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REUSABLE AGENA STUDY

FINAL REPORT

EXECUTIVE SUMMARY

VOLUME I

CONTRACT NAS 8-29952

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LOCKHEED MISSILES & SPACE COMPANY, INC.

A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION

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Vol I

REUSABLE AGENA STUDY
FINAL REPORT
EXECUTIVE SUMMARY

Prepared for

National Aeronautics and Space Administration,
Marshall Space Flight Center,
Huntsville, Alabama

Contract No. NAS8-29952

LOCKHEED MISSILES & SPACE COMPANY

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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Section I
INTRODUCTION

The Shuttle Agena Upper Stage interim tug concept which is emphasized in this summary report is based on a building block approach. These building block concepts are extensions of existing ascent Agena configurations.

Several current improvements, incorporated or in development since 1970, have been used in developing the Shuttle/Agena Upper Stage concepts (Fig. 1-1). High-density acid (HDA) is used as the Agena Upper Stage oxidizer. The baffled injector is used in the main engine. The DF-224 is a fourth generation computer currently in development and will be flight proven in the near future.

The Agena Upper Stage building block concept (Fig. 1-2) uses the current Agena as a baseline, adds an 8.5-inch (21.6 cm) extension to the fuel tank for optimum mixture ratio. uses monomethyl hydrazine (MMH) as fuel, exchanges a 150:1 nozzle extension for the existing 45:1, exchanges an Autonetics DF-224 for the existing Honeywell computer, and adds a star sensor for guidance update. These modifications to the current Agena provide a 5-foot (1.52 m) diameter Shuttle/Agena Upper Stage that will fly all Vandenberg Air Force Base (VAFB) missions in the reusable mode without resorting to a kick motor.

The Δ velocity of the Agena is increased by use of a strap-on propellant tank (SOT) option. This option provides a Shuttle/Agena Upper Stage with the capability to place almost 3900 pounds (1769 kg) into geosynchronous orbit (24 hour period) without the aid of kick motors.

The baseline Agena Upper Stage building block concept depicted in Fig. 1-2 is available in two configurations, Nominal and Augmented. The two configurations are identical except in the avionics area and in the 5-foot diameter Agena core tank material. The Shuttle interface, including the cargo bay support structure, is the same for both configurations. The configuration recommended as a candidate interim Space Tug is the Nominal configuration. This recommended Nominal configuration is emphasized in both this summary report and in the detailed technical report.

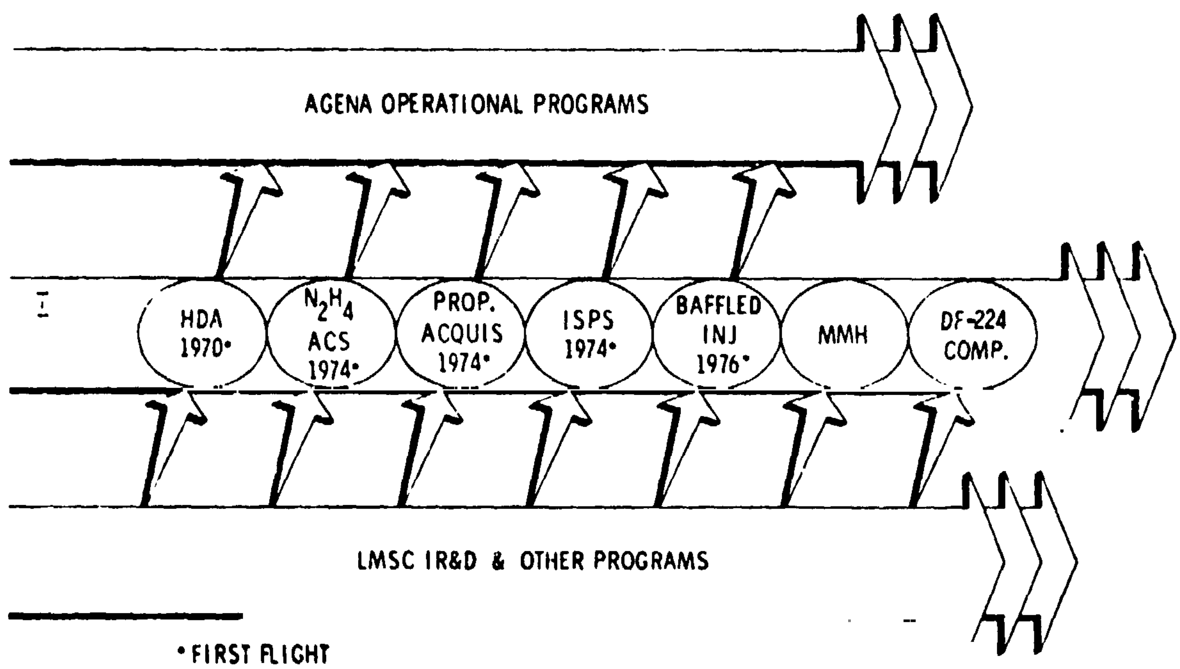

Fig. 1-1 Agena Improvements Since 1970

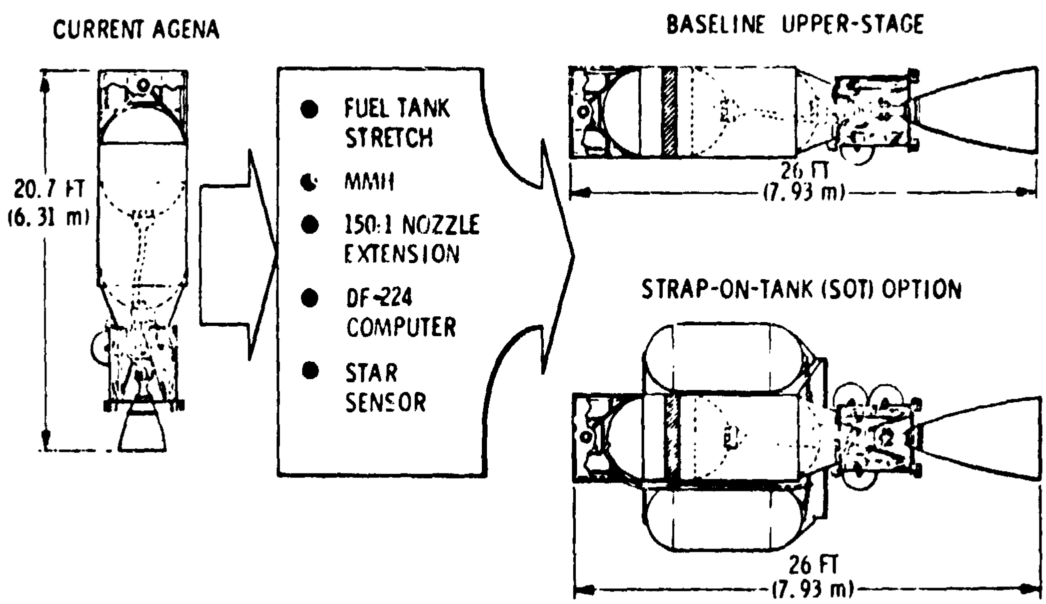

Fig. 1-2 Building Block Concept

Section 2
STUDY OBJECTIVES

The specific objective of this Reusable Agena Study was to establish a Shuttle/Agena Upper Stage concept as an interim Space Tug that meets, or exceeds, NASA and DoD mission requirements. Several key issues were addressed in meeting this objective. These issues included:

- Feasibility of building block concept
- Special mission flexibility
- Mission model capture
- Performance
- ETR versus WTR
- Safety
- Low cost
- Expendable booster transition
- Growth

The building block concepts presented in this report are attractive and feasible approaches to a Shuttle Upper Stage. These concepts exhibit the flexibility needed to meet the requirements of special missions such as on-orbit spacecraft servicing, and for special payloads as long as 40 feet. One hundred precent mission capture is achieved for two entirely different mission assignments of (1) assuming both KSC and VAFB are operational, and (2) assuming all missions are flown from KSC.

Another important issue concerns the period of transition from expendable boosters to use of the Shuttle. It seems highly desirable that the Shuttle Upper Stage be easily adaptable, with minimum modification, to either Shuttle or conventional booster launches during this transition period.

Equally important is the capability for further growth within the bounds of existing technology. Since mission models tend to change, and payloads always seem to increase in weight, the building block concept should permit growth to higher levels of performance without unreasonable penalties in cost, risk, or schedule.

Section 3
RELATIONSHIP TO OTHER NASA EFFORTS

The original Shuttle/Agena Compatibility Study was initiated in 1971. (Fig. 3-1) This study involved definition of the required expendable Agena modifications for compatibility with the Space Shuttle, and preliminary design of the required cargo bay interface support equipment. The Shuttle/Agena Compatibility Study follow-on, performed for Lewis Research Center during 1973, continued the earlier work for an expendable Agena.

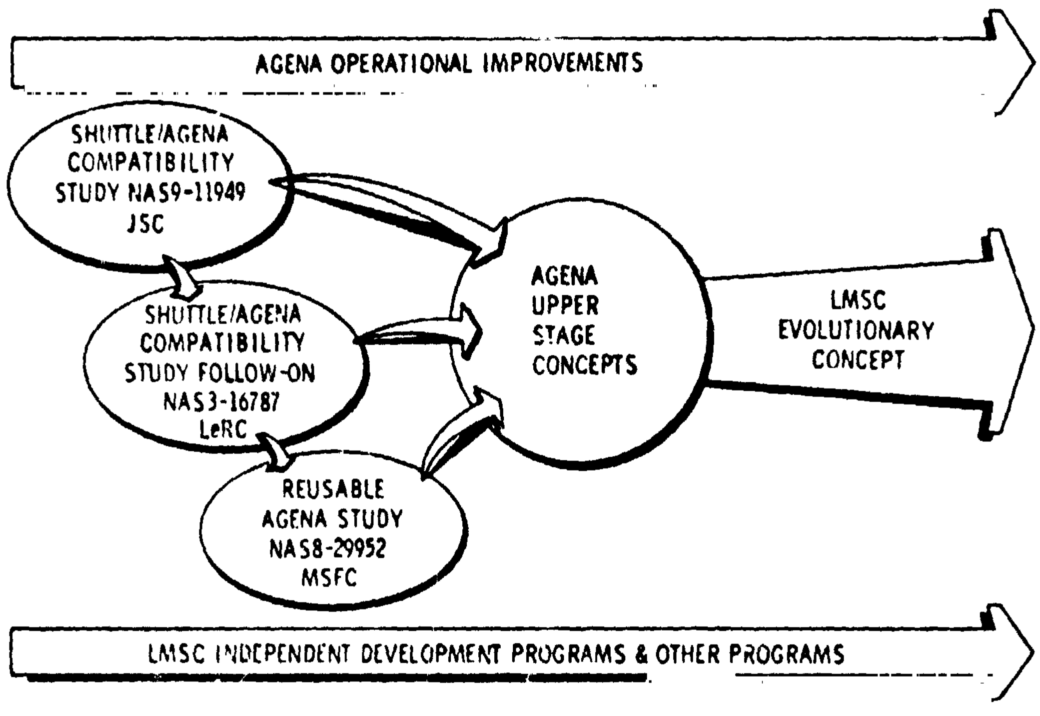

Fig. 3-1 Shuttle/Agena Background

Section 4
METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS

A building block concept of a Reusable Agena was selected with consideration of mission performance, low DDT&E cost, low operating cost, low risk, high reliability, and safety. Shuttle/Agena Upper Stage missions will consist of payload delivery followed by stage-only recovery. Maximum use of hardware that is flight-proven or under development was made to minimize risk and to keep DDT&E costs low.

The following key guidelines are applicable to the study:

- Maximum use will be made of components in existence or under development.
- The mission accomplishment reliability goal is 0.97.
- Performance figures reflect a 10-percent across-the-board weight contingency allowance for the 10-foot diameter and drop tank Agenas.
- Performance figures for the Nominal and Augmented Shuttle/Agena Upper Stage reflect a combined 2 percent contingency on existing hardware and a 10-percent contingency on new or modified hardware.
- A 1.7-percent flight performance reserve applies to the 10-foot diameter and drop tank Agenas.
- A 1-percent flight performance reserve with an added 50 lb fuel bias applies to the Nominal and Augmented Shuttle/Agena Upper Stage concepts.
- The communications system will be fail operational/fail safe.
- The minimum synchronous equatorial payload capability for payload delivery and return of the empty Agena is 3500 pounds (1587.6 kg).

Section 5
BASIC DATA GENERATED AND SIGNIFICANT RESULTS

The Shuttle/Agena Upper Stage concept depicted in Fig. 5-1, meets or exceeds all requirements for an interim Space Tug. This Agena Upper Stage concept utilizes high-density acid (44 percent N_2O_4) and monomethyl hydrazine (MMH) as propellants. The main engine is a Bell 8096L with a 150:1 nozzle expansion ratio giving an I_{sp} of 324 seconds (3180 N sec/Kg). It has a total main propellant load, including the optional strap-on tanks (SOTs), of approximately 56,000 pounds (25400 kg). It has a hydrazine, monopropellant hot-gas attitude control system and features a fourth generation Autonetics DF-224 computer.

All vehicle equipment, except for the optional SOT feature and minor engine modifications, is either existing and flight proven or is in development with a first-flight date scheduled for no later than 1976.

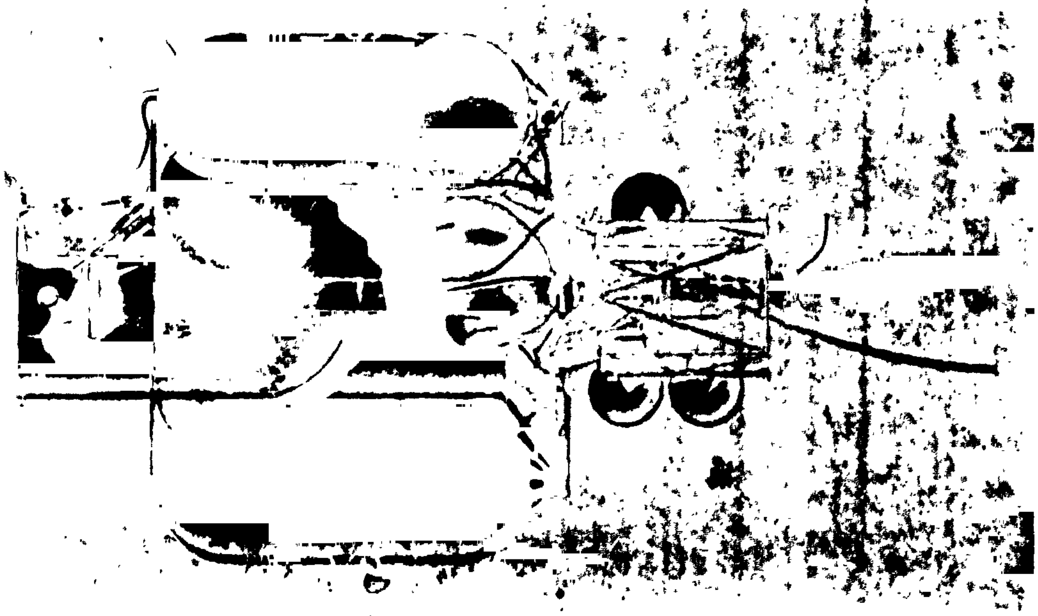

Fig. 5-1 Shuttle/Agena Upper Stage

The flight-proven Bell 8096 rocket engine will be modified, as illustrated in Fig. 5-2. These minor modifications are needed to permit engine restart beyond the existing three-start capability, to permit hot-pump restart with no time constraints, to increase I_{sp}, and to operate the gas generator at the optimum mixture for the HDA/MMH propellant combination.

Two avionics concepts have been established for the Shuttle/Agena Upper Stage concept. A comparison between the two is presented in Fig. 5-3. The Nominal concept is basically a single-string guidance and data management system with backup stabilization electronics for emergency stabilization of the Agena during the on-orbit retrieval operation. The Augmented concept is a dual-string guidance and data management system. The backup retrieval stabilization electronics is not needed in the Augmented concept because one of the dual IMUs furnishes this function

As can be seen from Fig. 5-3, the Augmented Agena Upper Stage concept is 85 pounds (38.6 kg) heavier and has a higher mission accomplishment reliability figure. The synchronous equatorial injection accuracy for each concept meets the study requirements, with the horizon sensor on the Augmented concept providing increased injection accuracy.

A more detailed weight statement for the Nominal and Augmented concepts are presented in Fig. 5-4 and 5-5.

5.1 SHUTTLE INTERFACE

The primary Shuttle interface item is the cargo bay support structure (CBSS). Since both the Nominal and Augmented Shuttle/Agena Upper Stage concepts fly either with the SOT option or as a core vehicle alone, the CBSS must accommodate both configurations. Figure 5-6 presents a CBSS concept for use with the SOT option. It consists of a welded, tubular aluminum truss frame in two parts: the forward section transfers only lateral loads to the cargo bay attach points, while the aft section transfers lateral and longitudinal loads. The Agena is secured in the CBSS by two pinned attachments at the forward end of the Agena and by a hinged clamp-type latch that mates with a circumferential V-ring located on the outer periphery of the aft SOT support structure.

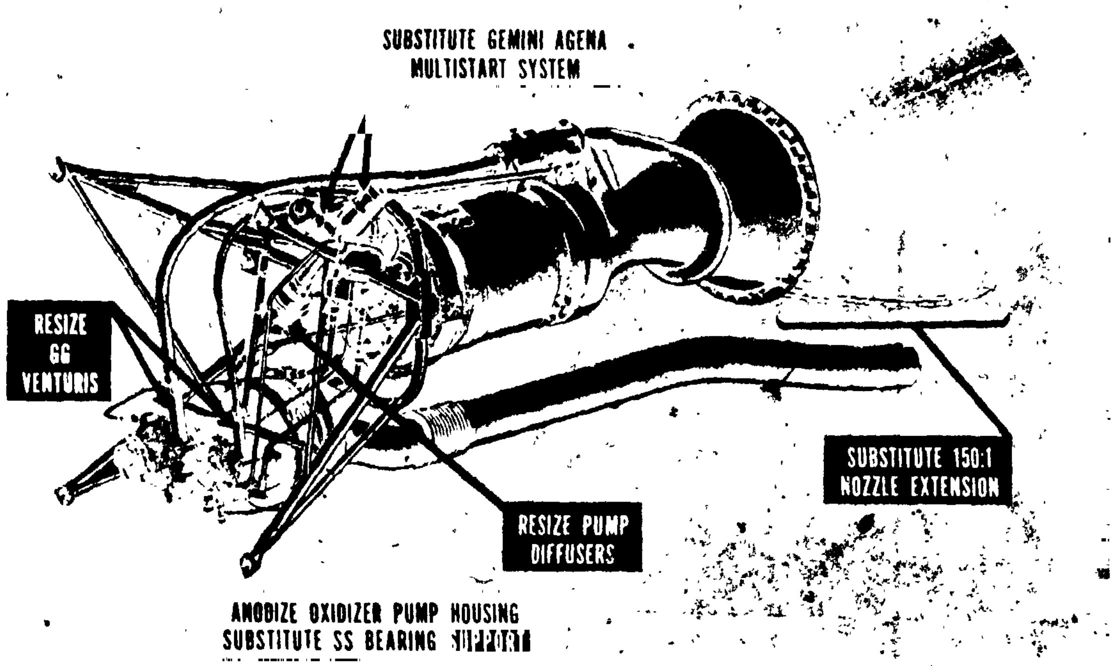

Fig. 5-2 BAC 8096 Engine Modifications

NOMINAL	AUGMENTED
DUAL HIGH MODE THRUSTERS	DUAL HIGH + SINGLE LOW MODE THRUSTERS
QUAD OMNI ANTENNAS + AMPLIFIER	DUAL PARABOLIC + QUAD OMNI ANTENNAS
PRIMARY BATTERY TYPE 30 + TYPE IVB (BACKUP 1 TYPE IVB)	PRIMARY BATTERY TYPE 19C2 + 2 TYPE IVB (BACKUP 1 TYPE IVB)
BALL BROS. STAR TRACKERS	BENDIX STAR TRACKER
SINGLE HONEYWELL IMU	DUAL HONEYWELL IMU
	QUANTIC HORIZON SENSOR
SINGLE STRING DF224 COMPUTER	DUAL STRING DF 224 COMPUTER
BACKUP RETRIEVAL ACS ELECTRONICS TAPE RECORDER	
WEIGHT 2,912 LB	WEIGHT 3,051
RELIABILITY .974	RELIABILITY .980
ACCURACY (3 SIGMA)	ACCURACY (3 SIGMA)
TANG. 116 NM (216 km)	TANG. 116 NM (216 km)
NORM. 6 NM (11 km)	NORM. 6 NM (11 km)
RAD. 60 NM (111 km)	RAD. 60 NM (111 km)

Fig. 5-3 Nominal/Augmentation Comparison

Subsystem	Core Only lb (kg)	Core With SOT lb (kg)
Structure	610	1,295
Propulsion	568	768
Avionics		
Electrical	234	239
Guidance/Navigation	127	127
Data Management	149	166
Communications	85	85
Thermal	27	57
Contingency (2%/10%)	83	175
Dry Weight	1,883(854)	2,912(1,321)
Nonusable Residuals	74*	203*
Propellant Reserves (1% FPR)	52	83
Burnout Weight	2,009 (911)	3,198 (1,451)
Usable Propellants	14,765	55,516
Usable ACPS Propellant	40	54
Start Stop Losses	129	218
Ignition Weight	16,943 (7,685)	58,986 (26,756)
Support Equipment	1,636 (742)	1,536 (697)
Total Installed Weight W/O Payload	18,579 (8,427)	60,522 (27,453)

Fig. 5-4 Nominal System Weight Summary

(*Includes 50 lb fuel bias)

Subsystem	Core Only lb (kg)	Core With SOT lb (kg)
Structure	567	1,252
Propulsion	574	774
Avionics		
Electrical	217	276
Guidance/Navigation	222	222
Data Management	149	166
Communications	106	106
Thermal	27	57
Contingency (2%/10%)	107	198
Dry Weight	**1,969(893)**	**3,051(1384)**
Nonusable Residuals	74*	203*
Propellant Reserves (1% FPR)	52	83
Burnout Weight	**2,095(950)**	**3,337(1514)**
Usable Propellants	14,718	55,516
Usable ACPS Propellant	43	54
Start Stop Losses	176	218
Ignition Weight	**17,032(7,726)**	**59,125(26,819)**
Support Equipment	**1,636(742)**	**1,536(697)**
Total Installed Weight W/O Payload	**18,668(8,468)**	**60,661(27,516)**

Fig. 5-5 Augmented System Weight Summary

(*Includes 50 lb fuel bias)

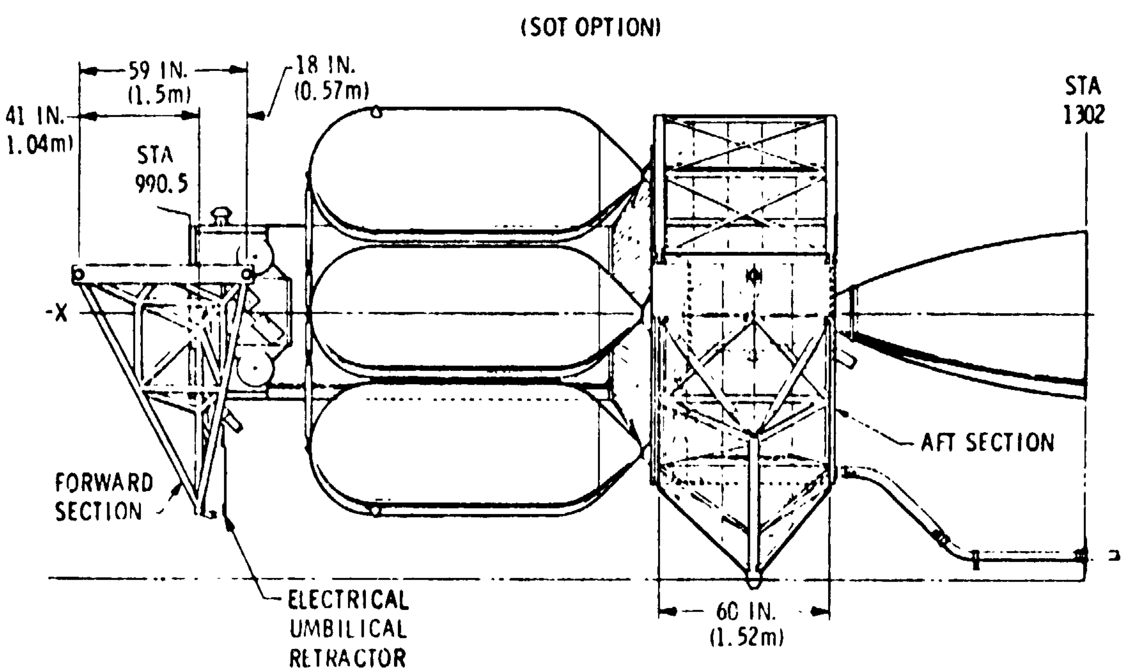

Fig. 5-6 Cargo Bay Support Structure, Side View

Agena deployment (Fig. 5-7) requires only retraction of the propellant emergency dump and electrical umbilical connectors, attachment of the Shuttle-attached manipulator, and opening of the segmented clamshell doors. The Agena and attached payload can then be lifted straight up out of its support structure and the cargo bay for deployment.

When the reusable mission Δ velocity is compatible with the 5-foot (1.52 m) diameter core vehicle (no SOT option), a CBSS conversion kit is used (Fig. 5-8). The deployment sequence is exactly the same as with the SOT option CBSS.

For payloads in the 10,000 to 20,000 pound (4500 to 9100 kg) class, the CBSS requires minor strengthening. The corresponding CBSS weight penalty, even for a 20,000 pound payload, is only 67 pounds (30.4 kg).

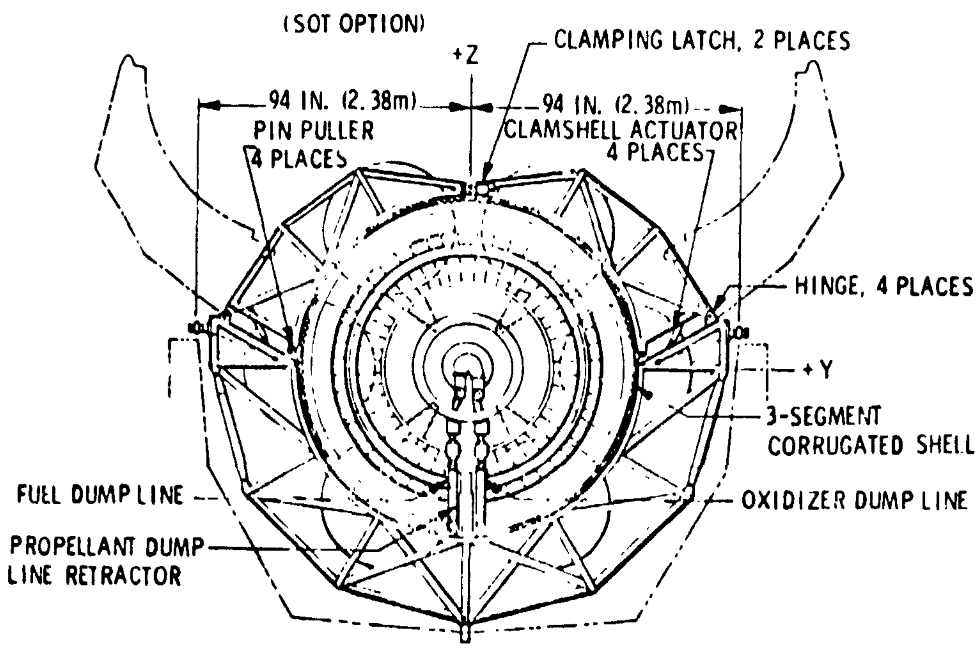

Fig. 5-7 Cargo Bay Support Structure, Forward View

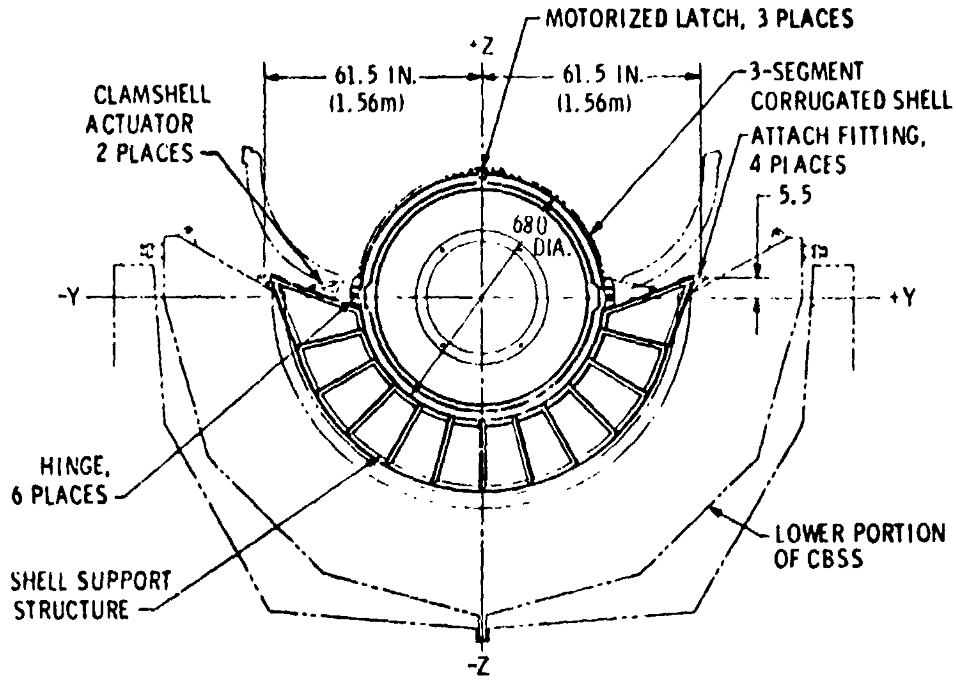

Fig. 5-8 CBSS Conversion Kit

The only other major Shuttle interface equipment item is the Agena service panel. This panel is the avionics, control, and caution/warning display interface with the Agena. This panel could be located in the Mission Specialist console. It performs Agena health checks, conducts the Agena predeployment check, controls Agena-related deployment and retrieval functions, controls emergency dump, and contains caution and warning displays. These functions are performed without support from the Shuttle avionics or data management systems except for electrical power and a tie-in with the Shuttle communication system for downlink transmittal of Agena data.

5.2 PERFORMANCE

The 5 foot (1.52 m) diameter core Agena can accomplish all Western Test Range (WTR) assigned missions in the reusable mode without the SOT propellant option and without the use of a kick motor. Both the Nominal and Augmented configurations have this capability (Fig. 5-9 and 5-10). The Agena Upper Stage with the SOT option can accomplish all Eastern Test Range (ETR) and WTR launches for the 1980–1983 mission model in the reusable mode (except for two flights in one interplanetary mission) without the use of a kick motor.

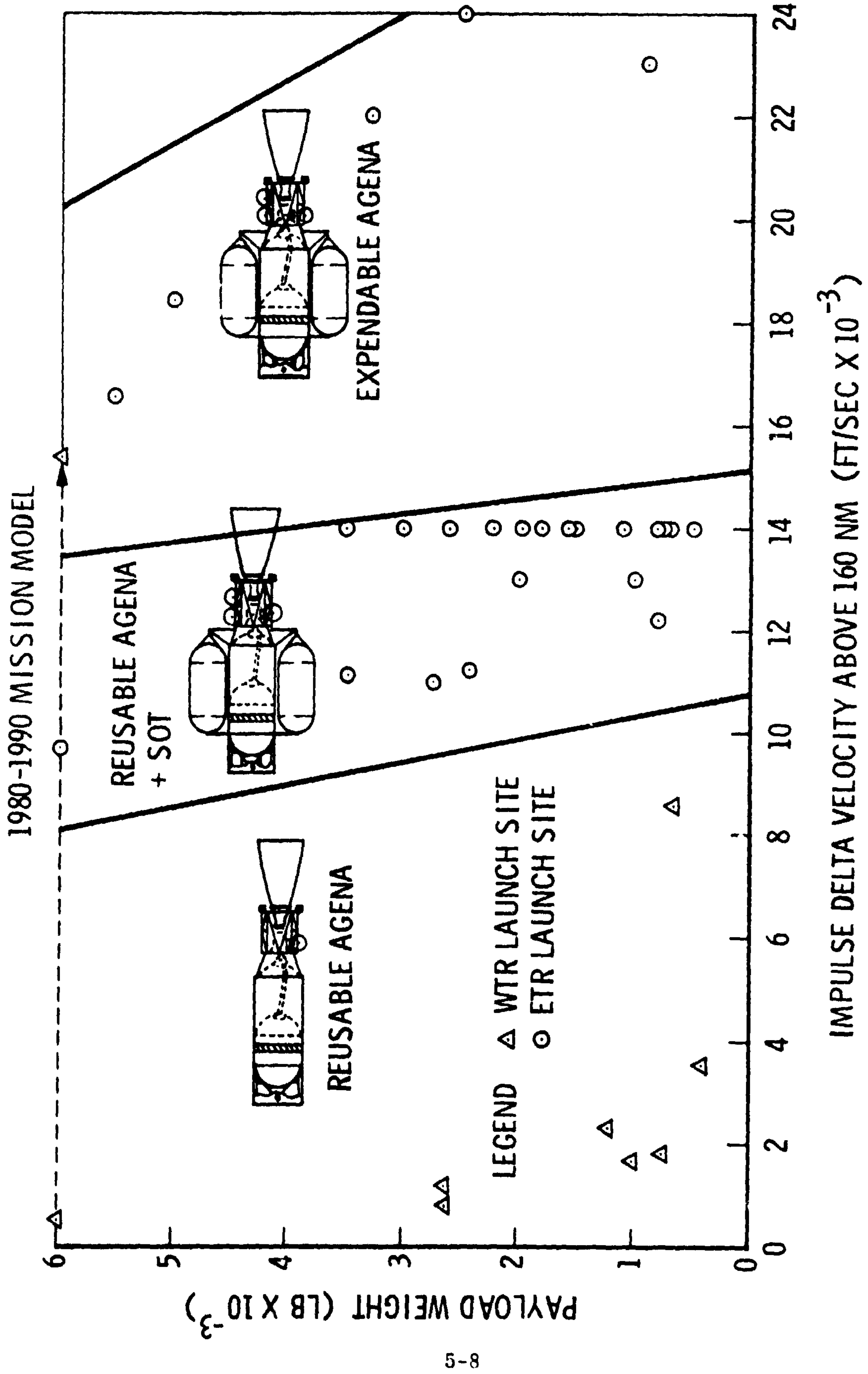

Fig. 5-9 Nominal Shuttle/Agena Upper Stage Performance

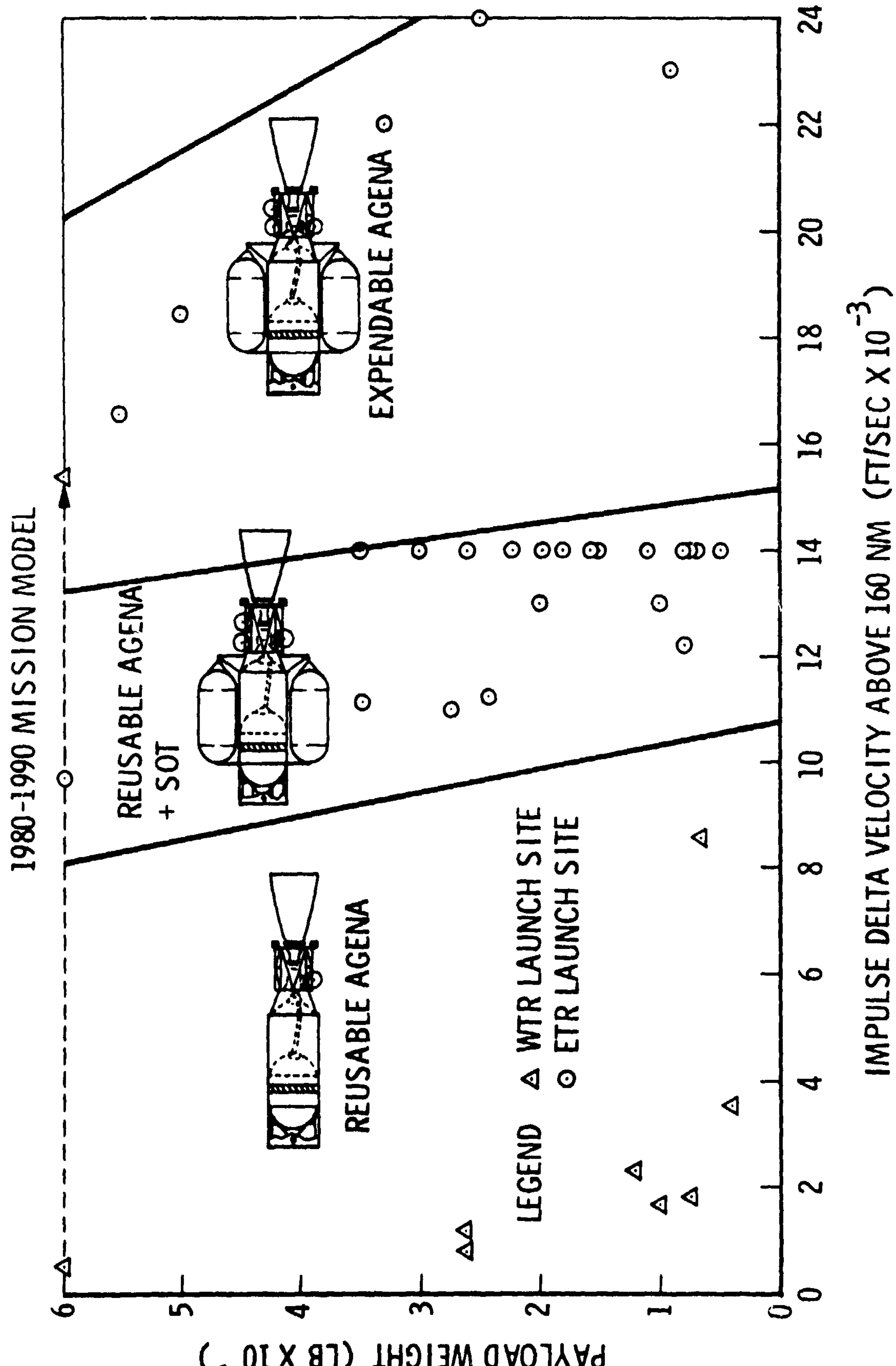

Fig. 5-10 Augmented Shuttle/Agena Upper Stage Performance

The Nominal Agena Upper Stage (single-string avionics) performance is presented in Fig. 5-11 as a function of the Agena building block approach.

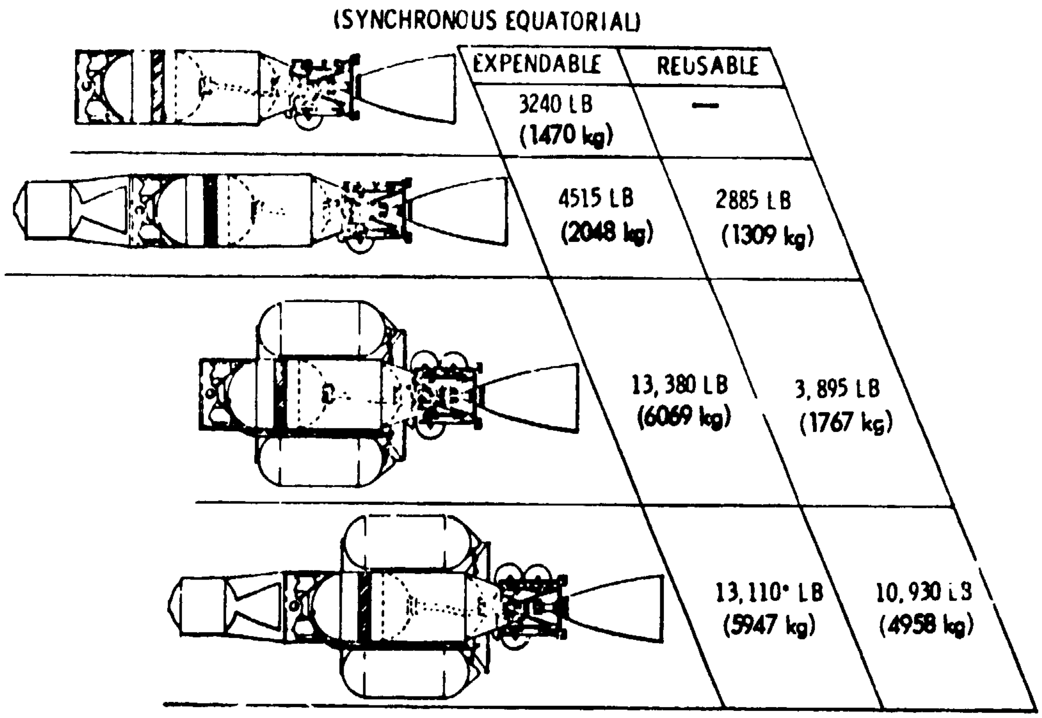

Fig. 5-11 Agena Building Block Performance

A summary table of both the Nominal and Augmented Agena performance is presented in Fig. 5-12.

Configuration	Nominal lb (Kg)		Augmented lb (Kg)	
	2%/10% Contingency	10% Contingency	2%/10% Contingency	10% Contingency
5 Ft Dia Core Plus Optimum Kick Motor	2885 (1309)	2710 (1225)	2870 (1302)	2700 (1225)
Core Plus Strap On-Tank Propellant Option	3895 (1767)	3362 (1525)	3560 (1615)	2980 (1352)
Core Plus Strap-On Tank Propellant Option Plus Optimum Kick Motor	10930 (4958)	10838 (4916)	10763 (4882)	10610 (4813)

Fig. 5-12 Shuttle/Agena Upper Stage Performance-Reusable Mode

5.3 SAFETY

There are three prime considerations of concern for Agena Upper Stage safety, as follows:

- Positive propellant tank pressure control (redundant automatic, astronaut override)
- Positive propellant dump (on pad, during ascent, and on orbit)
- Fail operational/fail safe during orbital retrieval (redundant communications, redundant attitude control system, and astronaut override by RF command)

One of the safety concerns is the integral bulkhead of the Agena main propellant tank. A number of safeguards and backups have been provided for both nominal as well as emergency conditions. Individual, dedicated pressure regulators are provided to maintain a positive pressure across the bulkhead under nominal operating and emergency dump conditions. The computer located in the Agena service panel automatically monitors oxidizer and fuel tank pressures for both the main and SOT tanks and controls pressurization line shutoff valves and tank vent valves. The tank vent valves are quad redundant. The astronaut at the mission specialist console can manually override any or all of the computer controlled valves as desired. As a final backup, the emergency dump system can be used to control tank pressures.

The Agena emergency propellant dump system will accomplish a full propellant dump on pad, during ascent, and on orbit. During ascent, Agena dump is accomplished during the Shuttle main engine burn portion of the return-to-launch site trajectory. On-orbit the jet impulse of the existing propellant will impart sufficient impulse to the Shuttle to settle the Agena propellants for dump.

Fail operational/fail safe capability is provided for critical Agena functions during the retrieval operation. A fully-redundant communications system is provided for use as a backup if astronaut override of Agena functions is needed. A backup, redundant attitude control system is also provided and includes a dedicated battery power supply, hydrazine tank, and guidance electronics. Both the Nominal and Augmented Agena Upper Stage concepts provide redundant hot-gas attitude control thrusters.

5.4 OPERATIONS

The Agena mission profile for the reusable mode, Fig. 5-11, includes return of the Agena to the Shuttle orbit, its retrieval, followed by return to earth for maintenance and refurbishment for reuse. Agena flight-to-flight operations, Fig. 5-12, are paced by Shuttle servicing spans and require a total of 340 hours. Payload mating can be accomplished with the Agena either in the horizontal or vertical position. Loading propellants and gases can take place either at an on-pad or remote facility. Although it seems more desirable to load the Agena with propellants and gases prior to Shuttle mate, the Agena could be loaded within the cargo bay but with added Shuttle interface complications.

5.5 SPECIAL MISSION CONSIDERATIONS

A servicing mission involves the replacement of expended components on four widely separated spacecraft at synchronous equatorial positions, as shown in Fig. 5-13. This figure presents a typical mission profile for a servicing mission accomplished by the Agena Upper Stage core vehicle (no SOT option) with 351 pounds (159 kg) of rendezvous equipment and a 300 pound (136 kg) servicing module containing 1800 pounds (815 kg) of replacement components. The Agena rendezvous with each spacecraft in turn, and replaces 450 pounds (204 kg) of components at each spacecraft. The mission requires twelve days to accomplish, including phasing time between spacecraft.

The same mission can be flown in the reusable mode using the SOT propellant option. Here the Agena can replace 903 pounds (410 kg) of components at each spacecraft as shown in the tabulation below. This mission requires an extra day (total of 13) to permit time for the Agena to return to the Shuttle orbit for retrieval.

SERVICING MISSION

(SYN EQ – 300 lb (136 kg) requirement)

Expendable – 12 Days			Reusable – 13 Days		
Baseline			SOT Option		
	lb	kg		lb	kg
Satellite No. 1	450	204	Satellite No. 1	903	410
Satellite No. 2	450	204	Satellite No. 2	903	410
Satellite No. 3	450	204	Satellite No. 3	903	410
Satellite No. 4	450	204	Satellite No. 3	903	410

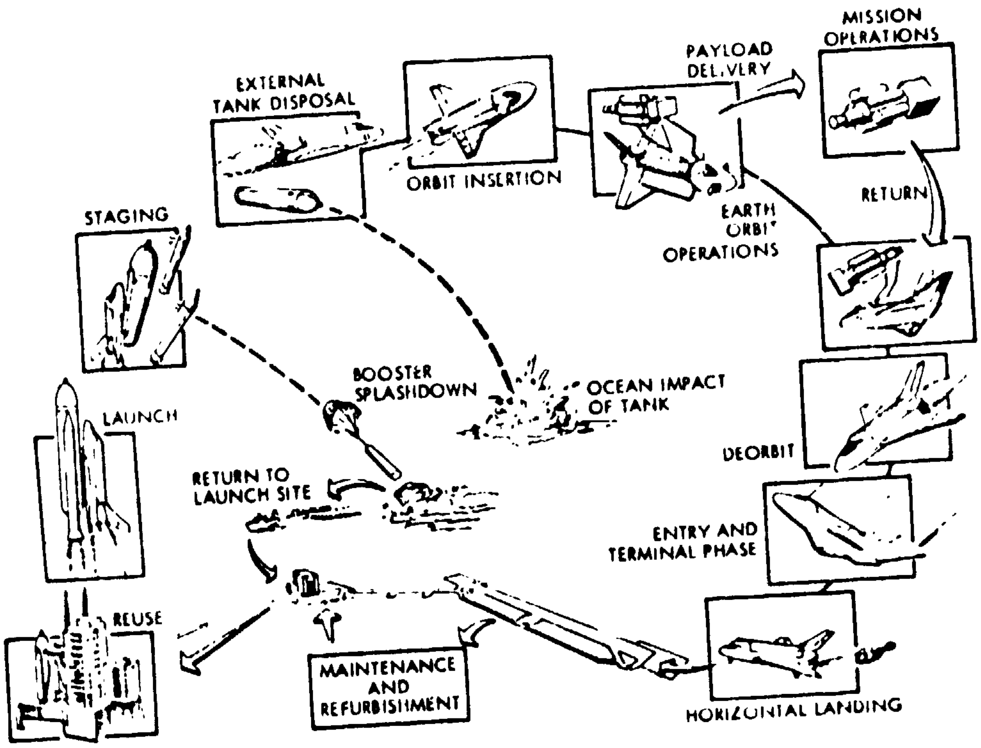

Fig. 5-13 Shuttle/Agena Upper Stage Mission Profile

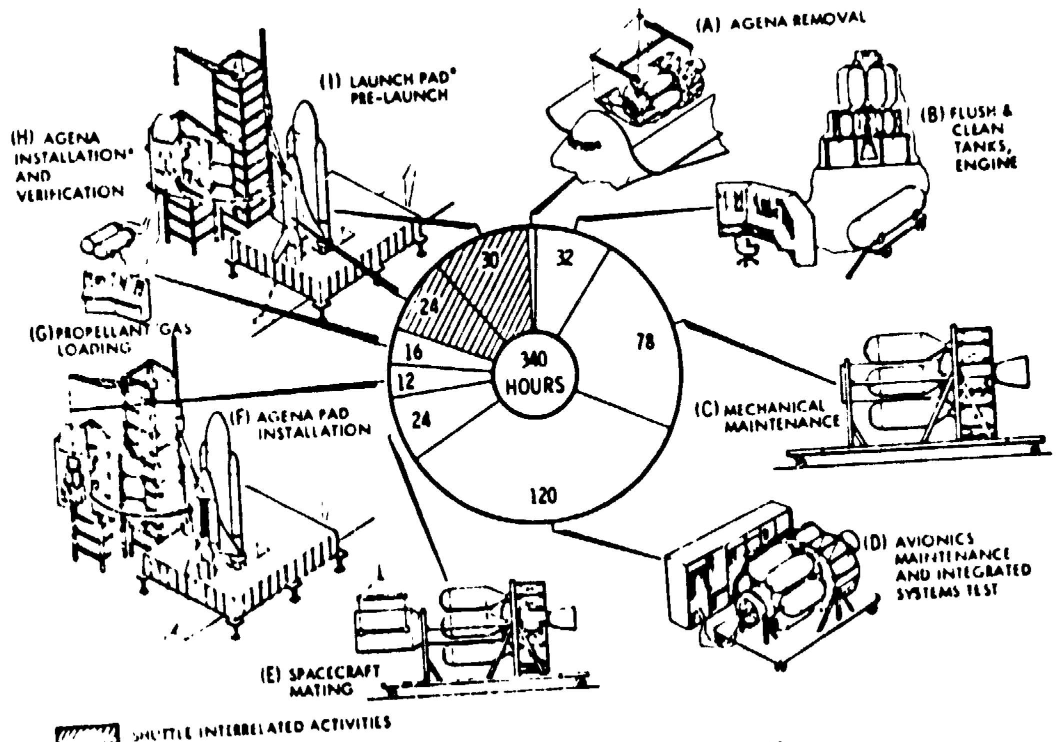

Fig. 5-14 Flight-to-Flight Operations

The Agena Upper Stage is approximately 26 feet (7.93 m') in length. The Agena can handle payloads as long as 40 feet (12.2 m) by the approach illustrated in Fig. 5-14. The nozzle extension length can be reduced by approximately 6 feet (1.83 m) by utilizing a convoluted nozzle that is extended to a 80:1 expansion ratio after Agena deployment in orbit.

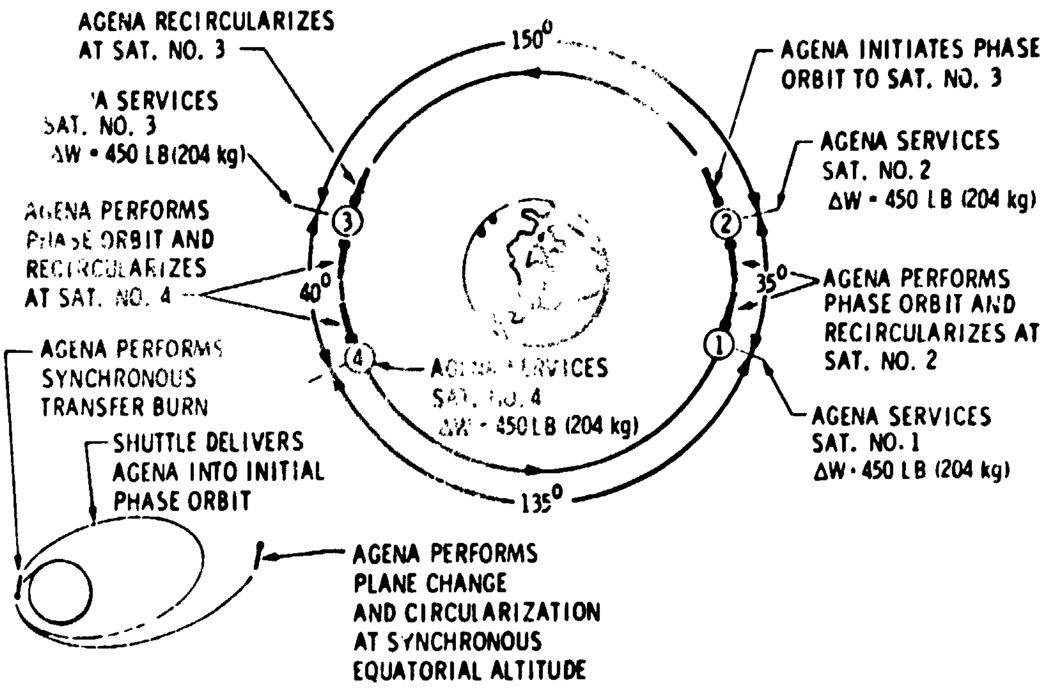

Fig. 5-15 Servicing Mission Profile

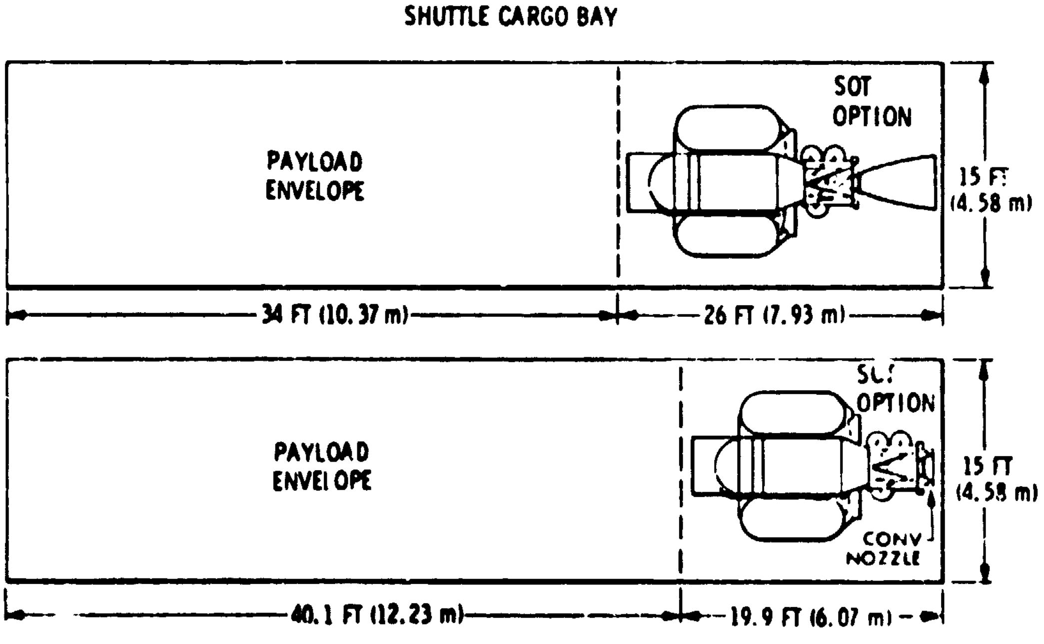

Fig. 5-16 Payload Envelopes

5.6 COST

The Shuttle/Agena Upper Stage system features low cost over its entire life cycle – from DDT&E through the Production phase and through four calendar years of Operations. The life cycle costs may be summarized as follows:

	DDT&E	Pro-duction	Opera-tions	Total
Nominal Concept	$49.7M	$53.3M	$81.3M	$184.3
Augmented Concept	$52.5M	$57.8M	$84.1M	$194.4

These costs, which were calculated in dollars of 1973 value, include two-launch-base capability and the equivalent price of development and production for the GFE main engine; the costs exclude prime contractor fee. The methodology to derive these costs used bottom-up estimating techniques in which inputs of labor hours and material/ subcontract dollars were estimated at the lowest levels of the work breakdown structure (levels 6 and 7 wherever possible).

The DDT&E costs are low because the Shuttle/Agena Upper Stage takes advantage of inheritance in stage design (from the Agena vehicle), in subsystems hardware (from ongoing LMSC and collateral programs), and in GSE and facilities (from Agena programs). A rigorous but efficient ground test program, in lieu of flight testing, further contributes to the low DDT&E cost. The breakdown of DDT&E costs is given below. For convenience in comparing Agena costs against those stages for which just one launch base was evaluated, the costs for ETR-only DDT&E activity associated with the Shuttle/Agena are summarized on the bottom line.

	Nominal Concept	Augmented Concept
Project Management	$ 1.146M	$ 1.146M
Systems Engineering/Integration	4.022	4.234
Vehicle Main Stage	(24.629)	(26.895)
Structures	1.643	2.042
Thermal Control	0.302	0.302
Avionics	9.469	10.718
Propulsion	7.940	8.558
Orbiter Interface	2.490	2.490
Auxiliary Tanks	2.683	2.683
Final Assembly (Tooling)	0.102	0.102

	Nominal Concept	Augmented Concept
Logistics (Training)	$ 1.078	$ 1.078
Facilities	0.587	0.587
Gse	5.704	5.704
Vehicle Test	(6.115)	(6.355)
Test Hardware	3.154	3.236
Test Operations	2.961	3.119
Flight Operations (Software)	6.452	6.452
Total (ETR/WTR)	$49.733M	$52.451M
ETR Only	$46.533M	$49.251M

The Shuttle/Agena Upper Stage has low Production costs because it is simple in design (single engine, earth-storable propellants) and because the core Agena stage has attained considerable maturity in production. A breakout of the Production costs is below. These costs cover the acquisition of a reusable vehicle fleet, Orbiter interface equipment, and initial spares.

	Nominal Concept	Augmented Concept
Project Management	$ 1.331M	$ 1.331M
Systems Engineering/Integration	7.794	7.794
Vehicle Main Stage	(35.208)	(38.826)
Structures	1.567	1.567
Thermal Control	0.345	0.345
Avionics	15.162	18.193
Propulsion	7.554	8.141
Orbiter Interface	2.782	2.782
Auxiliary Tanks	4.045	4.045
Final Assembly/Checkout	3.753	3.753
Logistics	0.840	0.840
Vehicle Spares	7.533	8.460
GSE Spares	0.573	0.573
Total (ETR/WTR)	$53.279M	$57.824M
ETR Only	$36.379M	$39.824M

Operations costs for the reusable Shuttle/Agena Upper Stage are low because this vehicle exhibits high mission efficiency. That is, it can fulfill an operational mission model with full vehicle reuse and without recourse to large numbers of kick stages. The breakdown of Operations phase costs is presented below. These costs cover prelaunch handling and checkout, propellants, Agena countdown, Agena control in flight, stage recovery and safing, and schduled/nonscheduled, maintenance (including spares for 93 flights 1980-1983. The costs also include main plant sustaining engineering and program management.

	Nominal Concept	Augmented Concept
Project Management	$1.465M	$1.465M
Systems Engineering/Integration	5.033	5.033
Vehicle Main Stage (Sustaining)	6.665	6.665
Logistics (Transfer/Handling/ Inventory Control)	2.830	2.830
GSE (Maintenance)	0.267	0.267
WTR Launch Operations	1.385	1.385
ETR Launch Operations	10.584	10.584
DoD Flight Operations	5.871	5.871
NASA Flight Operations	8.162	8.162
ETR Refurbishment/Integration	11.683	11.683
WTR Refurbishment/Integration	2.446	2.446
Spares, Main Stage	22.604	25.381
Spares, GSE	2.294	2.294
Total (ETR/WTR)	$81.289M	$84.066M
ETR Only	$67.989	$70.266M

Funding requirements for the reusable Shuttle/Agena Upper Stage require minimum investment in the critical years of Space Shuttle system development and remain nominal in following years. The peak in total program funding for either of the Shuttle/Agena concepts is under $40 million in fiscal years 1980 and 1981. Figure 5-17 displays the Shuttle/Agena funding requirements by fiscal year.

(All Costs in $ Millions)

Fiscal Year	77	78	79	80	81	82	83	84	Total
DDT&E									
Nominal	12.7	18.4	11.6	4.3	2.1	0.5	0.1	6.7	49.7
Augmented	13.8	19.7	11.9	4.4	2.1	0.5	0.1		52.5
Production									
Nominal			9.9	28.7	12.8	1.9			53.3
Augmented			10.7	31.2	13.9	2.0			57.8
Operations									
Nominal				2.2	20.1	25.7	26.6	6.7	81.3
Augmented				2.2	21.0	26.7	27.5	6.7	84.1
Total									
Nominal	12.7	18.4	21.5	35.2	35.0	28.1	26.7	6.7	184.3
Augmented	13.8	19.7	22.6	37.8	37.0	29.2	27.6	6.7	194.4

Fig. 5-17 Funding Requirements

The life-cycle costs of the growth Agena (for both ETR and WTR capability) may be summarized as follows:

DDT&E (10-use life goal, 8096B engine)	\$104.7 M
Production	51.9
Operations (93 flights, ETR/WTR)	76.3
Total	\$232.9 M

Cost data for the drop tank Agena configuration were not developed.

5.7 ALTERNATIVE CONCEPTS

The growth and drop tank Agena configurations shown in Fig. 5-18 both use the Bell Aircraft Corporation Model 8096B engine with N_2O_4/MMH propellants. With a 100:1 expansion ratio nozzle this engine will deliver a specific impulse of 326 sec (3198 N sec/kg). Concepts characteristics and comparisons are summarized in Fig. 5-19.

Some significant comparisons of these concepts are:

- The drop tank Agena features blowdown pressurization and cascade propellant feed in the SOTs to provide drop capability, while the growth stage incorporates regulated pressurization in the two main tanks. The pressure in the DTA core tanks is also regulated. (A parallel feed approach is also feasible for the strap on tanks of the drop tank Agena.
- The drop tank Agena uses existing core structure assemblies with new SOTs and core tanks made of 2021 aluminum. The growth stage Agena uses existing aft section structure, new separate tanks made of 2021 aluminum, and a modified SCS forward rack.
- From an avionics standpoint, both stages incorporate a BUSS, redundant communication assemblies, automatic RCS fault isolation and fail-safe control, a tape recorder, and similar types of batterires; therefore there are no significant differences except in equipment location in the forward section.
- The growth stage Agena is supported in the cargo bay by a single truss-shell structure with doors. The drop tank Agena uses strap-on tanks 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.

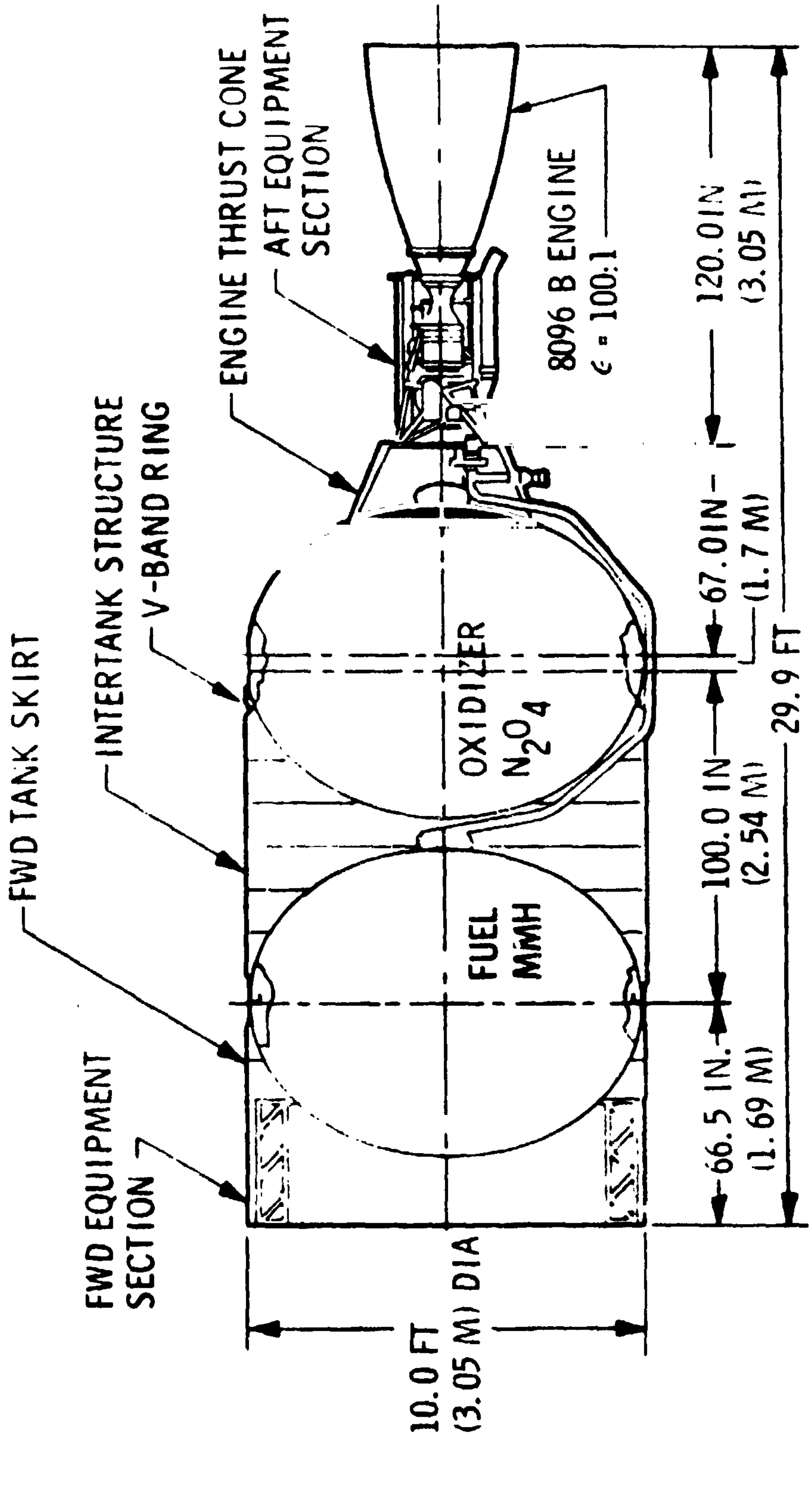

Fig. 5-18 Growth Agena Concept

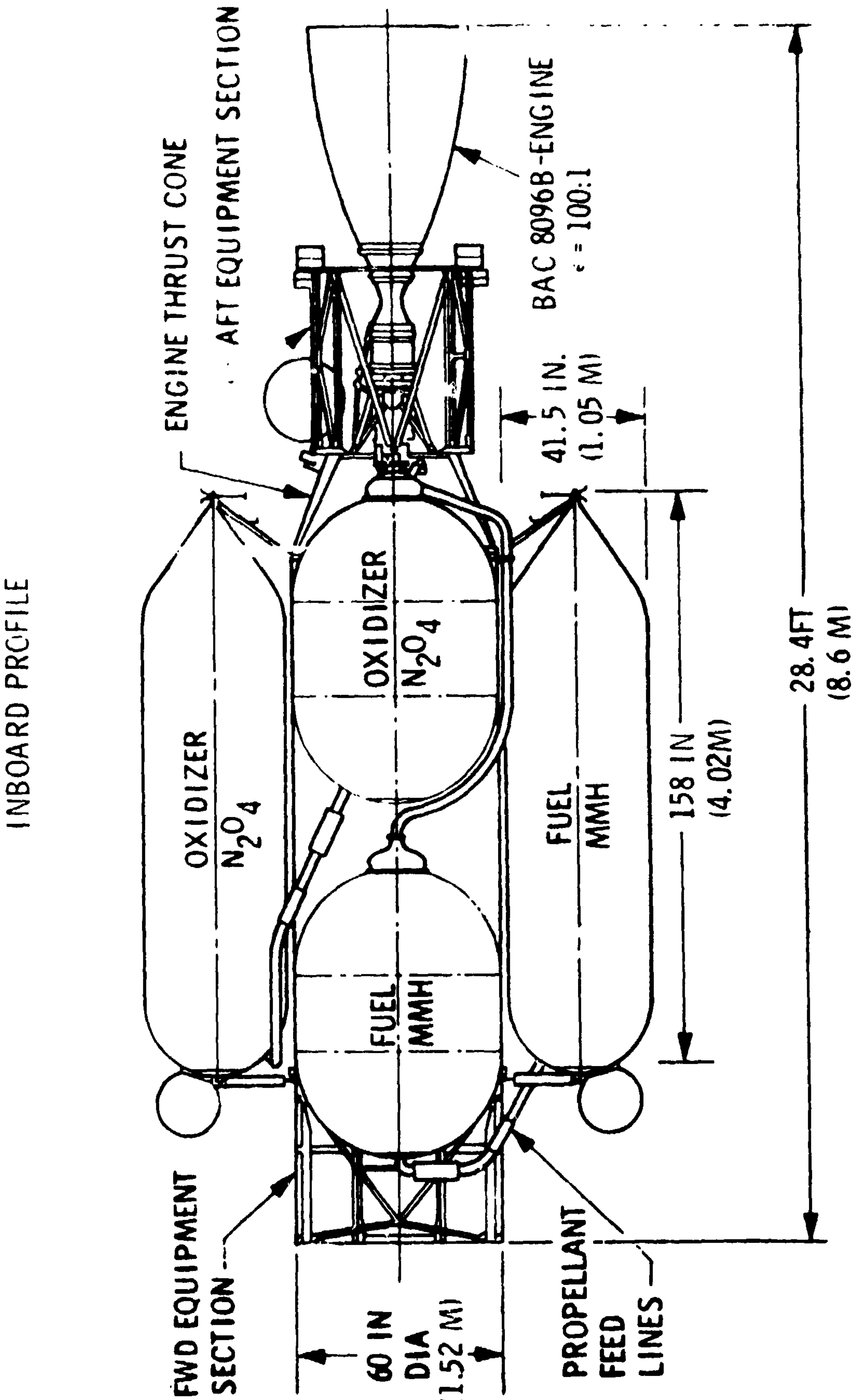

Fig. 5-18 Drop Tank Agena Concept

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)	Same as Growth
Thrust	8096B Engine = 100:1 16,000 lbf (71,200 N)	16,000 lbf (71,200 N)
ACPS (N_2H_4) I_{sp} / Thrust	125 sec (1227 N sec/kg) 175 sec (1718 N sec/kg) redundant in hi mode 0.5 lbf (2.2 N) 12 lbf (53.4 N)	Same as Growth Agena
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 SOT
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 and rack
Communications	Redundant	
Guidance & Nav.	Existing IMU, modified CEA & HSA; Star Tracker included	Same as Growth Agena
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 interfaces & retractor	Same as Growth, but reconfigured
Communications	Safety hardline; wave train, RF	Same as Growth
Display/CMDS	RDM and display panel	Same as Growth

Fig. 5-19 Alternative Concepts Characteristics/Comparison Summary

Weights for the growth and drop tank Agena concepts are summarized in Fig. 5-20.

Item	Growth Agena	Drop Tank Agena	
		Core	SOT & Core
Structure	1,321	717	1,310
Propulsion	673	542	882
Avionics	788	788	807
Thermal Control	49	32	62
Contingency (10%)	283	208	306
Dry Weight, lb (kg)	3,114 (1,411)	2,287 (1,037)	3,367 (1,527

Fig. 5-20 Drop Tank and Growth Agena Concept Weights

Performance data for growth and drop tank Agena configurations are presented in Fig. 5-21, 5-22, and 5-23. The 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-foot (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 SOTs can be jettisoned, in pairs, thus extending the performance envelope as shown in Fig. 5-21. Existing kick motors such as the TE-364-19 can assist this configuration in delivering moderate sized payloads to interplanetary missions.

Configuration	Payload lb	Payload (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. 5-21 Synchronous-Equatorial Payload Capability For N_2O_4/MMH Configurations I_{sp} = 326 Sec

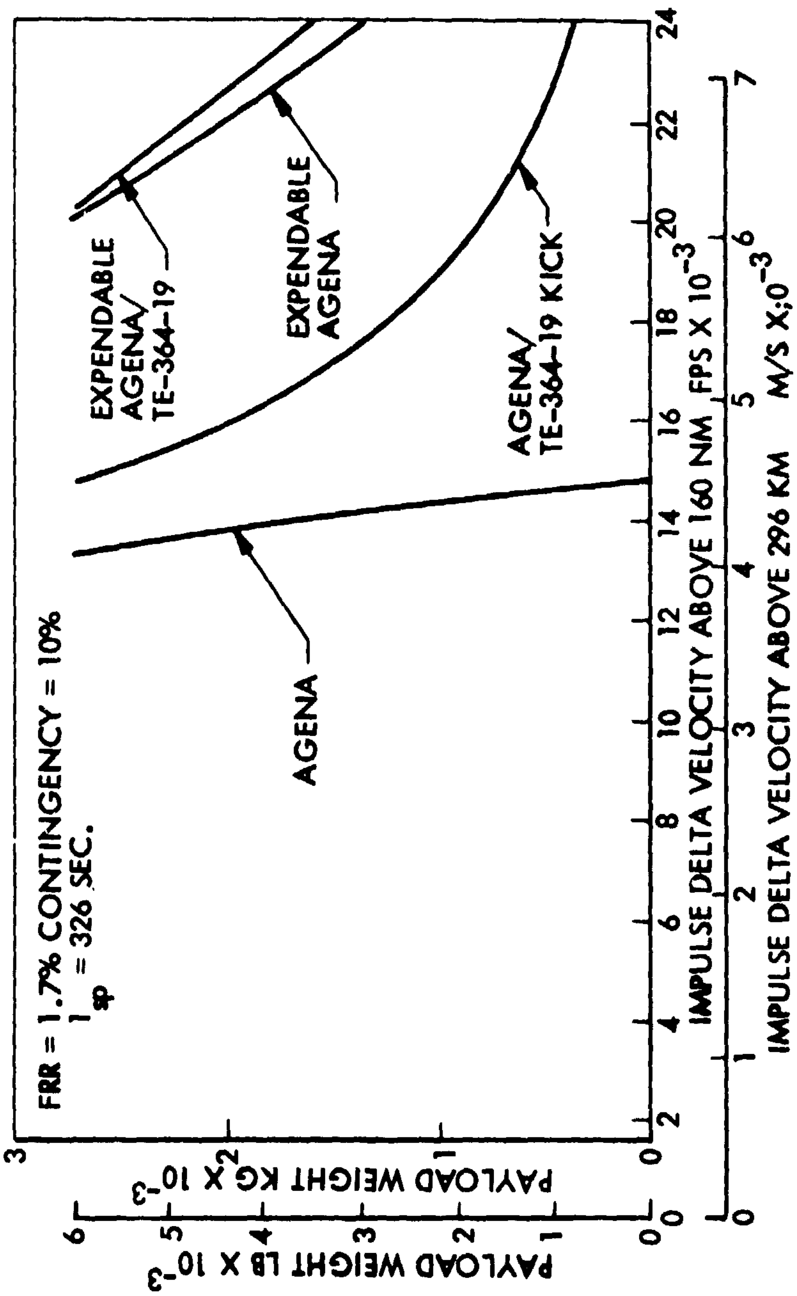

Fig. 5-22 Growth Agena Performance

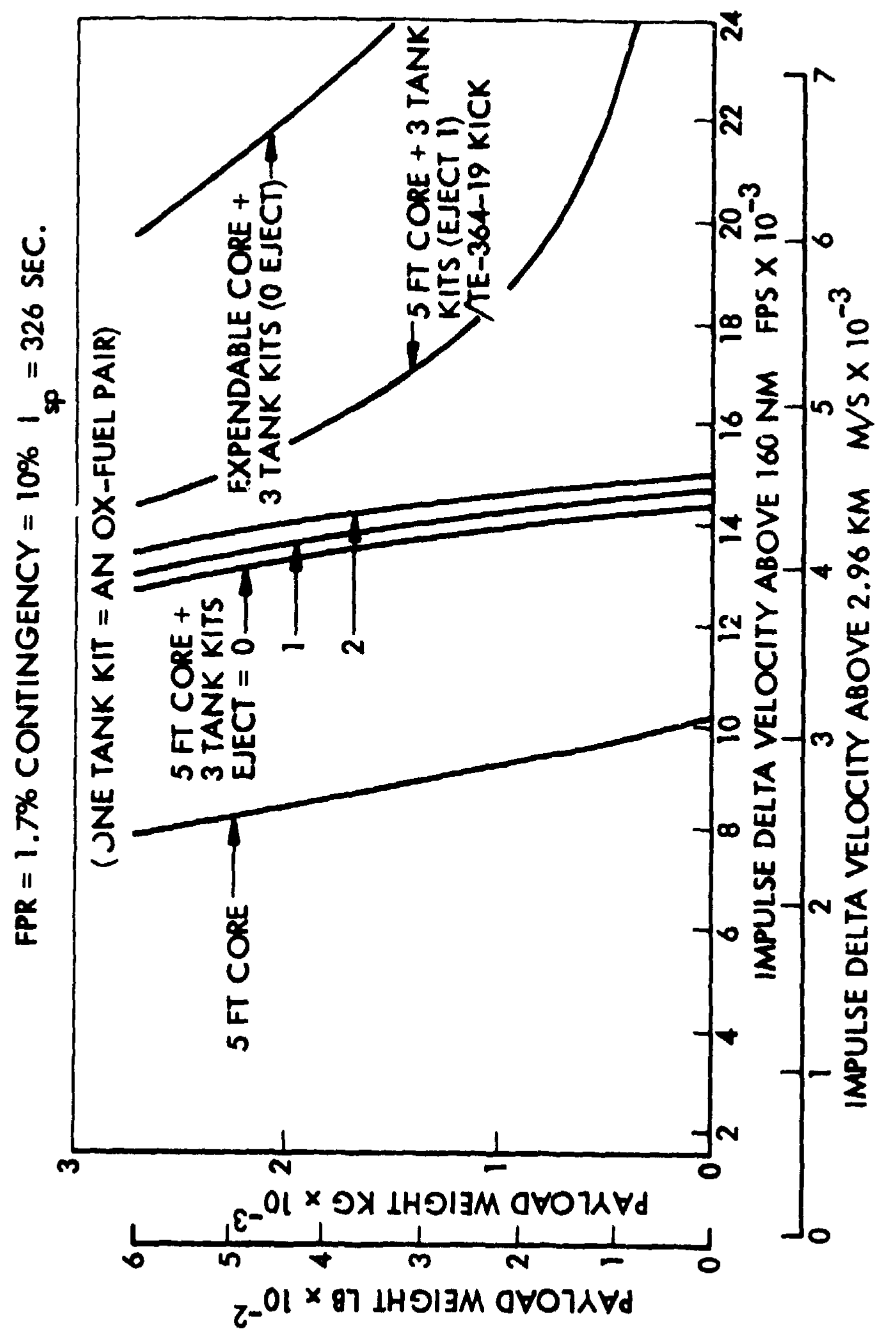

Fig. 5-23 Drop Tank Agena Performance

Section 6
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 $49.8 M 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 operational/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 system.

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.