vehicle computer control equipment the consoles and panel assemblies are available from existing equipment.

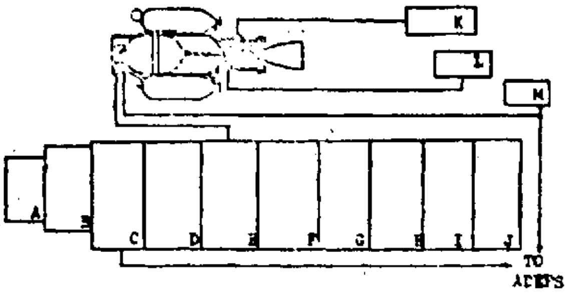
Agena Data Evaluation Processing System (ADEPS). The Agena Data Evaluation Processing System (ADEPS) will be located in the maintenance and checkout facility and will provide the capability for monitoring and evaluation of all Agena ground testing operations. Functional interfaces of this system are shown in Fig. 3.8.1-7. The system will consist of an RF and landline link telemetry ground communication system for data processing and a computer-controlled data analysis system. The ADEPS will have the capability of monitoring and evaluating Agena performance during any Agena integrated testing activity at the launch base either in the Agena maintenance and checkout facility or at other Shuttle-related facilities and the launch complex. The design incorporates Lockheed designed demultiplexing and data compression equipment and will use a Control Data Corporation 3100 computer or equivalent for data analysis and display. The system will include an interactive display station which can be remoted to permit computer controlled display of performance data at various locations on the launch base.



FLUSHING & PRESSURE TEST EQUIPMENT

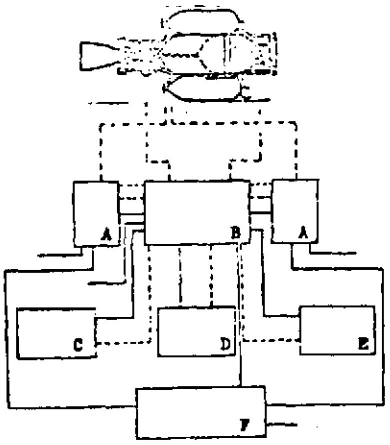
A. FLUSHING CONTROLS
B. NITROGEN SUPPLY
C. HELIUM SUPPLY
D. PRESSURE TEST CONSOLE
E. BRAYCO HYDRAULIC CART
F. ENGINE SERVICE CHECKOUT EQUIPMENT

MECHANICAL ALIGNMENT EQUIPMENT
- THEODOLITES
- TRANSITS



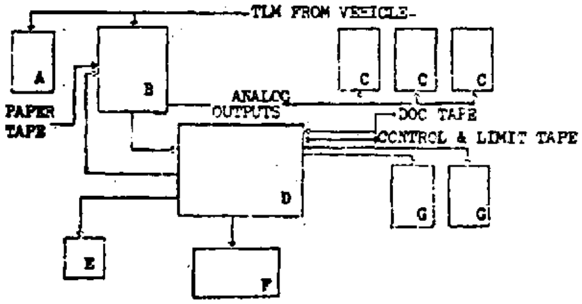
SYSTEM TEST COMPLEX

A. COMPUTER AUTOMATIC DATA SET
B. COMPUTER SYSTEMS TEST SET
C. TEST CONDUCTOR CONSOLE
D. TLM & PROPULSION CONSOLE
E. UMBILICAL SWITCHING & UMBILICAL TEST PLUG CONSOLE
F. ORBITER & GUIDANCE CONSOLE
G. POWER & INTERCONNECT CONSOLE
H. POWER MONITOR CONSOLE
I. RCS CONSOLE
J. ANALOG & EVENT RECORDERS
K. NITROGEN TEST CART
L. HYDRAULIC TEST CART
M. CRT



PROPELLANT LOADING EQUIPMENT

A. PROPELLANT HOLDING TANKS
B. PNEUMATIC CONTROL & DISTRIBUTION UNIT
C. HELIUM SUPPLY
D. NITROGEN SUPPLY
E. REACTION CONTROL SYSTEM
   - HYDRAZINE LOADING CART
   - FREON LOADING CART
F. PROPULSION CONSOLE TV SURVEILLANCE MONITOR LEAK DETECTOR



AUTOMATIC DATA EVALUATION & PROCESSING SYSTEM

A. TAPE RECORDER
B. PCM GROUND STATION
C. ANALOG RECORDERS
D. CDC 3100 COMPUTER
E. REMOTE CRT
F. PRINTER
G. TAPE RECORDER

Fig. 3.8.1-7 Shuttle/Agena Upper Stage – Ground Servicing/Test/Checkout Equipment Functional Interfaces

3.8.2 Orbit Operations

This paragraph presents flight operations concepts for the Shuttle/Agena and establishes requirements for the operation of the ground tracking network and mission control complex. A detailed sequence of events for a baseline Agena mission (five engine burn syn eq delivery-return empty) is presented along with the ground tracking support to perform this mission.

Groundrules and Assumptions.

1. Both the STDN and AFSCF networks shall be used but not simultaneously. The network to be used for the Orbiter, Shuttle/Agena, and spacecraft operation is determined by the spacecraft, i.e., Air Force missions will be completely controlled through the AFSCF and NASA missions controlled through STDN.
2. The STDN stations in operation at the time of the Shuttle/Agena flights will be Rosman, Kennedy, Goldstone, Fairbanks, Hawaii, Orroral, Guam and Johannesburg.
3. The AFSCF stations are COOK, KODI, HULA, BOSS, GUAM, INDI and POGO.
4. A mission control complex (MCC) for Agena operations will be established in convenient proximity to the Shuttle operations center. The network control center (NCC) will provide computers for the computation of quick turn-around ephemerides, updated state vectors, engine burn parameters, and uplink data transmission.
5. The Orbiter/Agena interface will enable Orbiter personnel to perform checkout, status monitoring, and commanding of the Agena.

Flight Operations Concepts. Flight support requirements were derived from the significant vehicle design and operational interface characteristics by the analysis process shown in Fig. 3.8.2-1.

Tracking and Control. Continuous satellite control network support is required from prior to liftoff through return rendezvous and docking with the Orbiter. Agena operation is, in general, nonautonomous. Status monitoring by ground or Orbiter personnel is required to detect faults or failure and to take appropriate action, e.g., switching to redundant equipment. Navigational updating (state vector updating) is required prior to each engine burn and is provided by ground ephemeris computation of radar tracking data supplied by the remote tracking stations. After transmission

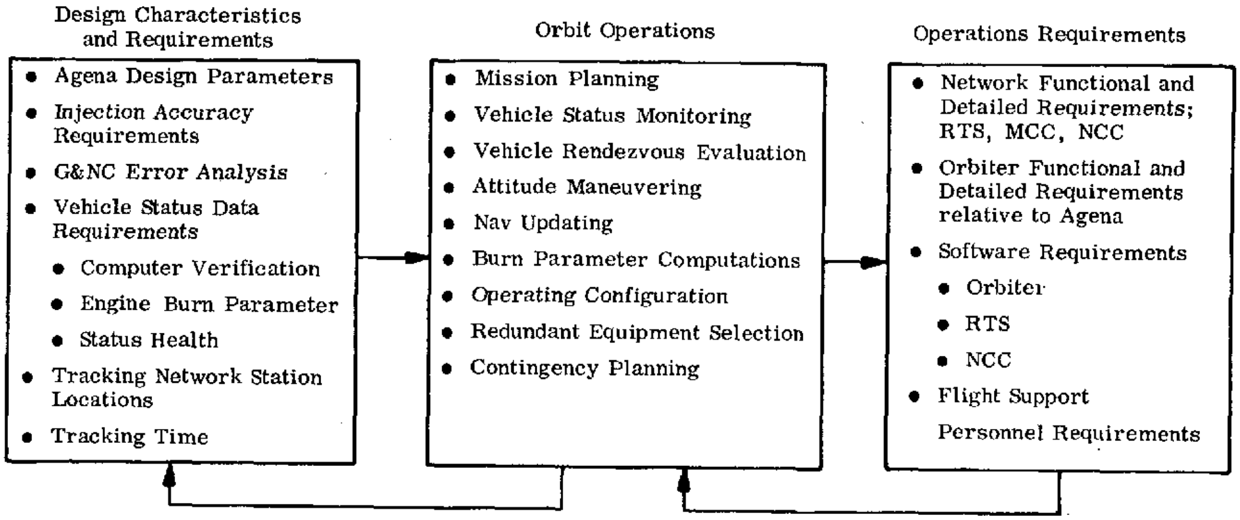


Fig. 3.8.2-1 Orbit Operations Requirements Analysis

of the updated state vector to the Agena, sufficient time must be allowed for a comparison between the engine burn parameters as computed by the spaceborne computer and those computed at the network control facility. The results of attitude updating are also evaluated at this time. If navigational updating and comparisons are not possible for a particular burn, the previously programmed parameters will, in most cases, provide acceptable injection conditions. For nominal mission planning, however, navigational updating is required.

The functional requirements of the RTS, MCC, NCC, and Orbiter are summarized in Table 3.8.2-1. Generalized descriptions of the key orbit operation functions are given in the following paragraphs.

Mission Planning. Complete mission planning will be performed before each launch to permit network coverage coordination, scheduling, format check-out, and rehearsals, as required. The primary outputs are a detailed functional timeline of all operations and definition of all support requirements. A detailed sequence-of-events will define

Table 3.8.2-1

ORBIT OPERATIONS SUPPORT RESPONSIBILITY

RTS

- Radar tracking
- TLM data recording
- TLM data processing
- TLM and radar tracking data transmission to network control
- Command generation and transmission
- Uplink data transmission

MCC

- Mission planning
- Data display and hardcopy
- Data analysis/vehicle status and operations evaluation
- Mission realtime control
- Airborne computer operational evaluation
- Operating confirmation

Network Control Center

- Ephemeris computation, post pass
- State vector generation
- Engine burn parameter computations
- Computer uplink data generation
- Voice communication

Orbiter

- Data display
- Data analysis/Vehicle status
- Realtime control
- Agena computer operational evaluation
- Data and command relay; Agena-RTS

the nominal Agena/Orbiter/RTS/MCC/NCC operations for monitoring and control. Mandatory network requirements will be determined and coordinated with Orbiter, S/C and requirements of other missions prior to launch.

Contingency Planning. Contingency plans will be prepared for possible spaceborne and ground based equipment failures. The primary contingency plan objective is to enable correct rapid response to anomalous conditions and either prevent a catastrophic failure or limit the effects to the anomaly, e.g., communications failure between the MCC and an RTS during commanding. The most critical anomalous condition known presently is the abort condition during Shuttle ascent. Propellant dump plans and dump sequences have been formulated and are given in par. 3.6.2. The possibility of returning the spacecraft because of a detected failure during the first Agena burn will be studied for each payload.

TLM Status Data. The general health and status of the Agena will be monitored throughout the operation, starting with countdown initiation. Redline values will be established for all significant parameters for monitoring by personnel at the MCC and by the Agena specialist in the Orbiter. In the event of an out-of-tolerance reading or uncommanded change, a determination will be made as to the validity of the data, effect on vehicle operation, and action to be taken. If significant Agena operations take place outside RTS contact capability, data will be taped by the Orbiter for later dumping and analysis, when possible. (For the nominal configuration, which has a tape recorder, the taping and dumping will be performed by the Agena).

Radar Tracking. Radar tracking must be obtained such that a valid state vector update can be transmitted to the Agena to enable revised engine burn parameter calculations prior to each engine burn. Also, an update must be performed prior to deployment from the Orbiter for the purpose of computer checkout. It is presently estimated that 30 minutes of continuous tracking will provide for sufficiently accurate ephemeris and state vector computations. This presents no problem at the higher altitudes, but cannot be met at low altitude. For these mission phases, two or three station contacts at different orbit locations could also provide sufficient accuracy. Ephemeris computations and the updated state vector will be calculated after sufficient radar tracking data have been obtained.

Navigational Update. Navigational updating is achieved by transmission of the state vector computed from radar tracking data. Radar tracking data are accumulated from the tracking stations and processed for ephemeris computation. An updated state vector (position, velocity and time) is computed and coded for transmission. Receipt of these data is established by the self-checking feature of the spaceborne computer.

Burn Parameter Computation. After the receipt of updated state vector data or, if updating is not applicable, as short a time span as practical prior to engine burn the Agena computer will regenerate the engine burn parameters for comparison with groundbased computations. Verification by comparison will nominally be required prior to go-ahead.

Ground Support Software. The development of computer programming and processing techniques is necessary in the following ground operations areas:

- Near realtime ephemeris and state vector computations
- Coding for uplink data transmission

- Command generation
- Telemetry formatting and out of limit or uncommanded change detection
- Engine burn parameter computations
- Star tracker acquisition and tracking verification.

It has been assumed that all but the first item will also be available from the Orbiter. That is, complete vehicle checkout, monitoring and configuration control can be achieved from the Orbiter.

Baseline Mission Flight Operations. The functional sequence of events for the baseline syn eq 38-hour mission is given in Table 3.8.2-2. The baseline mission requires five engine burns: (1) outbound transfer, (2) syn eq injection, (3) inbound transfer, (4) phasing, and (5) rendezvous injection. The total time from transfer to Agena power (pre-Orbiter deployment) to transfer to Orbiter power (post retrieval) is 38 hours.

The operating interface between the Orbiter and the Agena is described in par. 3.3.5.2, Agena Service Console. Complete monitoring and command capability will be provided from the Orbiter.

Significant highlights of this mission sequence are:

- Agena attitude update is performed by use of a horizon sensor system and star tracker. Necessary star information is contained in the memory of the Agena computer. Star identification is confirmed by groundbased computations
- An attitude update is performed as close to each burn as practical
- New burn parameters are computed each time there is a navigation update. Confirmation with Orbiter/groundbased computations is necessary prior to go-ahead for each burn
- The sequence-of-events provides for a total of 11.5 hours at syn altitude to provide for a worst-case phasing condition with the Orbiter.

Adequate radar tracking coverage is obtained from either network to provide for a state vector update prior to each burn. Coverage during first burn operations is discussed under combined network coverage. Although the amount of tracking for a valid state vector has not yet been definitely established, 30 minutes of continuous

Table 3.8.2-2

38-HOUR SYN EQ BASELINE MISSION

Agena Event No.	Agena System Time or (Duration) -Hrs	Agena Event or Mission Segment
1	0	Transfer to Agena power
1-2	(1.0)	Predeployment status check, initialize IMU, state vector update, engage deployment devices, disconnect dump vent lines and umbilical, verify Agena attachment integrity
2	1.0	Initiate Agena deployment
2-3	(1.1)	Deploy Agena, perform status and visual checks
3	2.1	Uncouple Agena
3-4	(0.6)	Orbiter maneuver and separate to safe distance
4	2.7	Initiate Agena ACS, rate control
4-5	(0.3)	Horizon search, acquisition, attitude control initiated
5	3.0	Agena stabilized
5-6	(1.3)	Perform status check, Nav and attitude update, compute burn parameters, maneuver for burn attitude
6	4.3	Transfer orbit insertion (Δi = 2.2)
6-7	(5.3)	Coast to apogee, Nav and attitude update, compute burn parameters, maneuver for burn attitude.
7	9.6	Syn orbit insertion (Δi = 26.3)
7-8	(11.6)	Deploy payload, status check, Nav and attitude update, compute burn parameters, maneuver for burn attitude
8	21.2	Transfer orbit insertion (Δi = 26.3)
8-9	(5.2)	*Coast to perigee*, Nav and attitude update, *compute* burn parameters, maneuver for burn attitude
9	26.4	Phase orbit insertion (Δi = 0.92)
9-10	(2.9)	Coast (1 Rev) Nav and attitude update, compute burn parameters, maneuver for burn attitude
10	29.3	Circularize at 170 nm (Δi = 1.28)
10-11		Status check, dump residual propellants, safe Agena engine circuitry
11	35.2	Orbiter rendezvous initial burn
12	35.9	Orbiter rendezvous braking burn
12-13	(0.3)	Maneuver Agena to docking attitude
13	36.2	Orbiter final approach initial burn
14	36.6	Orbiter final approach braking burn
14-15	(0.3)	Orbiter stationkeeping at 50 ft below Agena, status check, adjust attitude
15	36.9	Initiate Orbiter translation to retrieval position
16	37.0	Terminate Orbiter translation to retrieval position
16-17	(0.3)	Attach manipulator to Agena, deactivate Agena, status check
17	37.3	Verify attachment integrity
17-18	(0.3)	Retrieve Agena
18	37.6	Dock Agena to cradle
18-19	(0.4)	Latch Agena, connect vent lines and umbilical, status check
19	38.0	Transfer to Orbiter power

single station contact (at the higher altitude) or two station contacts of 300 sec at different orbit locations for the parking orbit have been taken as baseline requirements.

Mission Groundtrack. The mission groundtrack is shown in Fig. 3.8.2-2. The circled numbers refer to the sequential main engine burns. The location of each burn and the duration of each mission phase is given in Table 3.8.2-3. Rev 1 starts with the ascending node prior to the first contact.

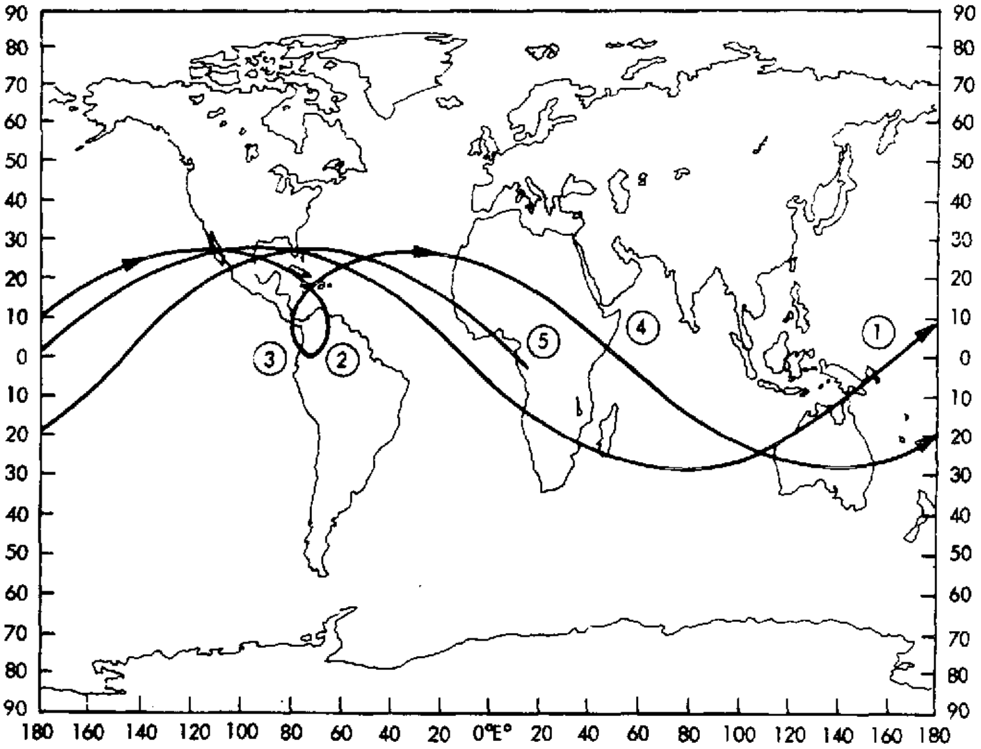


Fig. 3.8.2-2 Shuttle/Agena Upper Stage Baseline Syn Eq Mission Ground Track

Table 3.8.2-3

MISSION PHASE DURATION AND BURN LOCATIONS

Phase (Location)	Time (Hours)	Rev.
Orbiter Deployment - Outbound Transfer (156°E)	2.0	0.7 to 2.0
Outbound Transfer - Syn Eq Injection (75°W)	5.3	2.0 to 2.5
Syn Eq Injection - Inbound Transfer (75°W)	11.6	2.5 to 3.0
Inbound Transfer - Phasing Orbit (50°E)	5.2	3.0 to 3.5
Phasing Orbit - Rendezvous Injection (10°E)	2.9	3.5 to 4.5

Coverage/Update Summary. A summary of the RTS coverage and state vector updating for the STDN and AFSCF networks is given in Tables 3.8.2-4 and 3.8.2-5. The coverage analysis was started while in the 160 nm circular Orbiter parking orbit with the first station contact after deployment.

Table 3.8.2-4

SYN EQ MISSION STDN STATE VECTOR UPDATE ANALYSIS

Rev	Stations	RTS Function
1.1, 1.2, 1.3, 1.5	Hawaii, Goldstone, Kennedy, Johannesberg	Tracking, Update
2.0		1 Transfer Orbit Injection
2.1 to 2.5	Hawaii/Goldstone Kennedy/Rosmon	Tracking, Update
2.5	Kennedy/Rosmon, Goldstone, Hawaii	2 Syn Eq Injection
2.5 to 3.0	Kennedy, Rosmon, Goldstone, Hawaii	Tracking, Update
3.0	Kennedy, Rosmon, Goldstone, Hawaii	3 Transfer Orbit Injection
3.0 to 3.5	Kennedy, Goldstone, Rosmon	Tracking, Update
3.5	–	4 Phasing Orbit Injection
3.8 to 4.3	Orrarol, Hawaii, Goldstone, Kennedy	Tracking, Update
4.5	–	5 Rendezvous Injection

Combined Network Coverage. The amount of tracking coverage provided by the AFSCF does not allow for a state vector update after deployment for first burn updating. (The coverage from STDN may be marginal, dependent on the turn-around time required from receipt of radar data to state vector uplink transmission.) Tracking for navigational updating will have to be done prior to deployment as there are only two station contacts, HULA and COOK, between deployment and first burn ignition. These two contacts are required for state vector uplink transmission, engine burn parameter computation verification, and attitude updating. The last station contact is approximately 67 minutes prior to first burn, indicating that the burn maneuver will have to be monitored by the Orbiter. However, if Kennedy and Johannesberg are added, coverage is doubled with the last contact approximately 30 minutes prior to ignition (neither network provides first burn coverage).

Table 3.8.2-5

SYN EQ MISSION AFSCF STATE VECTOR UPDATE ANALYSIS

Rev	Stations	RTS Function
1.1, 1.2	HULA, COOK	Update (based on previous tracking)
2.0		1 Transfer Orbit Injection
2.1 to 2.5	HULA/COOK/BOSS	Tracking, Update
2.5	BOSS, COOK, HULA	2 Syn Eq Injection
2.5 to 3.0	BOSS, COOK, HULA	Tracking, Update
3.0	BOSS, COOK, HULA	3 Transfer Orbit Injection
3.0 to 3.5	BOSS, COOK	Tracking, Update
3.5	INDI	4 Phasing Orbit Injection
3.3 to 4.3	GUAM, HULA, COOK, BOSS	Tracking, Update
4.5	–	5 Rendezvous Injection

Section 4
ADDITIONAL CONSIDERATIONS

4.1 REUSABILITY

Key factors were selected to determine a spares list/refurbishment approach for programmatic purposes. The four factors considered were wearout, probabilistic anomalies, separate launch sites, and inadvertent damage caused by repetitive handling and checkout operations. These criteria were applied to the hardware selected from the design analysis and equipment surveys. Quantitative data were derived from component reuse analyses, reliability estimates, and LMSC experience, while qualitative conclusions were developed from logistics considerations. Specific results for the Growth Tank, Drop Tank and Shuttle/Agena Upper Stage concepts are provided in ref 2-1. The approach and significant results applicable to most asemblies and components of these concepts are presented below.

4.1.1 Reuse Assessment Criteria and Data Sources

Criteria applicable to each subsystem are listed in Table 4.1-1. The data sources used for subsystem assessment are listed in Table 4.1.2.

Table 4.1-1

REUSABILITY ASSESSMENT CRITERIA

Subsystem/ Criteria	Operating Life Hr/Day/Mo	Cyclic Life			Perform. Life	Calendar Life Yr
		Thermal	On/Off	Vib/Load		
Avionics	X	X	X		X Energy Discharge	
Propulsion	X	X	X	X (Vib)	X Burn Duration	X
Structures	X			X Loads Stress		
Thermal Control	X	X				

Table 4.1-2

REUSABILITY ASSESSMENT DATA SOURCES

Source	Applicable Subsystem			
	Avionics	Propulsion	Structure	Thermo
• Reliability Life Tests	X	X		
• Reliability Point Estimates (λ)	X			
• Qualification Tests	X	X		
• Development Tests		X		X
• Flight Data	X	X		X
• Palmgren-Miner Damage Theory			X	
• Engineering Analysis	X	X	X	X

4.1.2 Subsystem Reuse Assessment

Each of the selected components/assemblies in the structures, propulsion, avionics, and thermal control subsystems was assessed for reuse. Detailed results are provided in ref 2-1. The approach used is presented below.

Structures. Reusability of structure is based on the Palmgren-Miner theory that each stress cycle applied to a structure represents some measure of metal fatigue which is cumulative, and the metal used has some finite number of stress cycles it can receive before fatigue fracture occurs. This approach is a primary method used in the aircraft industry to predict aircraft life capability. Other more complex methods do not appear to provide more reliable results. In contrast to the Miner damage approach, the theory of fracture control presupposes the existence of a flaw which continues to grow under stress until failure. This approach is not directly applicable to thin pressure vessels such as the core and SOT because the critical flaw size requires a gage for proof test in excess of the gage otherwise required.

Until applicable fracture toughness data are available, the Palmgren-Miner theory will be used to assess life capability for all tanks as well as all structures assemblies.

Propulsion. The propulsion assessment was based on 8 starts per mission and a combined life of 6 days on-orbit life plus 8 days on the ground.

Several replacements are predicted based on calendar life limitations rather than on performance or cyclic life capability. Additional life capability data beyond present qualification levels is being continuously accrued for most of these units via existing using programs. This may justify 20 mission uses without changeout. However, existing data are used for conservative estimates of replacement requirements at this time.

For the Shuttle/Agena 8096L engine, testing to demonstrate 3 to 5 reuses is planned. The reuse assessment for this engine is based on existing reuse data provided in ref 2-1. As reuse experience is accumulated during existing and proposed developments, the number of reuse may be increased.

Avionics. Cyclic life capability of avionics was established by estimating on-off actuation capability of relays and other cyclic devices, and by estimating thermal cycle capability based on most probable failure points (solder connections, material bond junctions, etc.).

Calendar life consists of operating plus nonoperating life. Non-operating life capability was based on limited industry study data and LMSC experience on storage life.

Operating requirements per mission were derived from mission timelines, sequence of events, and proposed ground test operational sequences. Cyclic life requirements per mission for thermal and on-off cycles were derived by analysis of ground and flight operations for the three types of specified missions (low earth, synchronous, and high energy). Based on data on thermal cycle capability of solder connections as a function of temperature cycle, amplitude, and the numbers of cycles, cycle amplitudes for each of the three missions were normalized to reflect the equivalent numbers of cycles at a temperature cycle amplitude of 25 deg F. The numbers of equivalent cycles for the three types of missions were then averaged to derive the number of temperature cycles expected for one mission. This was done for equipment operating continuously, but cycling thermally because of the natural environment, and for equipment periodically powered on and off.

Thermal Control. For reuse, candidate materials were chosen for stable thermal-optical and physical properties, good abrasion resistance, efficient handling and rapid refurbishment. These materials were assessed relative to a 6-day mission life and the maximum expected thermal cycles per mission.

4.1.3 Projected Replacement/Refurbishment Frequency

Based on the reuse analysis approach discussed in par. 4.1.2 and on results provided in ref 2-1, the frequency of replacement and/or refurbishment (R/R) is summarized in Table 4.1-3. For each type of component, the number of flights expected before an R/R is required is shown along with the limiting life criteria i.e., calendar, operating (in the non-stored environment) and cyclic (thermal, on-off, etc.).

In some cases, calendar life limits the component reuse. These limits can probably be increased but are retained until further review and/or demonstration allows an increase. This is also consistent with the approach of using existing data as the basis for the reuse assessment rather than anticipated or predicted values. Calendar life is assumed as 4 years. Based on a fleet of 6 vehicles and approximately 120 flights in the 4-year period, each vehicle would be flown 20 times in 4 years or 5 times per year. Therefore, those calendar-life-limited components need replacing only once per the mission model.

The core tank reuse capability is analyzed to be greater than 100 stress cycles. At least 10 stress/reuse cycles have been demonstrated on the current tank design during ground testing at LMSC without failure or insipient indication thereof. However, to comply with safety reservations concerning ability to adequately check and demonstrate safety readiness for any subsequent flight, the core tanks will be replaced after every 10 flights. The SOT are designed for micrometeorite protection for the sync eq and similar-life high energy missions. For longer life missions where payload is not critical, protective shields can be added. Therefore SOT replacements are not forecast based on wearout or cyclic life considerations.

Table 4.1.3

PROJECTED REPLACE/REFURB FREQUENCY

		Flights Before Refurb/Replace		
		CAL Life*	Oper Life	Cycle Life
● Thermal Control Tape/MLI			6 RP	
● Propulsion				
8096L Engine			3 RF/RP	
Pressurization	Valves	15 RP		
	Regulators			10 RF
	Vent Discon	10 RF		
	Fill Discon		3 RF	
TVC – Pwr Pkg and Actuators				7 RF/RP
Feed-Fill-Dump	ISO Valves		3 RF	
	Dump Valves	15 RP		
	Bellows		8 RP	
	Discon		3 RF	
	Ox Sump		10 RF	
RCS Thrusters,	Filters		10 RF	
Tank, Valves		15 RP		
● Avionics				
GN&C	IMU		10 RF	
	CEA, HSA, STA			16 RF
DM&I	Computer			15 RF
	Control Console			20 RF
EPS&D	Batteries		1 RP	
	Distrib Boxes			16 RF
	Harnesses			16 RF
C&C	XPNDR, CDP			15 RP
	Anten, Sig Cntrl			16 RP
● Structures				
Thrust Cone				109
Aft Rack				68
Fwd Rack				>100
Core Tank				>100 10 RP**
Strap On Tanks (SOT)				>100
SOT Structure				>100
CBSS				>100

*4 Years Calendar Life; 200 Hrs Tank Wet Life (One 7-Day Flt/2 Mos for 4 Years)
**Replaced After Every Five Flights To Assure Safety

RP = Replace RF = Refurbish

The number of changeouts shown for the 8096L engine represents replacement of gas generator and thrust chamber assemblies after every third flight, and is estimated to be equivalent to 1/3 the cost of an engine. Other parts of the engine are changed as needed after each flight. Current experience indicates that the thrust chamber is good for 1 hour of operation time (three missions), the turbopump assembly is good for 5 hours (15 missions), seals good for 3 missions, and turbine manifold for about 3 hours (9 missions). The engine valves and controls appear to be capable of 2,000 cycles or at least 20 missions, and the nozzle extension is limited by coating life to about 2.5 to 5 hours (5-10 missions). Many of the engine parts can be reassembled so that the average effective life is probably greater than 5 missions. In addition to wearout replacement, normal refurbishment is required after each flight (seals replaced, lube oil changed, gimbal bearings lubed, purge, flush, etc.).

Batteries are replaced after each flight. The IMU is replaced every 10 flights because of operating life limitations. Most other avionics components show more than satisfactory reuse capability i.e., 15 to 16 flights before replacement (wearout because of potential thermal cycle limitations).

4.1.4 Spares Requirements

Spares requirements have been estimated in terms of new replacement units or refurbishment of original units based on the following:

- Component reuse analysis results, indicating replace or refurbish requirements because of wearout (Table 4.1-3).
- Component or assembly reliability data, estimating spares required for non-catastrophic statistical anomolies (see par. 4.2).
- Cumulative handling time during manufacture and prelaunch operations of existing LMSC expendable spacecraft, which provides information on damage experience caused by handling and checkout operations.
- Judgement considering that launch occurs from two separately located sites.

Wearout. The reuse analysis results from Table 4.1-3 indicate those components that because of wearout, need to be replaced/refurbished on a scheduled maintenance basis. Requirements from a non-scheduled standpoint are discussed in the following paragraphs.

Statistical Replacement. From component reliability data, those components with calculated reliabilities less than 1.0^{-} (at a practical confidence level) were selected for sparing. All selected components have reliabilities in the range of 0.98 to 0.999 at 50 percent confidence. From a statistical and experience standpoint, it was judged that for a fleet of 6 vehicles flying 97 flights (4-year mission model) that an anomaly could occur once for each of these components which are shown in Table 4.1-4.

Handling Experience and Launch Sites. Handling and checkout of LMSC expendable vehicle and spacecraft place a large number of hours on these vehicles. Based on assessment of the expected handling and checkout hours for an Agena with 20 uses, the ratio of reusable to expendable has been estimated at 1.15. Historical data of

Table 4.1-4

AGENA SPARES REQUIREMENTS SUMMARY

- Replacements and Refurbishments As Specified From Reuse (Wearout) Analysis
- Additional Components Based on Reliability Assessment (1)
  - Engine
  - IMU
  - Computer
  - Star-Tracker Optics
  - Flt Control Elect
  - Propellants Isolation Valves
  - Horizon Sensor Electronics
  - Star Tracker Electronics
  - Transponder
  - Horizon Sensor Trackers
- Additional Components for Handling and Launch Site Aspects
  - One Complete Set of Avionics, Propulsion and Thermal Spares
  - Three Each Fuel and Ox SOTs
  - No Major Structural Assemblies Required

(1) Refurbishment cost shown in parenthesis

the expendable stages show no significant non-repairable damage incidents relative to structure or components; therefore, this factor does not drive spares requirements.

One complete set of propulsion, avionics and thermal spares has been allocated based on handling experience and judgement regarding launch site aspects. Because all flights originate from one launch site in the first two years, it does not appear that dual sets are needed for those spares that are required. Structural assembly spares do not appear to be required. Because damaged SOTs are not necessarily repairable with high confidence relative to safety, one complete set of SOT spares are planned (3 ox, 3 fuel).

4.2 RELIABILITY ANALYSES

Reliability analyses were conducted for the nominal and augmented Shuttle/Agena concepts and the Growth Agena. Reliability data, methods and analyses are provided in ref 2-1. Results are summarized in Table 4.2-1.

The initial reliability apportionment to the subsystems and their principle elements was based on the 0.97 reliability goal specified in the work statement. The round-trip geosynchronous mission was used as the baseline for reliability assessment.

The estimates for the components selected for the three concepts assessed are shown under Reliability Assessment. Mission time is 38 hours from deployment to recovery. Reliability calculations for event-oriented propulsion and avionics components were related to the five propulsion burns. Calculations for time-dependent avionics components and propulsion pressurization solenoid valves include an 11-hour dormant (non-operating) period from liftoff to deployment in addition to the active time indicated above. A 2-hour readiness check period after deployment is also included.

Table 4.2-1

AGENA RELIABILITY ASSESSMENT SUMMARY

(Synchronous Equatorial Mission – 5 Burns – 38 Hours Active)

Subsystem	Initial Apportionment	Reliability Assessment			
		Nominal Shuttle/Agena	Augmented Shuttle/Agena	Growth Agena	Basis*
Structures	0.9999	1.0	1.0	1.0	E, D
Propulsion	0.988	0.9840	0.9840	0.9842	
8096 Engine	0.992	0.9881	0.9881	0.9881	D
Bellows, Valves, Disconnects	1.0	1.0	1.0	1.0	D, P, E
Main Propellant Valves (Fd/Dump)	0.998	0.9964	0.9964	0.9966	D, P
Press. Valves, Regulators	0.9994	0.9995	0.9995	0.9996	D, P
Thrust Vector Control	0.9994	1.0	1.0	1.0	D
Attitude Control	0.999	1.0	1.0	1.0	D, P
Avionics	0.982	0.9899	0.9918	0.9899	
IMU, CEA	0.992	0.9927	0.9961	0.9927	D, P
Guidance Sensors, Electronics	0.998	0.9992	0.9972	0.9992	D, P
Computer, CIU, Recorder	0.996	0.9992	0.9997	0.9992	P, E, D
Communications	0.997	1.0	1.0	1.0	P, D
Instrumentation (External)	1.0	0.9999	0.9999	0.9999	P, E
Batteries	0.9995	0.9994	0.9994	0.9994	P, D
Power Distrib, Control	0.999	0.9995	0.9995	0.9995	P, D
Thermal Control	1.0-	1.0-	1.0-	1.0-	E, D
Vehicle	(Goal) -0.97	0.9741	0.9759	0.9742	

*D – Demonstrated P – Parts Count E – Estimated

Component reliability assessments are from one of three sources: demonstrated data (D), parts count (P), or engineering estimate (E). Demonstrated data is represented by flight history or ground test data (computed at the 50 percent confidence level) for Agena components that are identical to or modifictions of the selected Agena components. Where such data were not available or did not provide a sufficient data base (primarily electronic boxes), point estimates were made using generic parts failure rates of similar Agena components/assemblies. Engineering estimates were determined from LMSC test data for similar components. The reliability estimate for thermal control is based on engineering analyses.

As shown, structures and thermal reliability vary insignificantly between concepts. It is recognized that the reliability of the strap-on structure for the Shuttle/Agena concepts is slightly less than for a non-SOT vehicle. However, the reliability after completion of development and qualification is predicted to be consistent with most existing structures of comparable design and operation; i.e., 1.0^-.

The propulsion reliability for the Shuttle/Agena concepts reflects additional feed and pressurization components, relative to the Growth Agena.

Avionics reliability of the Growth and Nominal Shuttle/Agena concepts is enhanced by two communications links and internal CEA and CIU redundancy incorporated to meet fail op/fail safe requirements. The increased reliability of the Augmented concept is because of an added IMU and a dual string computer. Paragraph 3.3.3 and ref 2-1 address the management of the redundancy upon which the reliability calculations are based.

The reliability of each vehicle configuration exceeds the goal. The cargo bay equipment ($R = 1.0^-$) is not included in the vehicle assessments. Neither is the BUSS (Electrical $R = 0.9999$) for the Nominal concept and the Growth Agena.

Reliability of these Agena concepts is sensitive to the engine and IMU. Reliability can be increased relatively easily by incorporating a redundant IMU and related controls/management, as is done in the Augmented configuration. To further increase vehicle reliability to 0.98 or greater, the engine reliability can be increased. The current engine value (0.9881) is based on flight data only (i.e., number of burns and duration thereof) corrected to required confidence. To achieve the necessary reliability, a formal reliability demonstration program can be conducted (200 starts on 2 flight-type engines at sea level and altitude conditions). The resulting data, when combined with existing flight data, would yield an engine reliability of 0.99 so that the vehicle assessment would be at least 0.98 for the reusable synchronous equatorial mission.

4.3 SPECIAL MISSION CONSIDERATIONS

4.3.1 Servicing Mission

A preliminary analysis of a postulated on-orbit servicing mission has been completed. This mission includes two servicing modes as indicated in Table 4.3-1. The first mode can be accomplished either by a totally-expendable approach or by return of the Agena Upper Stage and service module to the Space Shuttle. The second servicing mode involves return of the Agena, the service module, and all space repairable units* (SRU) to the Space Shuttle.

In addition to the service module itself, several mission-peculiar equipment items must be added to the existing Shuttle/Agena Upper Stage configuration as shown in Fig. 4.3-1. A laser radar is added to function as a terminal guidance system for acquisition and rendezvous with the orbiting spacecraft. A secondary propulsion system is added to provide fore and aft, low level, thrust vector control during the rendezvous and docking operation with the orbiting spacecraft.

For long life missions such as the servicing missions, electrical power sources other than batteries must be provided. Solar arrays have been provided on hinged swing-out panels. These panels have been mounted on the core, 5-foot diameter stage

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*The term "space repairable unit" refers to the spent hardware in the orbiting spacecraft that was replaced by the Agena during completion of the servicing mission.

Table 4.3-1

MISSION SUMMARY

Mission Option	Description	Service Mode	Agena Stage
A	Service Only – Totally Expendable	I (12 Days)	Shuttle/Agena Upper Stage Core Only
B	Service Only – Return of Agena and Service Module (SM) For Salvage	I (13 Days)	Core Stage Plus 3 Sets of Standard Strapon Drop Kits
C	Service and Return of Agena, SM and all Space Reparable Units (SRUs) For Salvage	II (30 Days)	Same As For Mission Option B

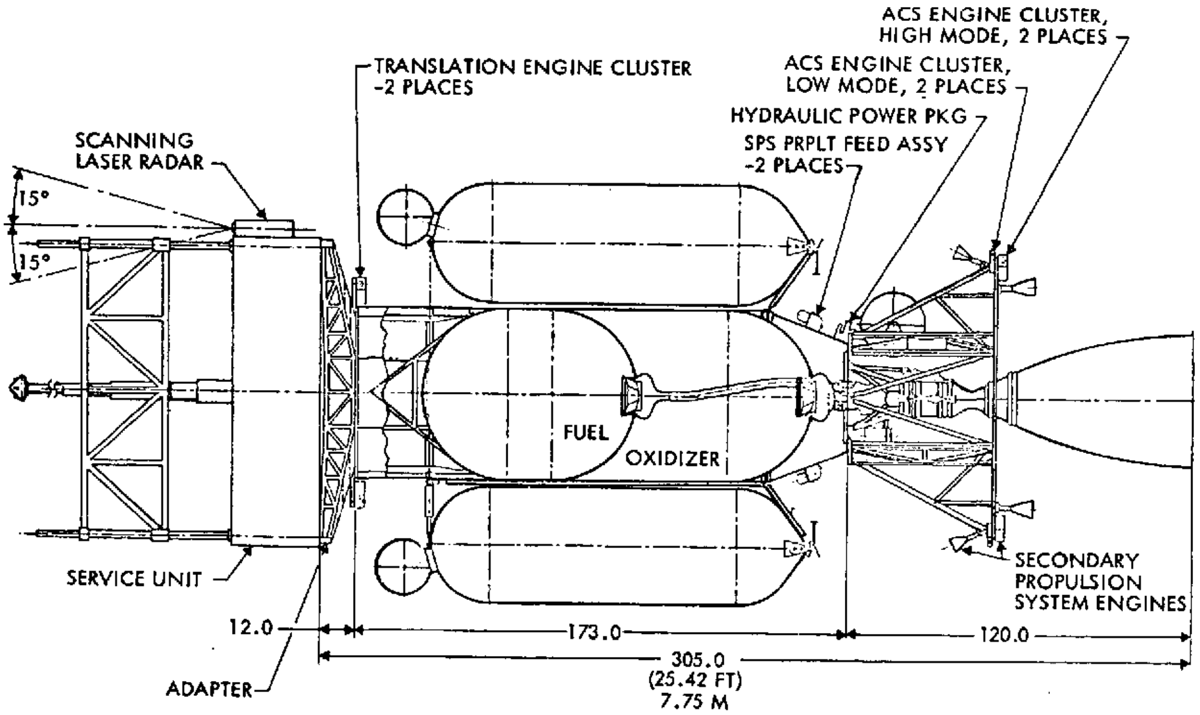

Fig. 4.3-1 Service Mission Configuration

behind the strap-on tanks. The stage receives power from conventional batteries during the early part of the mission. As the propellants from the strap-on tanks is used and the tanks are dropped, the hinged panels swing out and the power source is switched to the solar panel.

Another modification from the Shuttle/Agena Upper Stage nominal concept is the addition of drop capability to the strap-on tank propellant option.

The mission option A (refer to Table 4.3-1) orbit sequence is illustrated in Fig. 4.3-2. The sequence of events for this 12-day service/expendable mission is as follows:

- The Agena Upper Stage is delivered into the initial phasing orbit at an altitude of 160 nm.
- The Agena transfers to synchronous altitude and circularizes.
- Agena phases and rendezvous with each spacecraft in turn and services each spacecraft with 450 pounds of equipment
- After servicing spacecraft No. 4 the Agena is expended along with the 300-pound service models.

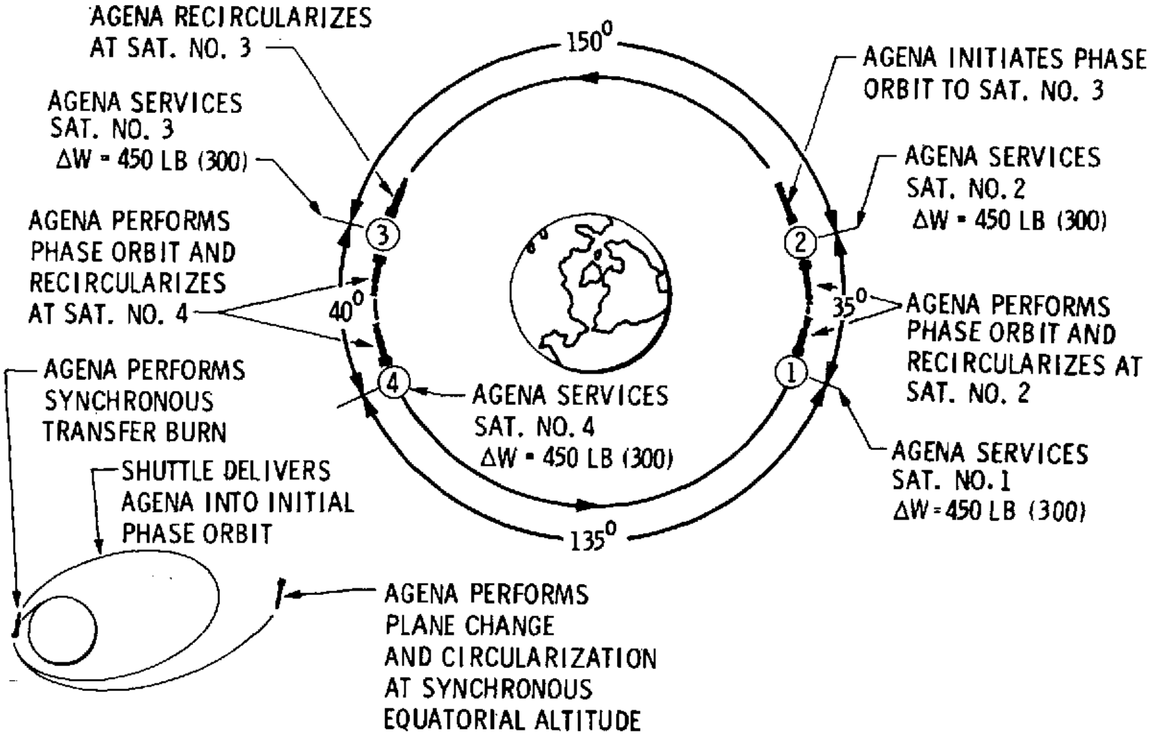

Fig. 4.3-2 Mission Option A Orbit Sequence

The sequence for the 13-day servicing/return mission is the same as for the expendable except that the Agena is initially delivered into a 100 by 400 nm elliptical orbit by the Shuttle. As the Agena services each spacecraft in turn with 903 pounds of equipment, the replaced equipment is expended. After servicing the fourth spacecraft, the Agena returns to the Shuttle orbit, with a 500 pound service module, for retrieval and return to earth.

The 30-day, fully reusable servicing mission (Table 4.3-1) follows the same sequence as for the 13-day reusable servicing mission except as follows:

- More time is expended in phasing between the spacecraft.
- 300 pounds of equipment is exchanged at each spacecraft.
- After servicing the fourth spacecraft, the Agena returns to the Shuttle orbit with 500 pound sevice module and all of the 1200 pound of exchanged equipment.

In summary, the Agena Upper Stage can readily perform the servicing mission in both the expendable and reusable modes. The on-orbit performance capability for each of the three mission modes is shown in Table 4.3-2.

Table 4.3-2

ON-ORBIT SERVICE MISSION PERFORMANCE

	Agena Payload Capability
Mission Option	-3σ, lb I_{sp} = 324 Sec
A^1	2100 $(1550)^3$
B^2	4110 $(1810)^3$
C^2	1700 $(1060)^3$

NOTES:

1. Shuttle injects Agena into initial phase orbit
2. Shuttle injects Agena, performs part of initial phase orbit and retrieves Agena from a 100 x 800 elliptical orbit
3. Capabilities for Shuttle using 100 nm circular orbits only

4.3.2 Long Payload Mission

The Shuttle/Agena Upper Stage can accommodate up to 40 feet (12.2 m) payloads by several practical alternatives which decrease overall length from 26 feet (7.94 m) to 19.9 feet (6.07 m). Candidate length reduction alternatives are:

1. Delete the forward equipment rack (approximately 2.5 feet (0.76 m) reduction), install avionics equipment on the aft rack, and decrease the length of the fixed engine nozzle by 3.6 feet (1.1 m).
2. Decrease the fixed nozzle length by 6.1 feet (1.86 m) with resulting change in expansion ratio from 150:1 to 21:1.
3. Install a stowed nozzle.

The first alternative requires rack deletion, equipment relocation, and a nozzle extension kit. Because aft rack equipment packaging and the more aft CG location could be a disadvantage, this is not a prime alternative.

The second approach is simple from a vehicle change standpoint, i.e., only a nozzle extension kit is required. The resulting I_{sp} is low ($\simeq$ 291 seconds, 2855 Nsec/kg) so that the mission would best be flown in the expendable mode. This configuration which is shown in Fig. 4.3-3, delivers about 10,900 pounds (4940 kg) of payload to syn eq orbit. The CBSS would be moved aft 59 inches (1.5 m) (max allowable based on Orbiter interface attach points). To achieve the remaining 15 (0.38 m) inches of aft relocation (total reduction = 6.1 feet (1.86 m), the lower (keel side) of the forward and aft CBSS assemblies would require some modification. A mission-peculiar CBSS would appear to be most practical. Its weight will not be significantly greater than the CBSS described earlier for the nominal 26-foot (7.94 m) Shuttle/Agena.

The third approach involves development of a stowed nozzle extension which deploys prior to or during first Agena start. Stowed nozzle/deploy feasibility has been and is being demonstrated through industry independent development and Government-sponsored programs. For Agena application a 70:1 nozzle can be incorporated as shown in Fig. 4.3-4, yielding an I_{sp} of 317 seconds (3110 N sec/kg), and placing nearly 3,000 pounds (1360 kg) payload to syn eq orbit. The condition which limits

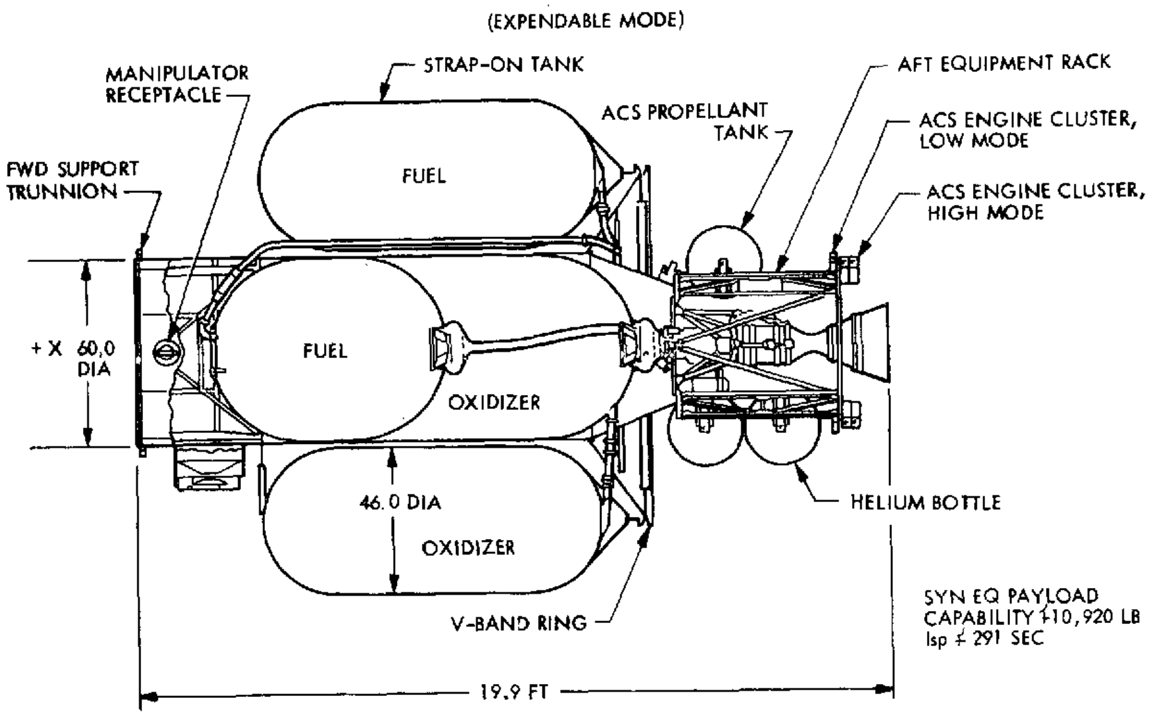

Fig. 4.3-3 Shuttle/Agena Long Payload Configuration – (Expendable Mode)

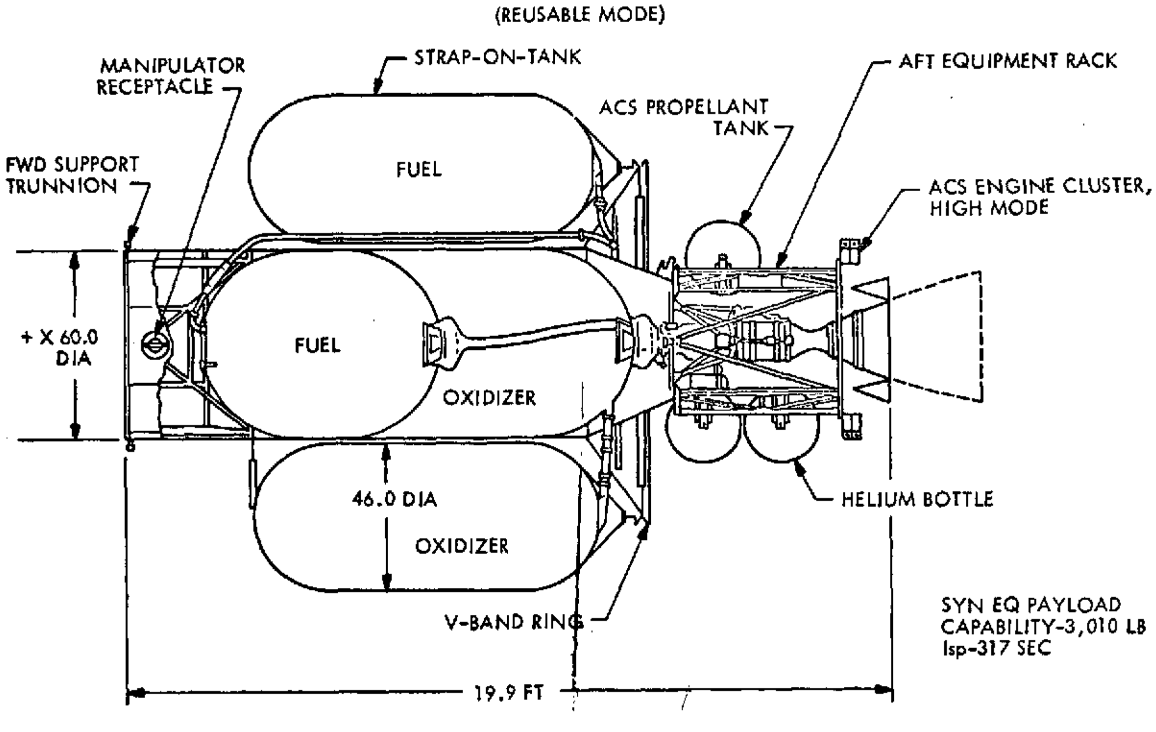

Fig. 4.3-4 Shuttle/Agena Long Payload Configuration – (Reuseable Mode)

the area ratio to 70:1 is the maximum axial length of about 12 inches (0.305 m) between the Agena aft rack aft bulkhead and the cargo bay aft limit (stowed nozzle exit plane). Based on current concepts of convoluted stowage, the 12-inch criterion allows an additional deployable length of 33 inches (0.838 m) relative to the exit plane of the fixed 21:1 nozzle.

Prior to Agena retrieval, the deployed nozzle can be expended or retracted to its original position. The expendable nozzle design would include a simple extension scheme but the existing attach joint design would require change. For a retractable nozzle, the existing attach joint would probably suffice, but the deploy/retract mechanism would be more complex than for the expendable approach. The retractable nozzle would not have to be designed for reuse.

The CBSS design is the same as for alternative two.

4.3.3 Compatibility with Conventional Booster Vehicle During Shuttle Transition Period

It is desirable that the Shuttle/Agena Upper Stage retain compatibility with conventional booster vehicles during the Shuttle transition period. Compatibility requires minimum required changes to the Agena Upper Stage to fly on a booster such as the Titan, with the same capability as exists today. Figure 4.3-5 illustrates the required changes and additions to the Agena Upper Stage to operate as an Ascent Agena on a Titan booster vehicle.

In order to convert the Shuttle/Agena Upper Stage for use as an Ascent Agena there are two deletions required: (1) deletion of the Shuttle/operations-peculiar software, (2) the deletion of the 150:1 expansion ratio nozzle necessary to preserve clearance dimensions between the Agena engine nozzle and the Titan forward propellant tank. The substitution of a 50:1 nozzle extension preserves dimensional clearance and still provides more than adequate performance margins for ascent missions.

SHUTTLE/AGENA
UPPER STAGE

DELETIONS	ADDITIONS
• SHUTTLE/AGENA UPPER STAGE SOFTWARE • 150:1 EXPANSION RATIO NOZZLE	• BOOSTER ADAPTER • NOSE FAIRING • DESTRUCT SYSTEM • EXISTING ASCENT SOFTWARE • 50:1 EXPANSION RATIO NOZZLE

ASCENT AGENA
(TITAN BOOSTER)

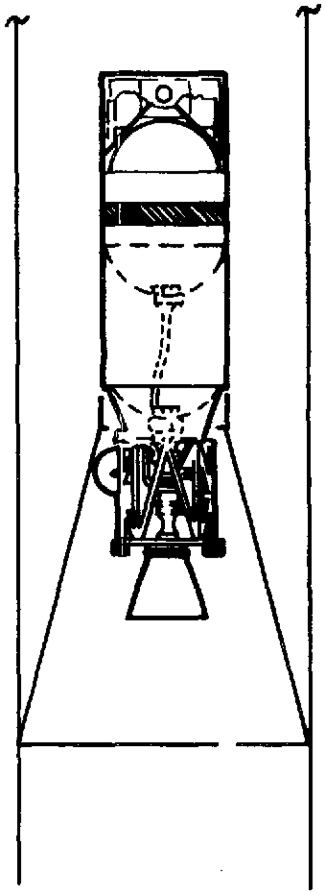

Fig. 4.3-5 Shuttle/Agena Upper Stage Transition to Ascent Agena

4.4 FURTHER GROWTH CONSIDERATIONS

The Shuttle/Agena Upper Stage performance potential extends beyond that of the Nominal concept described in this report. This performance potential can be achieved with existing technology, minimum risk, and minimum cost. For example the six optional strap-on tanks remain fixed to the core vehicle throughout the mission and are retrieved by the Shuttle along with the core vehicle. A considerable performance increase is feasible by modifying the SOT concept so that pairs of SOTs are dropped as the propellant contents are expended. The resultant effective decrease in Agena inert weight results in a direct payload capability weight gain as indicated on Table 4.4-1.

A second potential performance increase, in addition to that of dropping the SOTs, can be achieved by changing propellants from HDA/MMH to nitrogen tetroxide (N_2O_4)/MMH. This propellant change would result in an I_{sp} gain of at least 5 seconds, retaining the 150:1 expansion ratio nozzle extension.

Table 4.4-1

AGENA GROWTH CONSIDERATIONS

Change	Syn Eq (lb) Payload Gain
Change Propellants To N_2O_4/MMH	800
Drop SOT Tanks	
1 Pair	540
2 Pair	1,080
3 Pair	1,620

4.5 ALTERNATIVE CONCEPTS

Two interim Space Tug concepts were developed early in the study prior to introduction of the Shuttle/Agena Upper Stage: A drop tank version of the SOT concept and a 10-ft diameter core tank growth stage concept.

4.5.1 Configuration Descriptions

4.5.1.1 Growth Agena. This configuration, which is shown in Fig. 4.5-1, is designed as a single stage vehicle, utilizing the Bell Aircraft Corp. Model 8096B engine. The configuration is designed for a total propellant loading of 56,600 lb. Using N_2O_4/MMH as propellant and a 100:1 expansion ratio nozzle, the engine will deliver a specific impulse of 326 sec. The overall length of the vehicle is 29.9 ft, and the total installed weight with full propellant load and support system is 61,645 lb. A 150:1 area ratio can be installed to provide an I_{sp} of 330 sec, at a vehicle length of 31.5 ft.

This configuration is similar to the Agena Ascent Vehicle in that it is composed of five major components which can readily be assembled or separated for inspection or replacement. The major difference from the existing Agena design is the tank section, which is increased from 5-ft to 10-ft diameter and contains two separate tanks for the fuel and the oxidizer. This change is incorporated for increased safety, for reusability, for easy inspection and refurbishment, and to provide the large propellant load that is required.

The configuration comprises the following five major components:

1. Forward section. A lightened SCS* section serves as an interface platform for mounting the payloads and as an equipment rack which accommodates all the avionics and pressurization equipment. The rack provides easy access to these components and provides modular installation. Fig. 4.5-2 shows the installation of the equipment in the forward rack and shows the growth capability (spare bays).
2. Fuel tank section. The fuel tank section consists of fuel tank with access cover, tank sump, forward tank skirt and aft intertank structure.
3. Oxidizer tank section. The oxidizer tank section consists of the tank with access cover, sump, and forward intertank structure.

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*Satellite Control Section

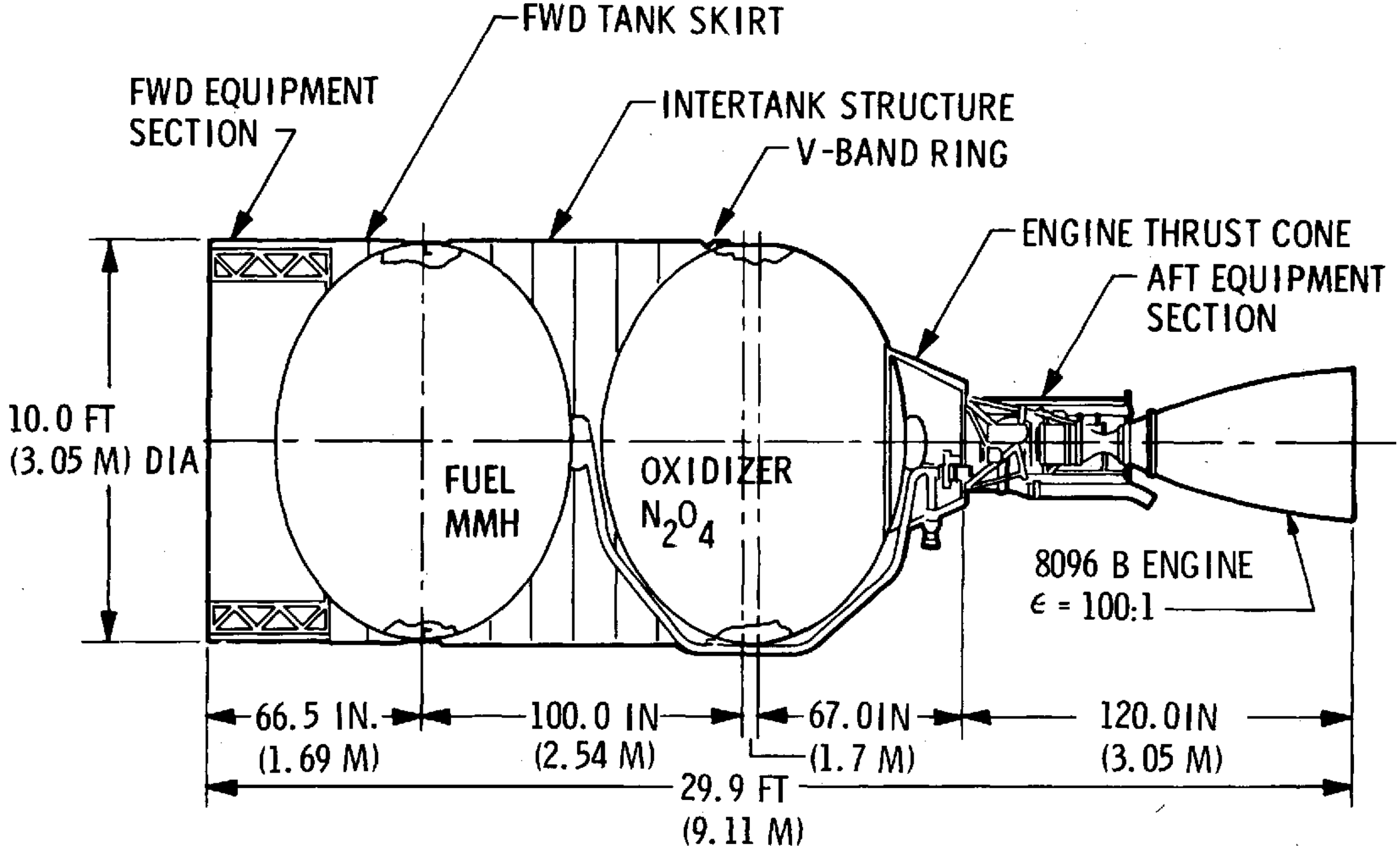

Fig. 4.5-1 Growth Agena Inboard Profile

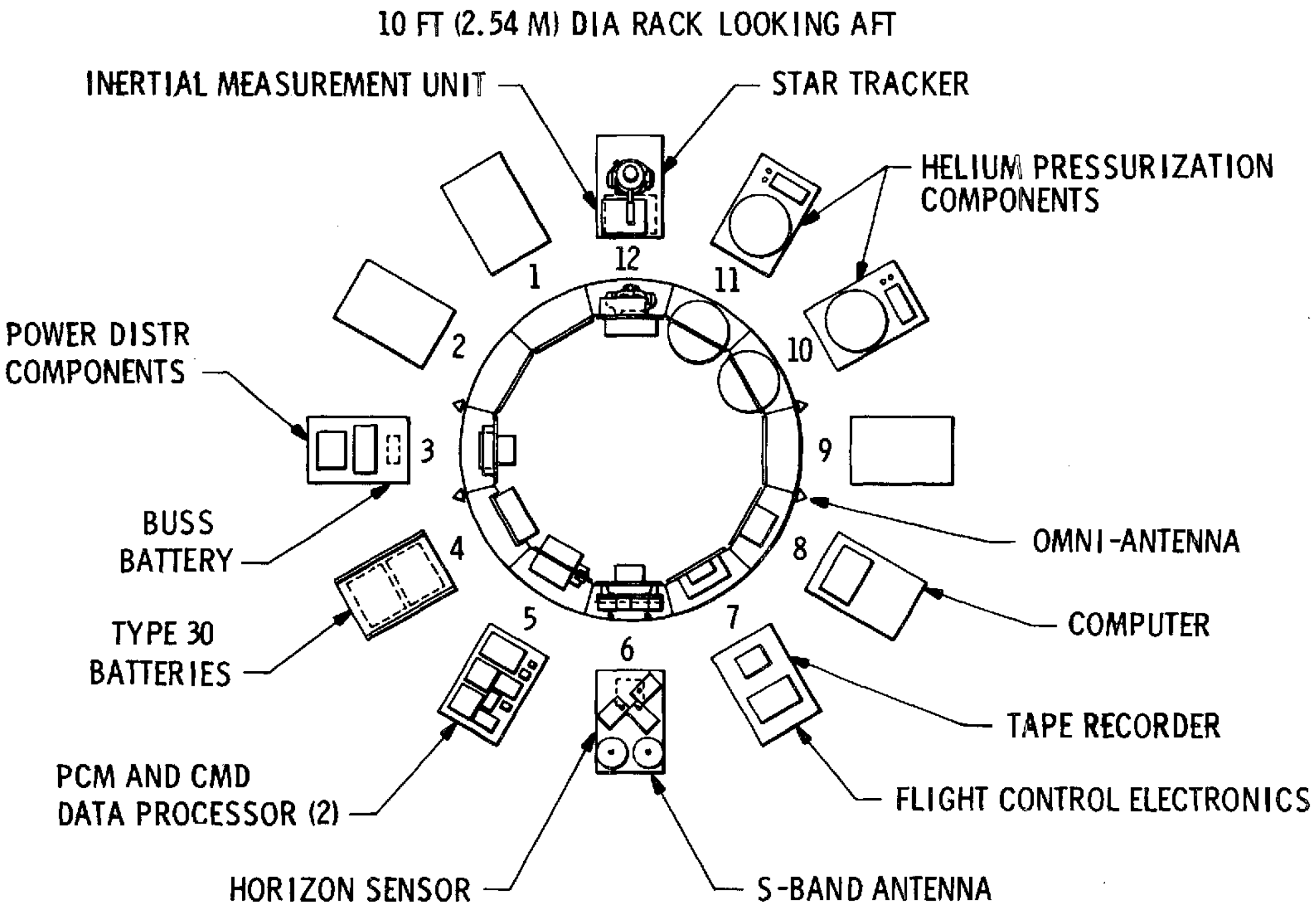

Fig. 4.5-2 Growth Agena Forward Section

4. Aft section. The aft section consists of the existing Agena engine thrust cone which attaches to the oxidizer tank and supports the engine, and the existing Agena aft equipment rack which supports the engine and propulsion equipment, and RCS and BUSS components.
5. Rocket engine. BAC 8096B engine with 100:1 expansion ratio nozzle.

The configuration is composed of existing hardware components wherever possible. A summary of the major assemblies is given below:

Structure. The existing Agena thrust cone is used with only minor modifications to its forward interface with the tank dome. The forward equipment rack is the existing Satellite Control Section (SCS) which is lightened and requalified to confirm its strength capability for the reusable Agena Tug application. The propellant tanks are a new design using existing forming capability for 10 ft. diameter domes.

The cargo bay support structure (CBSS) is a new design which will undergo development and qualification. This CBSS, shown in Fig. 4.5-3, differs from the SOT concepts in that the structure is a single assembly consisting of a lower shorter truss frame with an integral shell and doors.

Avionics. The inertial measuring unit and Star Tracker are existing guidance components, while the Quantic 4B horizon sensor is slightly modified. Flight control electronics are redesigned to accommodate new interfaces. The Autonetics DF-224 flight computer is currently in development and will be qualified by 1975. The safety/status display panel in the orbiter is new, and the tape recorder is existing equipment. Forward and aft power distribution and control boxes and electrical harnesses are redesigned; the cargo bay mechanism control box is new. The command data processor and the SGLS transponder are slightly modified to incorporate the existing USB transponder. Existing power dividers, multicouplers and switches are used. The BUSS consists of existing gyros, battery, electronics and magnetometers.

Propulsion. The modifications to the 8096 engine consist of turbopump and gas generator material changes, modification of the 5-legged baffled injector for N_2O_4/MMH propellants, increasing the Columbium nozzle extension area ratio to 100:1, and lightening/requalification of the multistart system. The engine is tested to certify 10 reuses.

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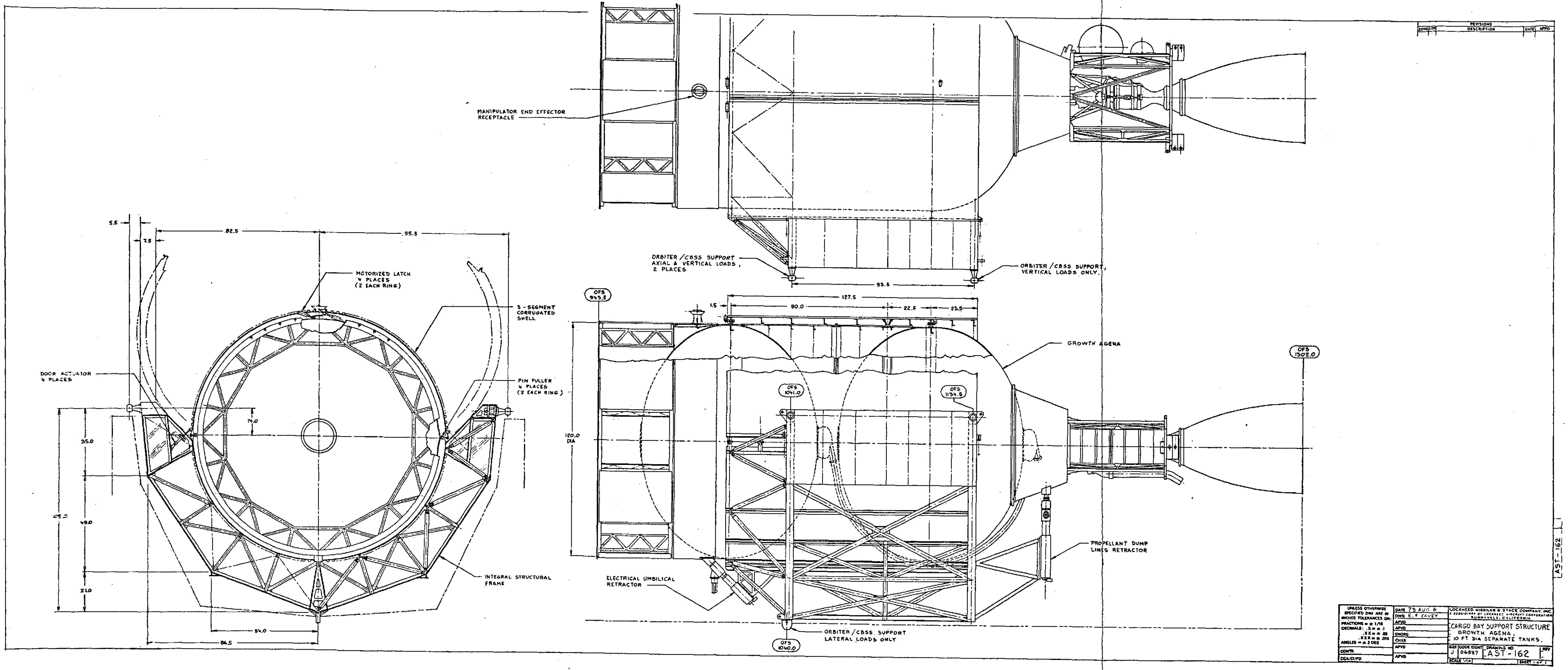

Fig. 4.5-3 Cargo Bay Support Structure, Growth Agena, 10-ft Diameter Separate Tanks

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Material capability of 200 KSI ultimate strength is planned to achieve lightweight helium bottles (new component), while existing regulators, relief valves, and shut off valves can be used as is or with minimum changes and requalifications. Existing tank sumps, TVC actuators, and hydraulic pumps are used, while a change to the RCS/SPS hydrazine thruster screen retainers is made to increase reusability.

Thermal Control. Available paint, MLI, FOSR and Mystic tape from LMSC/industry are used for thermal control.

4.5.1.2 Drop Tank Agena. This configuration, which is shown on Fig. 4.5-4, consists of a basic 5-ft diameter core vehicle with 6 strap-on propellant tanks (SOTs). The SOTs can be dropped or retained as determined by mission performance requirements. The vehicle is designed for N_2O_4/MMH propellant, using the BAC 8096 B engine at a specific impulse of 326 sec.

This configuration is also designed for structural reusability, safety, and larger propellant load, and therefore incorporates some of the design features previously described for the 10-ft diameter configuration. The system is composed of various sections and modules that can readily be assembled or separated for inspection, refurbishment or replacement. The core tank section is divided into two separate tanks for fuel and oxidizer for increased safety and ease of refurbishment.

The basic core vehicle is a complete system by itself and may be flown as such for some missions, depending on energy requirements. The core vehicle thus contains all the avionics and basic equipment. The vehicle is built up in the same way as previously described for the 10-ft diameter configuration, using the same 5 basic assemblies. These assemblies include the same basic components as the 10-ft configuration; therefore the system will have the same basic characteristics and capabilities. The installation of the avionics equipment in the forward section is shown in Fig. 4.5-5.

The add-on tanks are attached to the core vehicle by an aft support cone, which is fastened to the aft ring of the core tank section. At the forward end, the tanks are attached by a system of struts that can be released to jettison the tanks. This release

INBOARD PROFILE

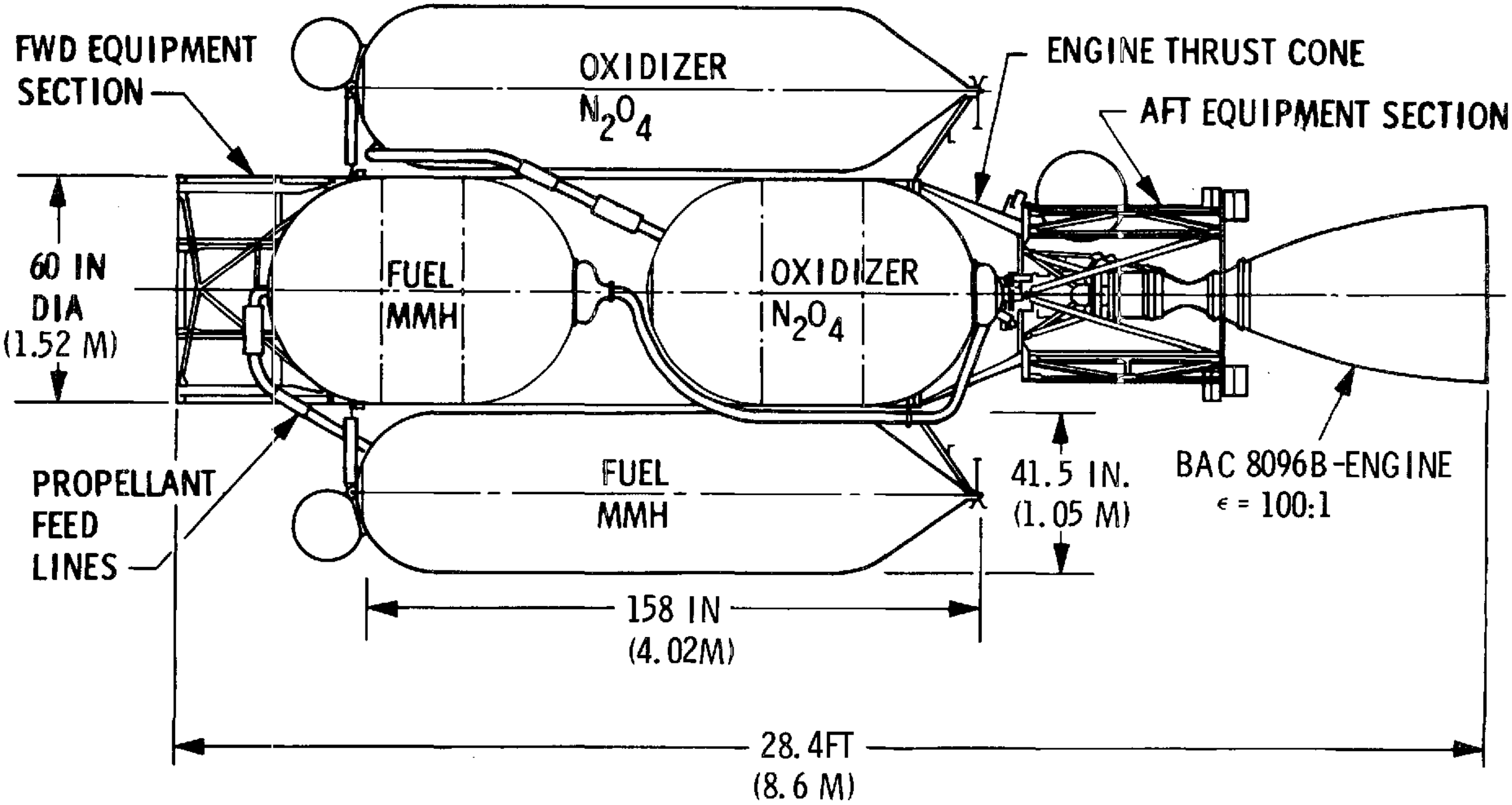

Fig. 4.5-4 Drop Tank Agena Inboard Profile

5 FT DIA RACK

BAY 1

BUSS POWER DISTR

BAY 2

HELIUM TANK

BAY 3

PCM AND CMD
DATA PROCESSOR

BAY 4

HORIZON SENSOR
S-BAND ANTENNA

BAY 5

PCM AND CMD DATA PROCESSOR

BAY 6

FLIGHT CONTROLS ELECTRONICS
COMPUTER

BAY 7

TAPE RECORDER

BAY 8

INERTIAL MEASUREMENT UNIT
STAR TRACKER

BAY 9

PRIMARY BATTERIES
SECONDARY BATTERY
POWER DISTR J-BOX

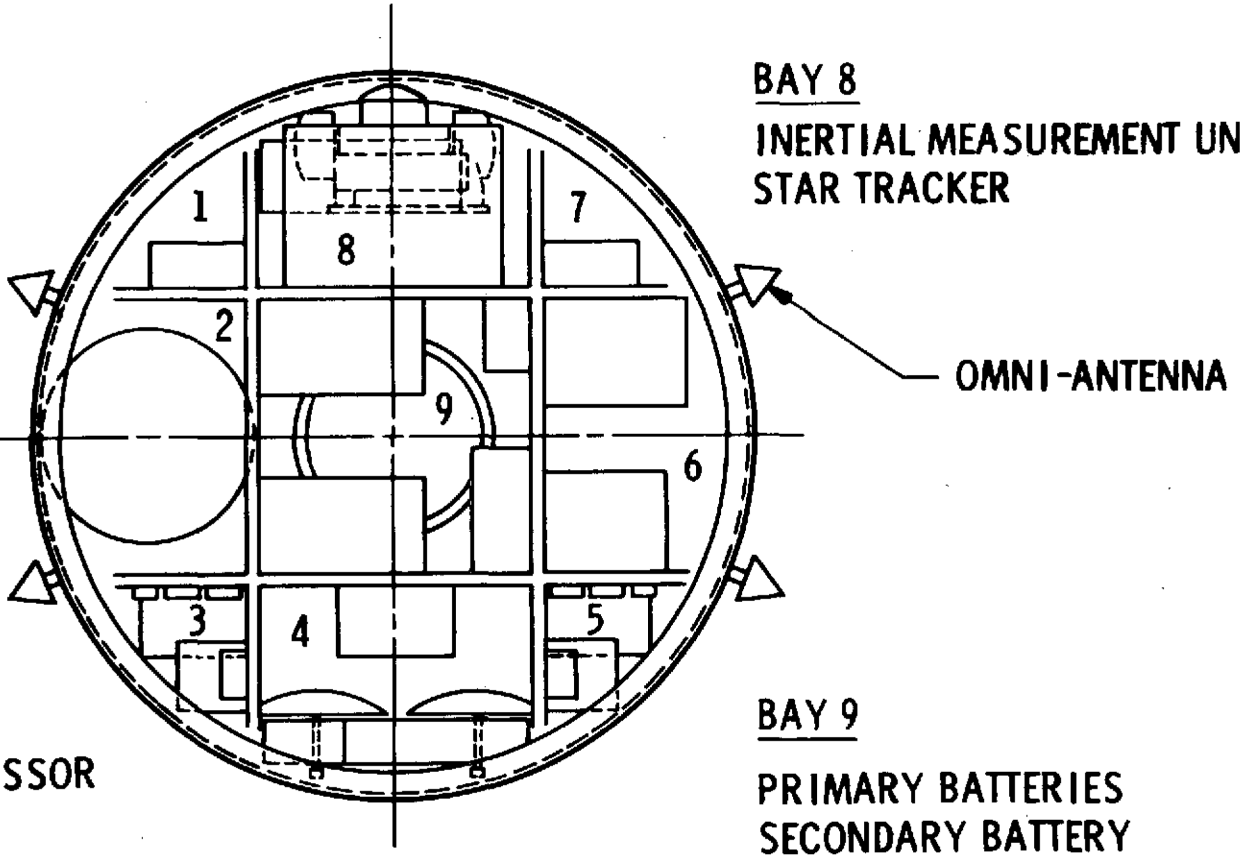

Fig. 4.5-5 Forward Equipment Section, Drop Tank Agena

mechanism is spring-loaded such that the tanks will be pushed outward from the core vehicle, rotating about the aft attachment point. The tanks are arranged in pairs of one fuel tank and one oxidizer tank; thus three sets of additional tanks are provided for the fully loaded configuration. The propellant feed is arranged in a cascade system. The propellant is pressure-fed from one tank into the next, and all propellant passes through the main tank in the core vehicle to the engine. The tank plumbing system has disconnect couplings for release of the empty tanks. The tanks can be released all at the same time, or be released one by one as the propellant is used. Each propellant tank contains a separate helium sphere for pressurization; the pressure is regulated, and shutoff valves for propellant and pressure gas are provided between each tank.

The core tanks are designed for the same requirements as the 10-ft diameter growth stage (i.e., minimum gage for the fuel tanks and pressure for the oxidizer tank). Micrometeorite protection for an 0.995 probability of success is also included in both tanks. The strap-on tanks are designed for minimum gage for the fuel tanks and pressure for the oxidizer tank, with the gage increased to meet a 12-hour micrometeorite protection capability while the tanks are loaded and pressurized.

Avionics, thermal and CBSS design are similar to the Nominal Shuttle/Agena Upper Stage concept.

An SOT separation scheme is illustrated in Fig. 4.5-6. Hinges at the bottom are attached to the outer rim of the cone support. The hinges transfer axial and lateral loads to the tank while it is parallel to the core. The forward end of each tank is attached to the core by one tension and two compression struts. The two compression struts, hinged to the tank, are inserted in recessed cavities on the core side. The tension strut is a cylinder-piston arrangement which can be released and pressurized on command of a pin-puller to detach and push away the drop tank from the core. The cables attached to the sleeve of the disconnects activate the unlatching devices and the tank is allowed to move away from the core. As it rotates, the hinge disengages and the tank separates.

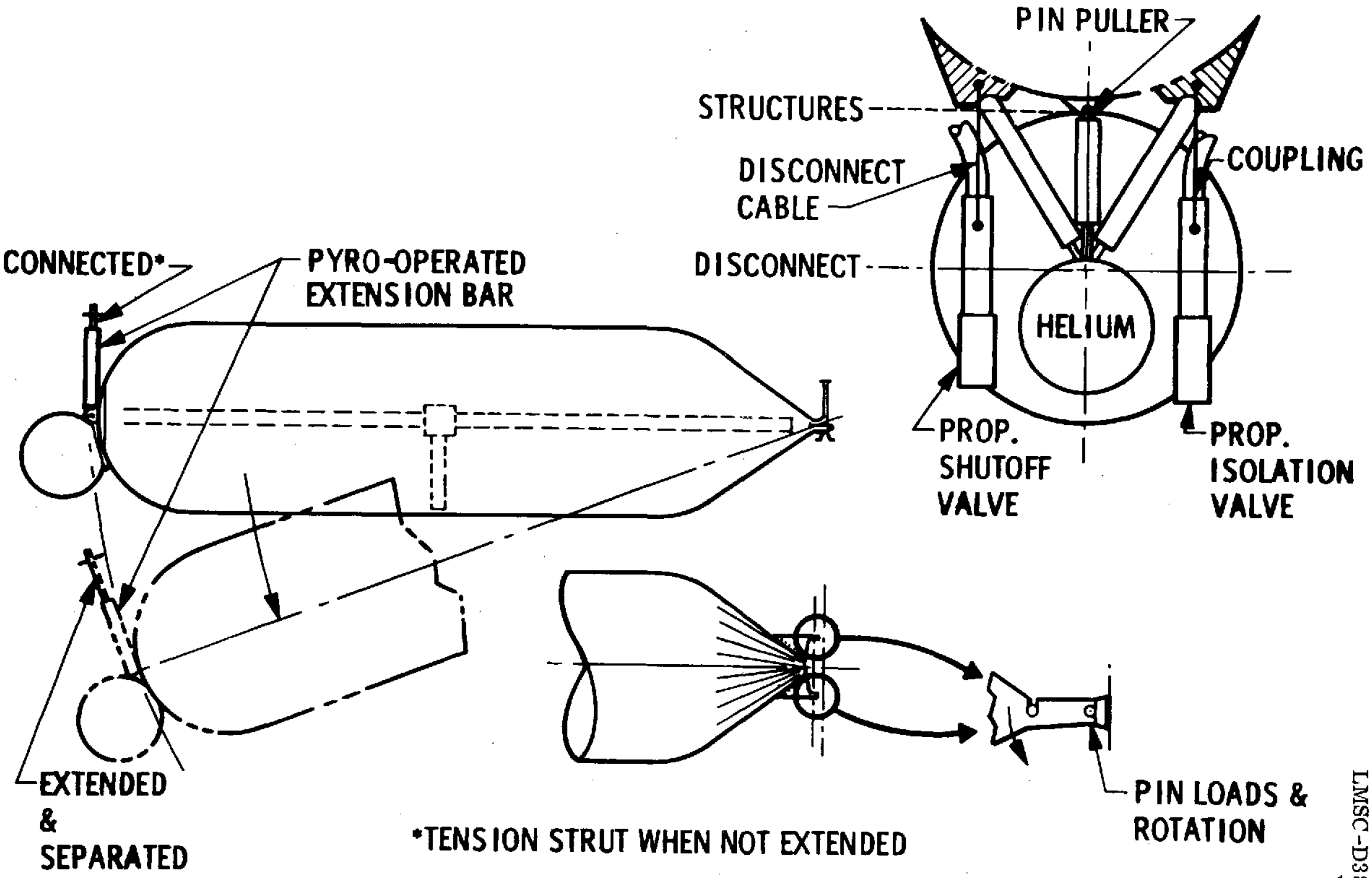

Fig. 4.5-6 Agena Drop Tank Separation Design

4.5.1.3 Concepts Characteristics and Comparison. The key characteristics of the Growth and Drop Tank concepts are provided in Table 4.5-1, and similarities and differences are described below.

Similarities. The Growth and Drop Tank concepts are similar in several respects. The basic 8096 engine installation design is common, with N_2O_4 for the oxidizer and MMH for the fuel. Hydrazine RCS is common, as is the regulated pressurization for the core tankage. Basic guidance and electrical power designs are the same. The communications assembly is redundant throughout. Data Management components are the same, as are data interfaces and manner of display in the Orbiter. Both concepts incorporate axial (vertical) propellant dump capability, allowing dump of all propellant while on the ground, during powered abort, and on orbit.

The Growth Stage concept provides positive safety features, i.e., the propellant tank pressure control is redundantly automatic and can also be controlled by astronaut override. Fail operational/fail safe communications and attitude control during orbital operations and Agena retrieval is achieved by redundant communications and critical control circuits; redundant RCS with controls electronics shutdown override are provided; and Orbiter or ground override can be achieved by RF command. (The Drop Tank concept was not assessed for safety in sufficient detail, but can be designed to meet all requirements, similar to the Growth or Agena Upper Stage designs.)

Differences. Significant differences between these configurations are highlighted as follows:

- The Drop Tank Agena features blowdown pressurization and cascade propellant feed in the SOTs in order to provide drop capability, while the Growth Stage incorporates regulated pressurization in the two main tanks. The pressure in the Drop Tank Agena core tanks is also regulated.
- The Drop Tank uses existing core structure assemblies with new SOTs and core tanks made of 2021 aluminum. The Growth stage uses existing aft section structure, new separate tanks made of 2021 aluminum, and a modified SCS forward rack.

Table 4.5-1

ALTERNATE CONCEPTS CHARACTERISTICS/COMPARISON SUMMARY

Item	Growth Agena	Drop Tank Agena
Dimensions		
Length	29.9 ft (9.12 m)	28.4 ft (8.65 m)
Diameter	10.0 ft (3.05 m)	12.0 ft (3.66 m)
Propellants	N_2O_4/MMH	N_2O_4/MMH
Engine I_{sp}	326 sec (3195 N sec/kg) 8096B Engine ϵ = 100:1	Same as Growth
Thrust	16,000 lbf (71,200 N)	16,000 lbf (71,200N)
ACPS (N_2H_4) I_{sp}	125 sec (1227 N sec/kg) 175 sec (1718 N sec/kg) redundant in hi mode	Same as Growth
Thrust	0.5 lbf (2.2N) 12 lbf (53.4N)	
Pressurization	Regulated	Regulated Core, Blowdown SOT
Propellant Feed	——	Cascade feed from SOTs
Abort Dump	100%	Same as Growth
Tankage	2 Separate Tanks	2 separate core tanks + 6 drop SOTs
Tank Attach	Interstage	Separable FWD rods and AFT cone for SOTs
Equip. Structure	Modified 10 ft (3.05 m) SCS; existing aft section	Existing 5 ft (1.52 m) FWD rack, AFT core & rack
Communications	Redundant	Same as Growth Agena
Guidance & Nav.	Existing IMU, modified CEA & HSA; Star Tracker included	
Data Mgt	DF 224 computer-single string, CIU and tape recorder	
Electrical (Primary)	2 Type 30 batteries	
Buss	Gyros, Magnetometer, J-Box, Type IV B Battery	
Orbiter Interface		
CBSS	Single truss and shell w/doors	FWD and AFT assemblies
DUMP	Liquid & pneumatic Ifaces & Retractor	Same as Growth, but reconfigured
Communications	Safety hardline; wave train, RF	Same as Growth
Display/CMDS	RDM and display panel	Same as Growth

- The Growth Stage is supported in the cargo bay by a single truss-shell structure with doors. The Drop Tank uses Strap-on-tanks which are supported in the same manner as the Agena Upper Stage concept, i.e., an aft truss assembly and a forward whiffle-tree-trunnion assembly (pivot capability for readily accommodating deflections). The aft assembly also incorporates a kit so that the core vehicle can be accommodated when it operates without drop tanks.

4.5.1.4 Hardware Status Summary. A status summary for the Growth Agena is discussed below.

Structure. The existing Agena thrust cone, aft rack, and lightened forward rack will be used. The tanks and interstage are new and made of 2021 aluminum. The CBSS is new, and made principally of aluminum alloys.

Avionics. The IMU is an existing GNC component, while the star sensor requires modification. Flight control electronics are modified because of new interfaces. The Autonetics computer currently in development will be qualified by 1975. The Agena display panel in the Orbiter is new. Power distribution and control boxes and harnesses will be modified to incorporate new interfaces and requirements. The command data processor is slightly modified to incorporate the existing USB transponder. The existing antennas are used, along with existing C&C power dividers, multicouplers, and switches.

Propulsion. The modifications to the existing 8096 engine to convert to the 8096B version consist of resizing the control components (venturis and oxygen valve), incorporation of a modified version of the 5-legged baffled injector into the TCS, increasing the Columbian nozzle extension to 100:1 area ratio, and lightening/ requalifying the multistart system. The engine would be tested to certify a 10-reuse capability.

Helium bottle material capability of 200 KSI ultimate is planned to achieve light weight (new component), while existing industry regulators, relief valves, and shutoff valves are used as-is or with minor changes. Existing sumps (propellant management), TVC actuators and hydraulic pump will be used, while a change to the RCS hydrazine thrusters (screen retention) will be made to increase reusability. The liquid dump/ pneumatic vent retractor in the cargo bay is new.

Thermal Control. Available MLI, FOSR, and mystic tape from LMSC/industry will be used for temperature control design. Heaters are incorporated into the hydrazine tanks and thrusters. A similar status exists for thermal control of the Drop Tank version.

The Drop Tank Agena avionics, propulsion, and thermal control subsystems are similar in equipment design and selection; therefore, the development status is essentially the same as that shown for the Growth Stage.

Structurally, the main difference is that the core tanks and the 41.5 inch SOTs are new and constructed of 2021 aluminum. (The existing 6061 aluminum core tank sections could be used in fabricating modified (rather than new) separate cone tanks and interstage). The existing Agena 5-ft diameter forward equipment section is used on the Drop Tank Agena, with only minor additions required for strap-on tank installation/dropping capability.

4.5.2 Weight and cg Summaries

A weight summary for the Growth Agena, Drop Tank Agena core only, and Drop Tank Agena including strap-on tanks is presented in Table 4.5-2. A contingency allowance of 10 percent of vehicle dry weight has been added to account for unknowns.

Center of gravity limits for the range of propellant loads from maximum to empty and for payloads from zero to 10,000 lb are shown in Fig. 4.5-7 for the Growth Agena and in Fig. 4.5-8 for the Drop Tank Agena.

Table 4.5-2

SYSTEM WEIGHT SUMMARIES (1) – LB (KG)

Item	Growth Agena	Drop Tank Agena	
		Core	SOT & Core
Structure	1,321	717	1,310
Propulsion (2)	673	542	882
Avionics (3)	788	788	807
Thermal Control	49	32	62
Contingency (10%)	283	208	306
Dry Weight	3,114(1,413)	2,287(1,037)	3,367(1,527)
Nonusable Residuals	127	70	243
PPS Reserves (1% of Δ V)	146	106	163
Burnout Wt	3,387(1,536)	2,463(1,117)	3,773(1,711)
Usable Propellants	56,000	15,100	56,500
Usable Hydrazine	100	100	100
Start/Stop Losses	275	275	275
Cargo Bay Equipment	1,883	1,636	1,536
Total Installation Weight (4)	61,645(27,962)	19,574 (8,879)	62,184(28,207)(5)

(1) Syn Eq Mission, Fixed Tanks, 3 pair SOTS (Fixed)
(2) Includes BUSS & SPS when applicable
(3) Includes BUSS where applicable
(4) Without payload
(5) Ejectable weight per tank set = 451 lb; total injectable weight = 1,352 lb

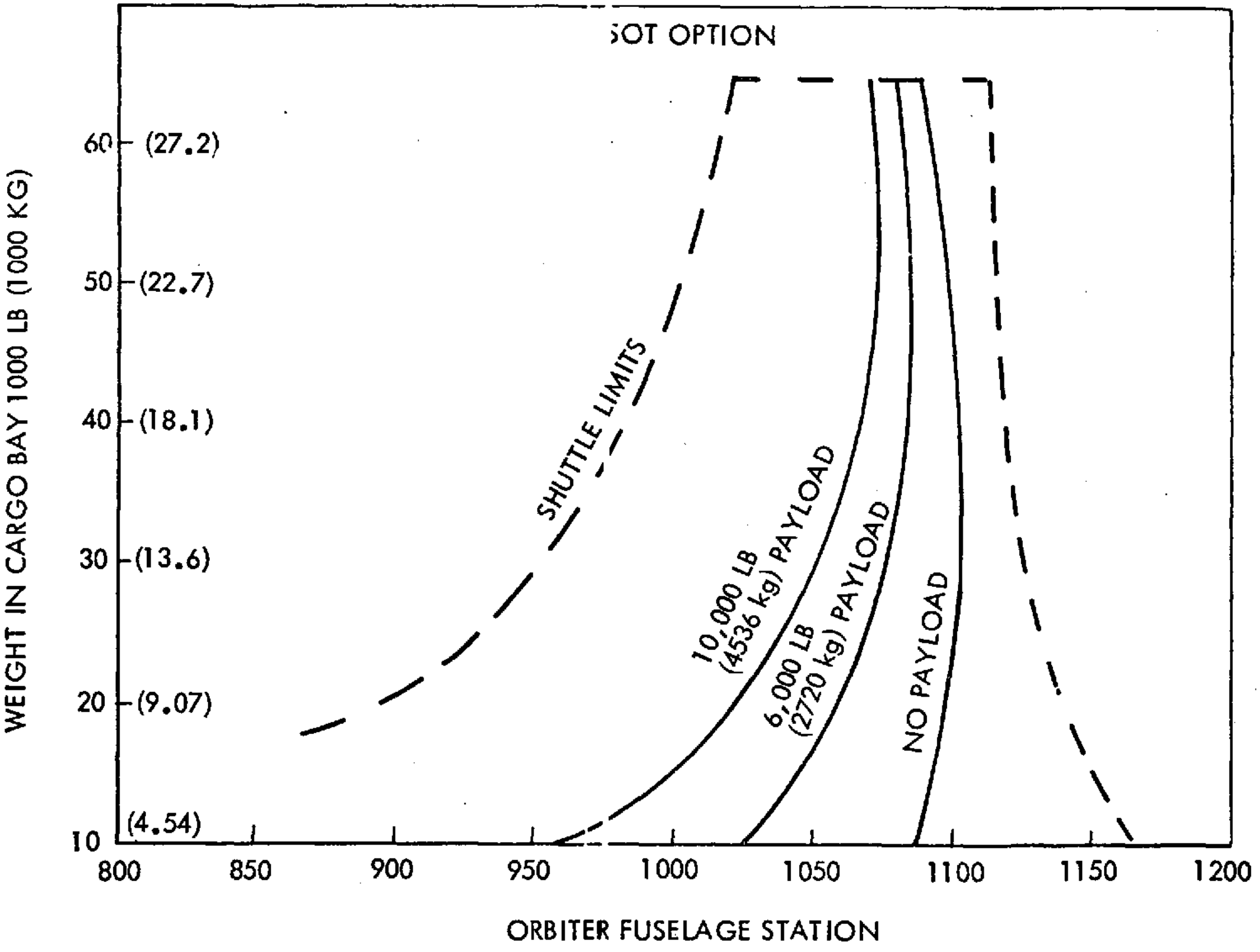

Fig. 4.5-7 Growth Agena CG Characteristics in Orbiter

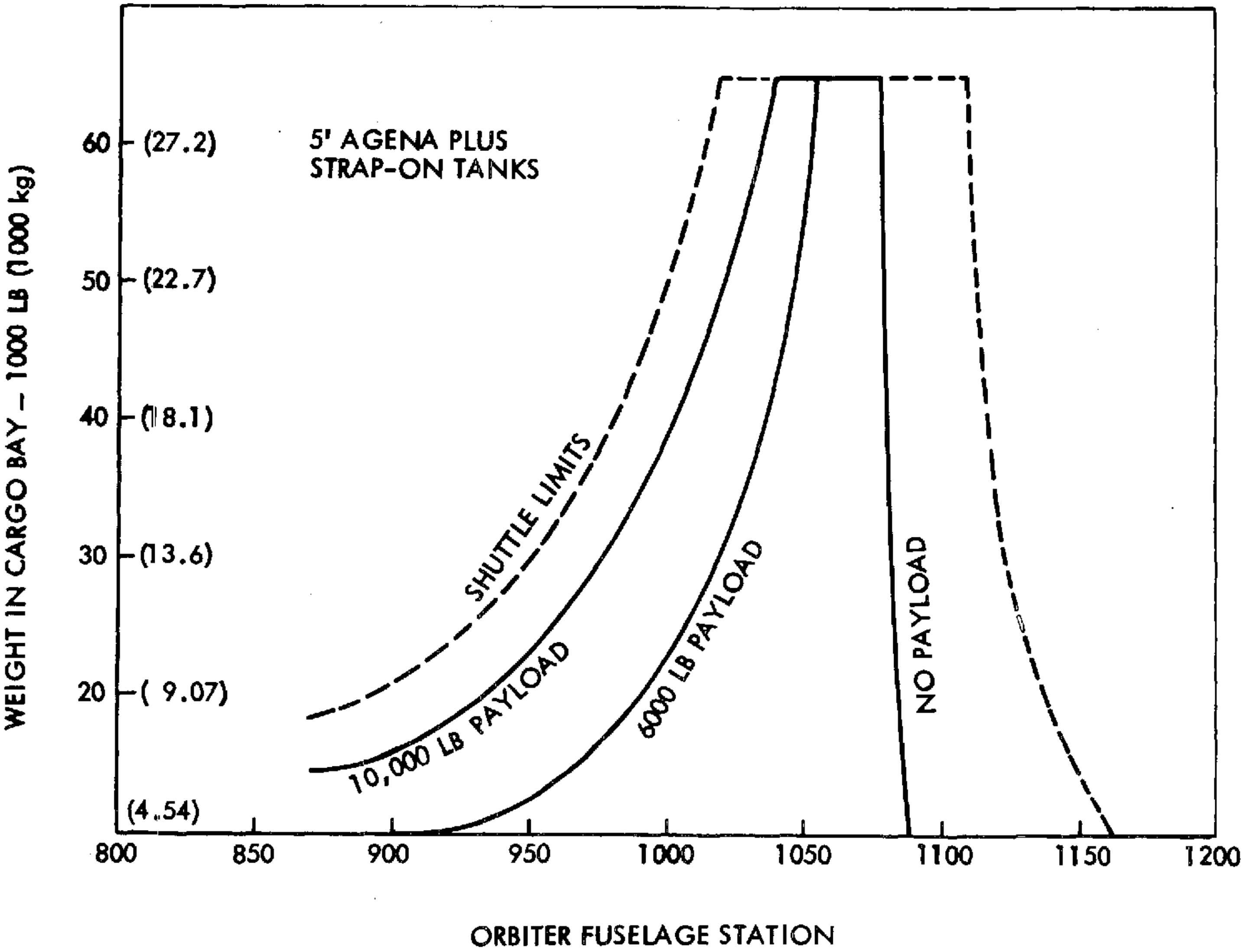

Fig. 4.5-8 Drop Tank Agena cg Characteristics in Orbiter

4.5.3 Growth and Drop Tank Agena Performance

Performance data for the alternative Agena configurations using N_2O_4/MMH propellants are presented in Section 3.7.2. The tables and figures in Section 3.7.2 show the performance realized with increased propellant capacity, increased I_{sp}, and capability to drop empty tanks.

Mission capture for the alternative configurations is presented in Section 3.7.3.3.

4.5.4 Ground Operations

The ground operations defined for the Growth and Drop Tank Agenas are identical to operations with the Nominal and Augmented concepts except for minor differences described below.

The Growth Agena is designed for handling with full propellants in either vertical or horizontal attitude. All strap-on tank concepts are designed for handling only in the vertical attitude when loaded with propellants.

Ground turnaround time for the Growth Agena is estimated to be 306 hours as compared to 336 hours for the configurations with strap-on tanks. The time difference is attributable to the additional complexity in refurbishing, loading, and checking the multiple tanks and lines of the SOT configurations. Propellant loading is assumed to take place on the pad in the vertical attitude, with payloads mated, before insertion in the Shuttle cargo bay.

4.5.5 Flight Operations

Flight operations are discussed in Section 3.8.2 for all configurations. There are no important flight operations differences between the Shuttle/Agena Upper Stage concepts and the alternative concepts.

4.5.6 Facility Requirements

Facility requirements for the Growth Agena or Drop Tank Agena are similar to those described in Section 3 for the Shuttle/Agena Upper Stage configurations. A major facilities summary is presented in Table 4.5-3.

4.5.7 Ground Test Program

The 10-ft diameter main propellant tank section of the growth stage is completely new structure. This dictates the structures test plan shown in Table 4.5-4. The details of this plan are as follows.

Technology verification tests are performed early in the program to provide design data. Coupons are tested to establish fracture toughness/flaw propagation data for the oxidizer tank material (2021-T81 Aluminum) in air, salt spray, and N_2O_4 propellant. Tests on four specimens are planned. Hypervelocity micrometeorite particle simulation tests will be conducted, using eight oxidizer-tank-thickness panels to provide design data for tank micrometeorite protection. Three panel tests on simulated intertank design are planned to provide early confirmation of panel design data as predicted by buckling theory. Design verification tests prove the design and, to some extent, provide qualification data. These tests are performed early in the program and also assess how manufacturing procedures affect predicted results. The oxidizer and fuel tanks will be leak-checked and then proofed to yield. Since the fuel tank is designed by minimum gage, it will be taken to burst to verify ultimate strength. The oxidizer tank, however, will be subjected to simulated mission duty stress cycles with N_2O_4 before it is taken to burst, to verify the effect of N_2O_4 on the stressed tank. The CBSS fittings which will attach to the Shuttle cargo bay will be tested to failure to verify crash load capability. Two sets will be required to verify two separate load paths.

Certification tests verify that the vehicle system meets program requirements. These tests include mission duty cycle (cyclic), dynamic modal, acoustic, slosh, shock and

Table 4.5-3

MAJOR FACILITIES SUMMARY

REQUIREMENT	SPECIFICATIONS	EXISTING FACILITY
MANUFACTURING/ASSEMBLY/ CHECKOUT ● MANUFACTURING AREA ● CHECKOUT COMPLEX ● ACOUSTIC TEST CELL ● SPACE SIMULATOR	10 FT VEH DIA; 30 FT LENGTH	(LMSC BUILDING 156 COMPLEX)
TEST		
● CAPTIVE FIRING STAND	16,000 LB THRUST, EARTH STORABLE PROPELLANTS	LMSC SANTA CRUZ TEST BASE STANDS 1 & 2
● SPACE SIMULATOR	10 FT DIA X 30 FT SPECIMEN SIZE	LMSC BLDG 156 CHAMBER
LAUNCH (EACH SITE)		(EXISTING KSC, CKAFS, VAFB FACILITIES)
● HYPERGOLIC PROPELLANT LOADING FACILITY	4,000 SQ FT INCL 2,000 SQ FT HIGH BAY WITH 50-TON CRANE	
● HYPERGOLIC VEHICLE FLUSHING FACILITY	6,400 SQ FT INCL 3,200 SQ FT HIGH BAY	
● REFURBISHMENT/INTEGRATION FACILITY	60,000 SQ FT SHOP, 8,000 SQ FT OFFICE; 5-TON CRANE	
● LAUNCH PAD HYPERGOLIC OFFLOADING FACILITY	2 X 500 SQ FT AREA; 4,000 GAL. STEEL TANKS (2)	RA-DD-215

Table 4.5-4

STRUCTURES TEST APPROACH

ASSEMBLY	SUBASSEMBLY	ASSEMBLY	COMB. ASSY*	VEHICLE	SYSTEM* VEH + CBSS
FWD RACK			#1	#1	#1
FUEL TANK		LEAK, PROOF, & BURST TANK #2	● LIMIT ● CYCLIC	● MODAL (SHAKE) ● SHOCK	● MODAL (SHAKE) ● DEPLOYMENT – RETRIEVAL MECHANISMS ● ACOUSTIC (W & W/O PROP SIMULATION)
		LEAK, PROOF, & SLOSH TANK #1 →			
INTERTANK SHELL (INCL V-BAND RING)	PANEL BUCKLING (3 PANELS)				
OXIDIZER TANK	● FRACTURE TOUGHNESS & FLAW PROPAGATION (24 COUPONS) ● MICROMETEORITE PENETRATION (8 PANELS)	TANK #3 LEAK, PROOF, NTO CYCLE & BURST	● LIMIT ● CYCLIC		
		TANK #1 LEAK, PROOF, & SLOSH →			
THRUST CONE AFT RACK					
CBSS	CRASH/ULTIMATE (ATTACH FITTINGS)	● LIMIT + 10% ● CYCLIC			
RETRACTORS					

RA-DD-127

*TO INCLUDE EQUIP, ENGINE, & P/L SIMULATORS
**SEPARATION AT FIELD JOINT

☐ DESIGN CERTIFICATION ☐ TECHNOLOGY ☐ DESIGN VERIFICATION mechanism functions, as well as limit loads. The sequence of testing will be as follows: At the tank assembly level, the oxidizer and fuel tanks, including sumps, will be leak-checked, proofed to yield, and then subjected to slosh vibration, using three levels of simulated propellant. The cargo bay support structure (CBSS) will be subjected to a loading of 10 percent in excess of limit design load to verify the strength and static stiffness.

All structure will then be assembled to the vehicle level, to include simulated or actual equipment, engine, and payload mass simulation. As a vehicle, the structure will be subjected to modal and shock tests with two levels of simulated propellant. The vehicle will then be combined with the CBSS to perform additional modal vibration tests with and without propellant. The system will then be subjected to a series of acoustic tests, with and without simulated propellant, to establish equipment and structural responses to the Shuttle cargo bay environment; and mechanisms tests to verify deployment and retrieval procedures.

The vehicle system will then be separated at the intertank field joint into two combined assemblies to perform the final limit load and cyclic (MDC) tests. Each combined assembly will be subjected to the design load envelope of 10 percent greater than limit load to include tank pressures during ground, Shuttle and space operations. Each combined assembly will then be subjected to the operational load spectrum also to include tank pressures during ground, Shuttle, and space operations to demonstrate reusability and predictable repair and replacement requirements.

The vehicle system, including CBSS, remains intact and available for additional ground use or tests at the discretion of NASA (for example, crash loads as a final test).

The life-cycle costs of the Growth Agena may be summarized as follows:

DDT&E	$104.7M
Production	51.9
Operations	76.3
TOTAL	$232.9M

These costs include a two-launch-base capability (ETR/WTR) and also include the price of the GFE engine. DDT&E costs reflect a development program based on full demonstration of major stage features including the Model 8096B main engine (N_2O_4/MMH propellants) and the design goal of a 10-mission minimum operational life. The DDT&E program for the Growth Agena is 9 months longer than the Shuttle/Agena Upper Stage to account for long-leadtime developments including the 8096B engine. Production costs cover acquisition of the vehicle fleet, Orbiter interface equipment, and initial spares. Operations costs are for a total of 93 flights from ETR (1980–1983) and from WTR (1983 only); they include costs for launch, flight operations, and stage refurbishment.

Costs for the drop-tank configuration were not established.

Section 5
CONCLUSIONS

The Shuttle/Agena Upper Stage interim Space Tug concepts described in this report are characterized by low cost, operational flexibility, safety, performance well beyond the minimum required, low development risk, and easily attained growth options.

The relatively low Agena DDT&E cost of $49.8M is a direct function of the minimum modifications required to adapt the existing Agena for use as a Shuttle upper stage. This adaptation includes compatibility with the Shuttle interface, Space Tug requirements and guidelines, and the eleven-year Tug mission model.

The strap-on-tank option provides propellant load flexibility that directly benefits both the Shuttle and payloads carried by the Tug. The capability to fly with varying propellant loads, without the usual penalty of off-loading, results in more efficient use of each Shuttle flight and more closely tailors the Agena performance capability to that needed by the payload for completion of its mission.

The 5-foot (1.5 m) diameter of the Agena lends itself to side-by-side packaging in the cargo bay with 2 or 3 Agenas mated with individual spacecraft, and deployed and flown one at a time. The payloads could be identical or there could be a mix of payloads and missions.

The Agena is a safe Upper Stage for operation in and about the Space Shuttle. Positive main propellant tank pressure control is provided by redundant automatic control of the tank pressurization and tank vent systems. Backup manual astronaut override of the automatic control system is also provided. Positive control full propellant dump is provided for on-pad, during ascent, or on-orbit emergency conditions. For the critical retrieval operation fail operation/fail safe capability is provided in the form of fully redundant communications and control and attitude control. Provisions for astronaut override by RF command is also provided through the Agena redundant communications systems.

Agena synchronous equatorial placement capability is substantially higher than the required 3500 pounds (1586 kg) with Agena return to the Shuttle orbit for retrieval by the Shuttle.

Only minimum modifications are required on the Agena for compatibility with the Shuttle and the mission model. These modifications are confined to minor main engine changes and the addition of the strap-on-tank option to provide for flexibility in mission Δvelocity needs. The development risk is therefore quite low and consistent with the operational maturity of the Agena.

The growth capability of the Agena extends well beyond that required for 100 percent capture of the existing mission model. This growth is easily achieved through minor modification of the vehicle and operating modes and is within 1973 technology levels.

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