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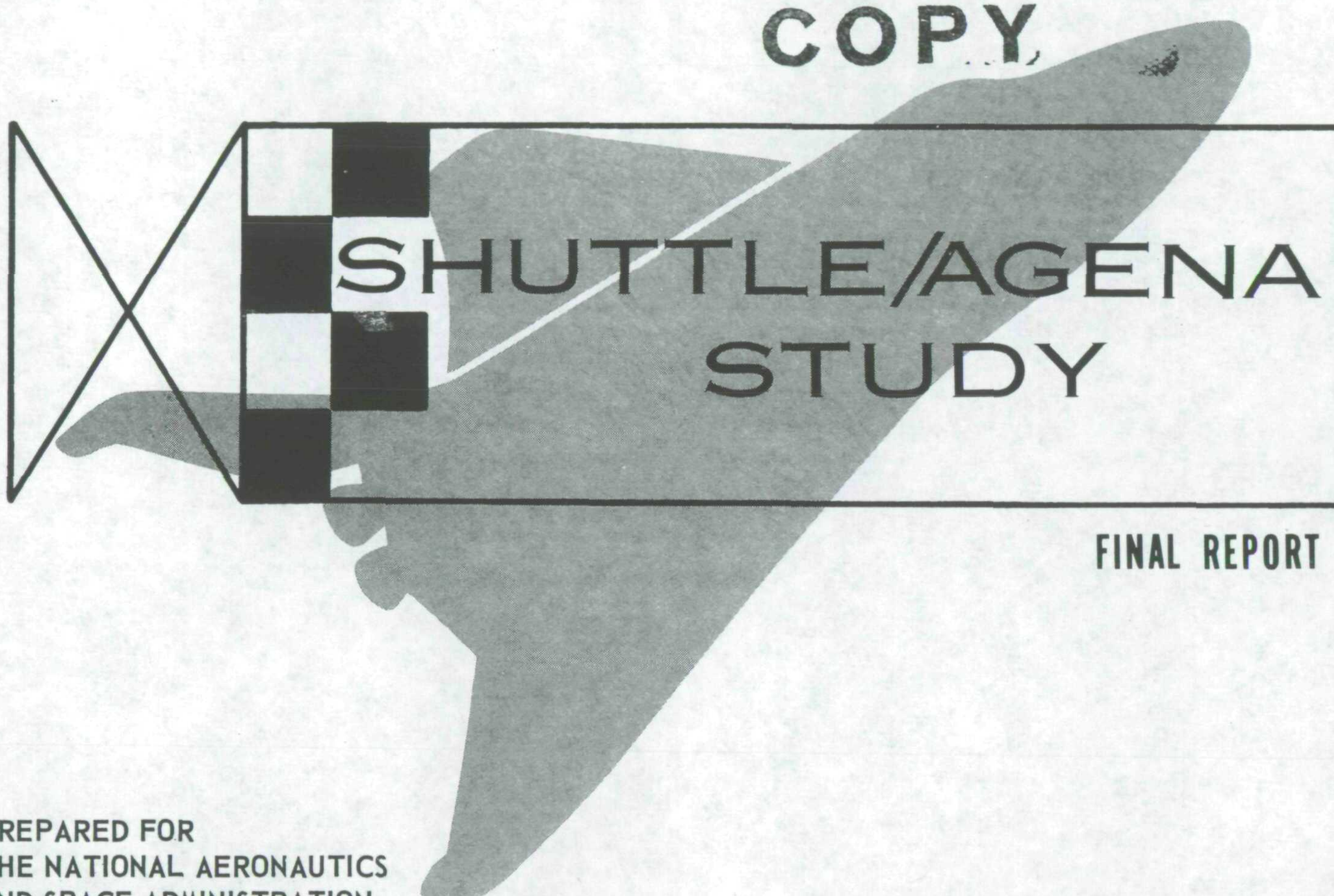

SHUTTLE/AGENA STUDY

FINAL REPORT

PREPARED FOR
THE NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER • HOUSTON, TEXAS

CONTRACT NAS9-11949

LMSC
SPACE SYSTEMS
DIVISION

VOLUME I

EXECUTIVE SUMMARY

LOCKHEED MISSILES & SPACE COMPANY, INC.
A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

25 February 1972

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MSC DRL Line Item 7
DRD MA-012T

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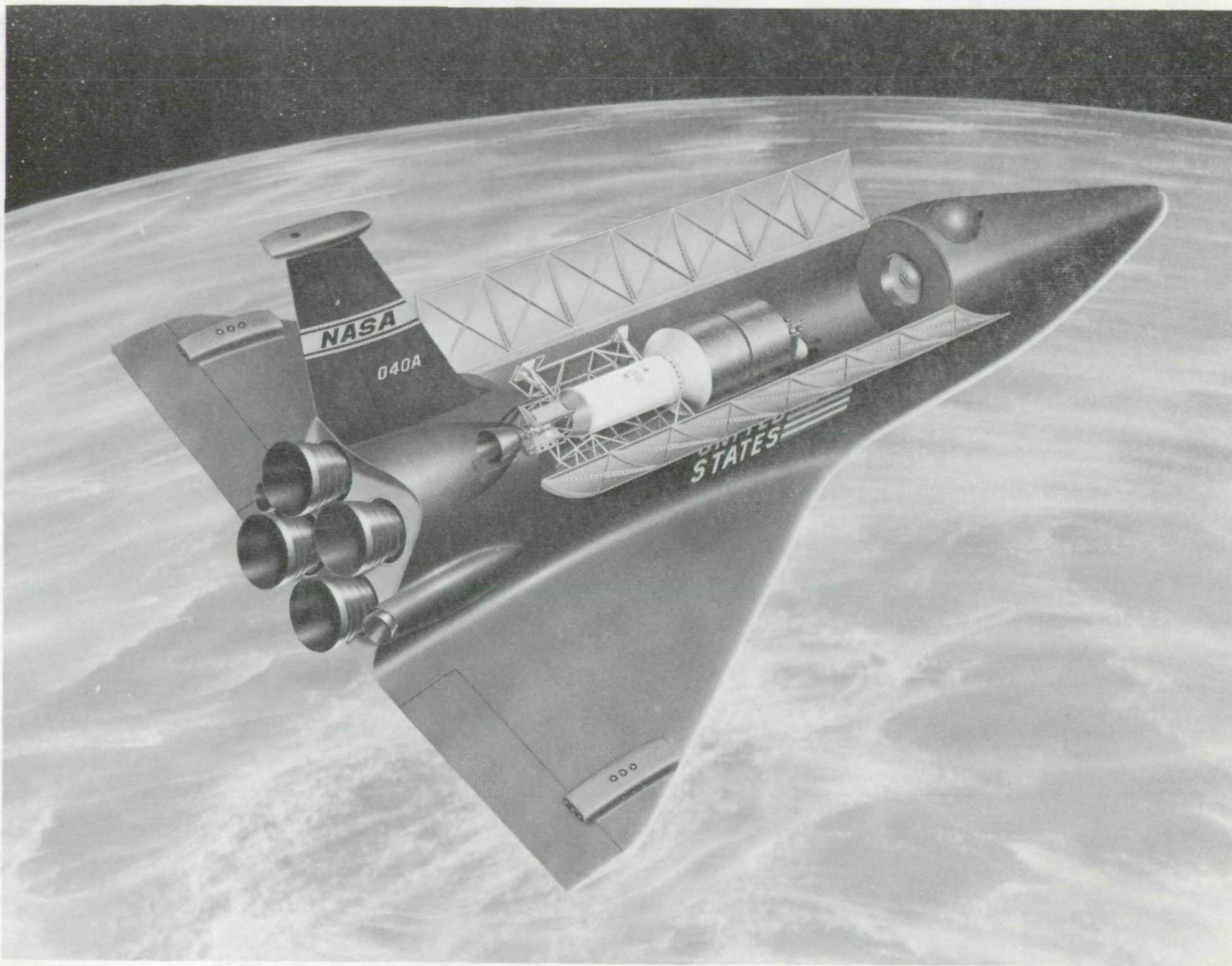
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FOREWORD

This final report has been prepared for the National Aeronautics and Space Administration's Manned Spacecraft Center, Houston, Texas, under Contract NAS9-11949. Volumes I and II are submitted as DRL line items 6 and 7, as specified in DRD MA-012T and MA-129T of the subject contract. Although not contractually required, supplemental data on the Ascent Agena and existing flight equipment are also submitted.

In compliance with customer guidelines regarding page limitations, the report is bound in separate books as follows:

• Volume I	Executive Summary
• Volume II, Part One	Program Requirements, Conclusions, Recommendations
• Volume II, Part Two	Agena Tug Configurations, Shuttle/Agena Interface, Performance, Safety, Cost
• Volume II, Part Three	Preliminary Test Plans
• Annex A	Ascent Agena Configuration
• Annex B	Catalog of Existing Flight Equipment
• Annex C	Space Shuttle Candidate Insulator/ Propellant Compatibility Test Program

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Section 1
STUDY BACKGROUND AND APPROACH

Lockheed's continuing interest in the potential application of the Agena vehicle to the NASA advanced space transportation system is evidenced by this study of the compatibility of the Agena space tug with the space shuttle. The present study was initiated in June 1971, under the direction of the NASA-Manned Spacecraft Center to (1) identify and define the significant space shuttle/Agena space tug interfaces and (2) establish the preliminary design for an Agena space tug including optional improved features.

Flight history of the Agena vehicles includes 320 launches as of 5 January 1972. Of these launches, 45 were in support of NASA programs. More than 80 percent of those were with the Agena in a spacecraft configuration, performing earth-orbit missions of from 2 weeks to more than 1 year. In the spacecraft configuration the Agena furnishes continuous support to the payload throughout the mission. Such support typically includes orbit insertion and maneuver guidance, attitude control, navigation and steering, electrical power, data management, discrete commands, and communications. The Agena success ratio has been outstanding, with all Agena flights successful since April 1967 – a total of 83 consecutive flights without an Agena failure.

The Gemini Agena Target Vehicle (Fig. 1-1) was the forerunner of the space tug. During five Gemini missions in 1966 the Agena performed orbit altitude and plane changes in an undocked mode and while docked with the Gemini spacecraft by ground command or by command from the astronauts. During one mission the Agena engine was started 11 times in an 11-day period. The Bell Aerospace Model 8247 engine used on the Gemini Agena vehicles was qualified for 15 starts. In addition to the main engine, the Agena vehicles incorporated a secondary propulsion system (SPS) that made small ΔV adjustments possible for rendezvous and docking maneuvers. The Agena space tug will be the direct descendant of the Gemini Agena Target Vehicle. Since the last Gemini Agena flight, product improvements, including the incorporation of a strapdown inertial guidance system, have resulted in higher reliability, greater accuracy, lower weight, and higher payload capability.

A groundrule for the study required that only the expendable mode be considered for the Agena space tug. Current Agena vehicle characteristics and equipment were selected to ensure a realistic definition of the space shuttle/Agena space tug interface. No allowance was made for technology advances that might be expected before the 1978-1981 period. Primary emphasis was on defining those Agena changes required for compatibility with the space shuttle. Mission-peculiar Agena changes required to accomplish three baseline missions were considered, so as to establish realistic performance capability and costing data. Orbital deployment of the Agena/payload combination was always assumed to occur with the space shuttle in a circular, reference orbit of 100 nm altitude.

LMSC followed an expanded team approach for this study, assigning a centralized project-level team of LMSC personnel with backgrounds in the required disciplines. Working relationships were then established with such separate echelons of specialized activity within LMSC as the Space Shuttle Program and payload effects and with Space Tug Economics study personnel. Liaison was maintained, on a technical level, with the USAF Space Transportation group at SAMSO. Before operational concepts were finalized, they were reviewed with Cape Kennedy personnel. A series of technical reviews and working sessions were conducted, with NASA personnel in attendance.

A broad, systems approach was taken to accomplish both study primary objectives (Fig. 1-2). The shuttle/Agena interface has been defined with respect not only to the physical interface, but also to the ground operation and post-deployment flight operation interactions. Complete requirements established for the Agena space tug include those for subsystem modification and for qualification and development test. Performance capability was determined on the basis of Agena mass properties corresponding to the requirements of each of the three baseline missions. A preliminary evolutionary stage design with greatly increased performance capability was also defined through use of the established Agena space tug design as a baseline and with minimum effect on the defined shuttle/Agena interface. A work breakdown structure to Level 6 and 7 in detail was used to assemble a complete set of cost data, including evolutionary stage costs.

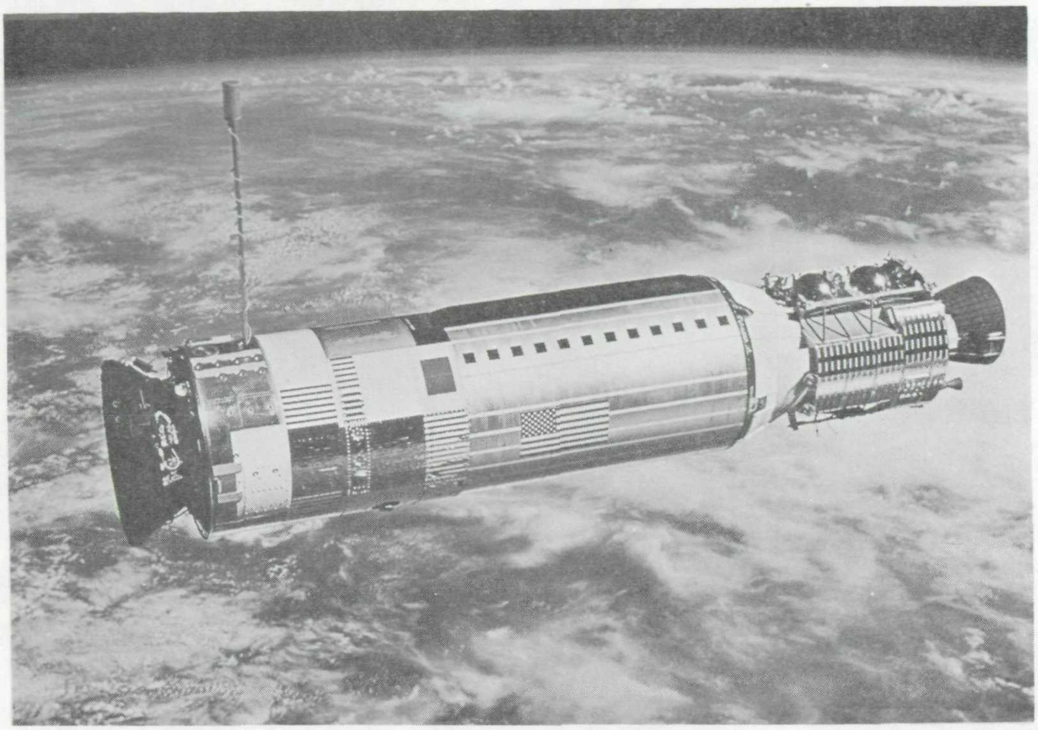


Fig. 1-1 Gemini Agena Target Vehicle

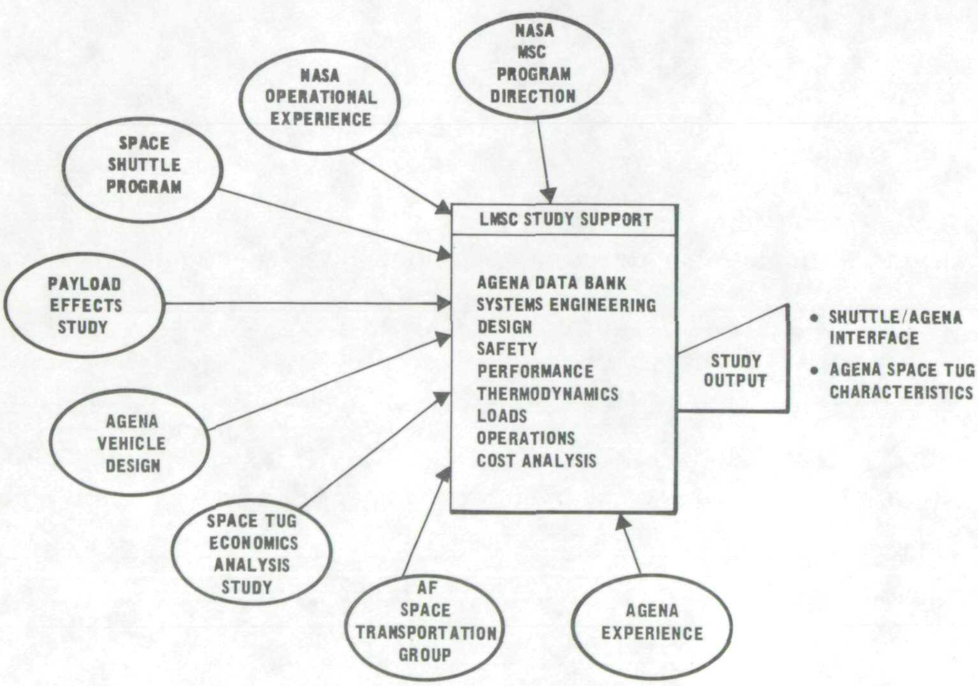


Fig. 1-2 Study Approach

Section 2
RESULTS AND CONCLUSIONS

The following specific results were achieved during the course of this study:

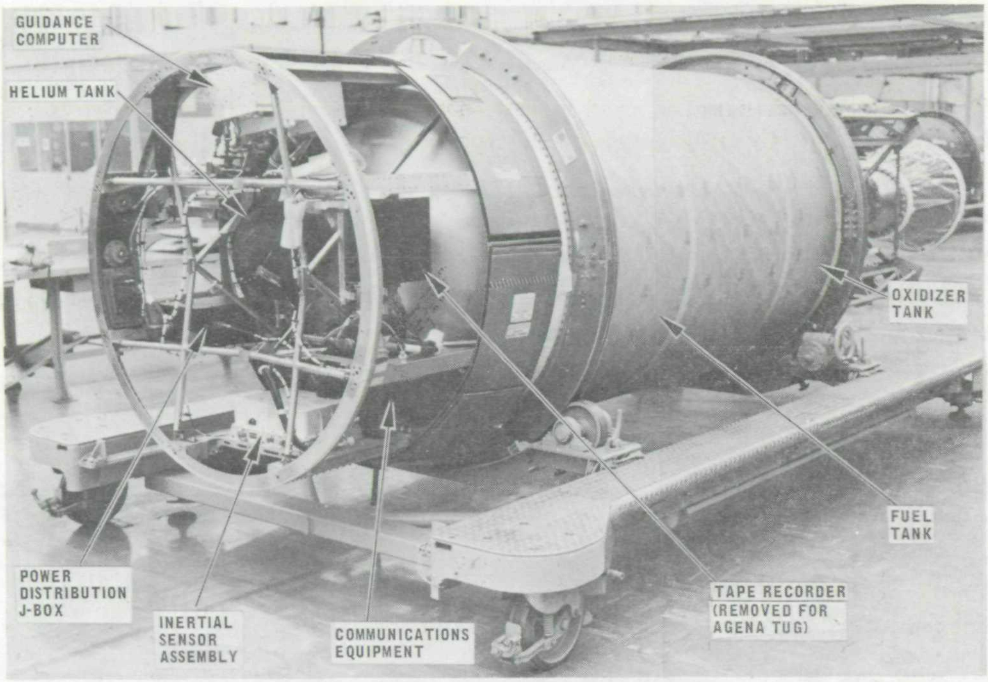
- The study demonstrated that the Agena modifications required for use with the space shuttle are feasible and are cost effective.
- The required space shuttle interfaces were identified. These interfaces are simple and minimal, primarily as a consequence of the high-density, earth-storable propellants used by the Agena.
- The study shows that the Agena has an excellent performance potential for space shuttle missions requiring additional performance beyond the capability of the shuttle.

A current and operational program Agena vehicle configuration was selected as a baseline vehicle (Fig. 2-1). The forward section contains most of the electronic equipment; the center section contains the fuel and oxidizer tanks; the aft section contains the primary propulsion and N_2 cold-gas attitude control system. The primary propulsion system includes the thrust chamber, turbopump assembly, gas generator and turbine, turbine exhaust duct, and the oxidizer and fuel couplings; the Agena space tug emergency dump system is connected to these couplings. Dump is controlled by two propellant tank isolation valves between the two propellant tanks and their respective turbopump inlets. The dump lines are routed through the space shuttle structure to overboard points at the orbiter main engine area.

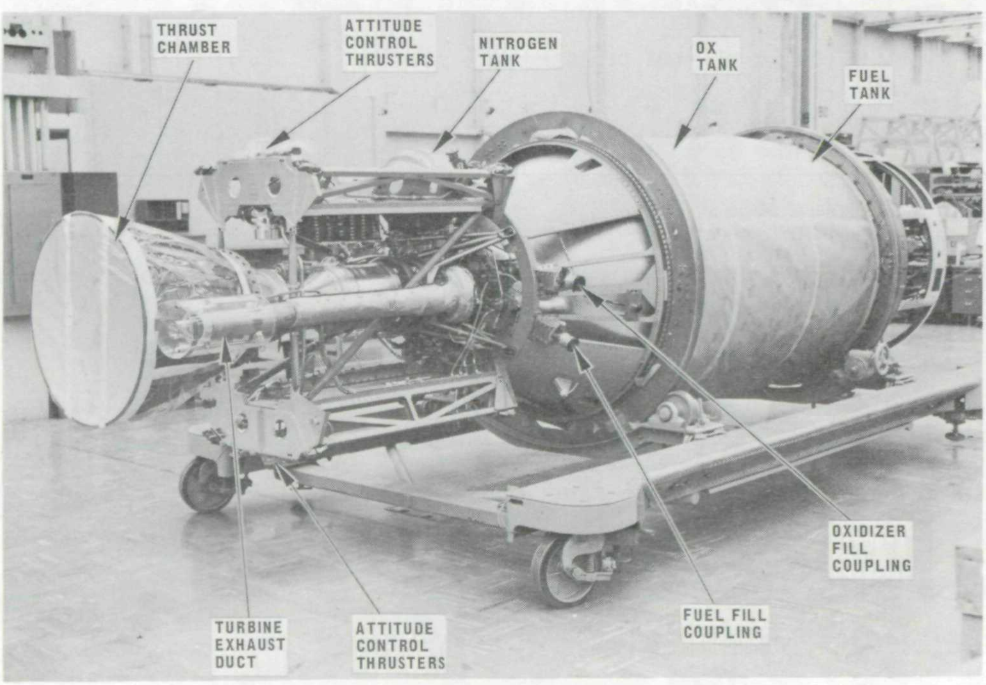
Very few changes are required to convert the Agena baseline vehicle to the Agena space tug configuration (Fig. 2-2). The most extensive structural change is the addition of two strengthening rings (Fig. 2-3), one at Station 384 and one at the payload interface plane, Station 247. These two rings include brackets for mounting the Agena and cantilevered payload on the cargo bay support structure.

The forward supporting ring (Fig. 2-3) is mounted on the existing eight payload adapter mounting holes at the forward end (Station 247) of the Agena forward equipment rack. The payload is cantilevered off this ring. The aft ring (Fig. 2-3), mounted at the Agena Station 384, provides two cradle attachment hardpoints. It is fastened to an existing bolt-hole circle on the Agena by 174 titanium cap screws. The bolt holes are normally used for mounting the booster adapter to the baseline vehicle.

The Agena space tug structural weights are increased over the basic Agena weights by the addition of the forward and aft support rings. The low earth orbit structural weight is somewhat reduced because an extended support cradle is used for the mission and therefore the forward Agena support ring is not used.



Forward View



Aft View

Fig. 2-1 Baseline Vehicle

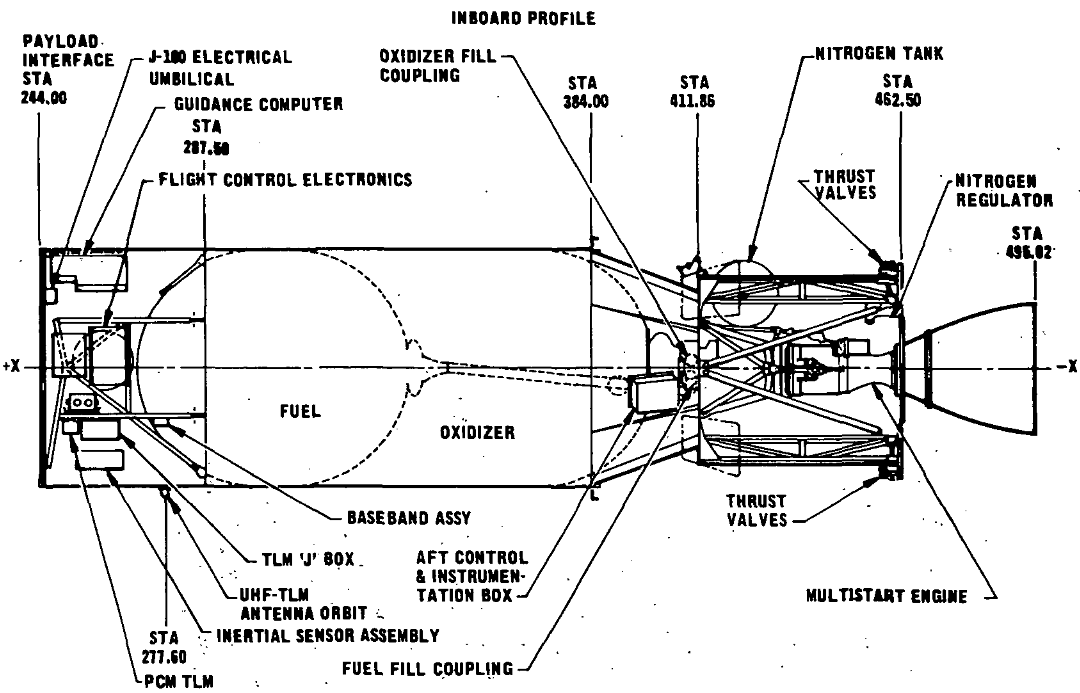
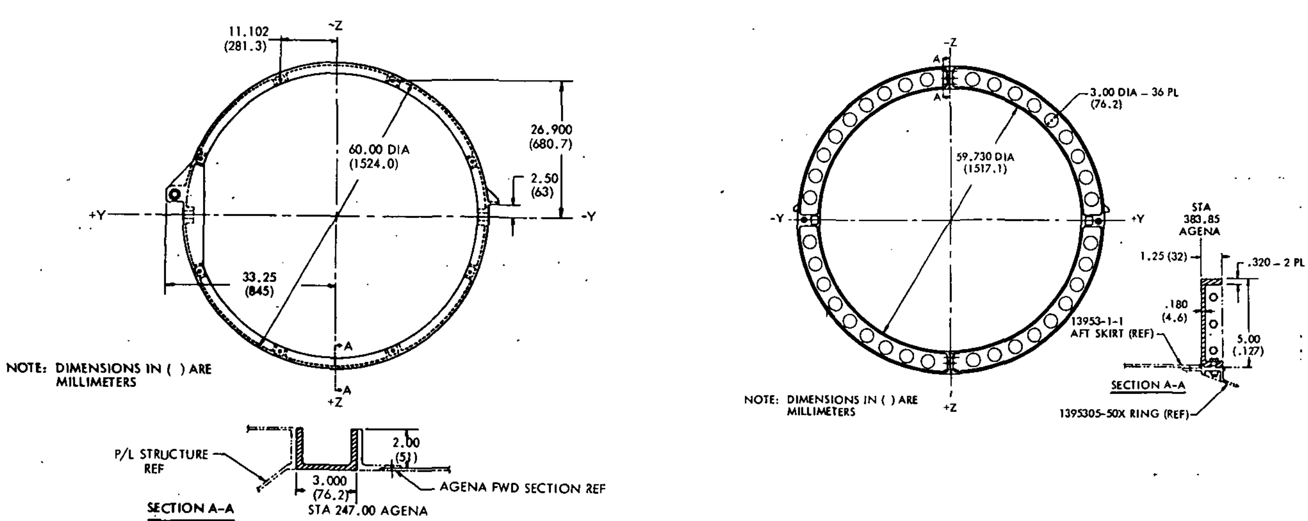


Fig. 2-2 Agena Space Tug Configuration



Forward Aft

Fig. 2-3 Agena Space Tug Support Rings

The propulsion system includes additional weight of 29 pounds for the multistart engine. Electrical power weights vary with mission-peculiar choices of battery types and the use of the solar array for the low earth orbit mission. The synchronous equatorial mission configuration does not include a solar array; it does include a heavier battery than that used in the baseline vehicle.

The guidance and ACS system weight reflects the addition of checkout sensors to enable prelaunch and predeployment flight readiness checks and the addition of the dual attitude control system for the low earth orbit 30-day duration mission.

The Agena space tug configuration injection into a synchronous equatorial transfer trajectory with an Intelsat IV payload is depicted in Fig. 2-4. Agena space tug weights are summarized in Table 2-1.

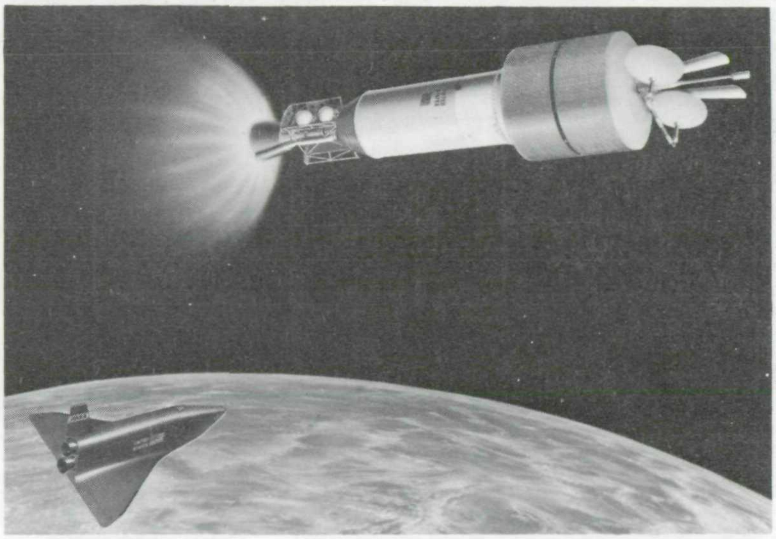


Fig. 2-4 Agena Space Tug With Intelsat IV Payload

Table 2-1
AGENA SPACE TUG WEIGHTS (LB)

Subsystem	Current Baseline Agena	Agena Space Tug		
		Planetary Injection	Synchronous Equatorial	Low Earth Orbit (30 Days)
Structures	519	608	608	566
Propulsion	341	370	370	370
Electrical Power	93	93	180	166
Guidance and ACS	155	166	166	351
Communications	20	36	45	36
Total Dry Weight	1,128	1,273	1,369	1,489
H_e Gas	3	3	3	3
N_2 Gas	30	30	30	78
Propellants (UDMH/IRFNA)	13,561	13,561	13,561	13,561
Ignition Weight	14,722	14,867	14,963	15,131

2.1 SPACE SHUTTLE/AGENA SPACE TUG INTERFACE

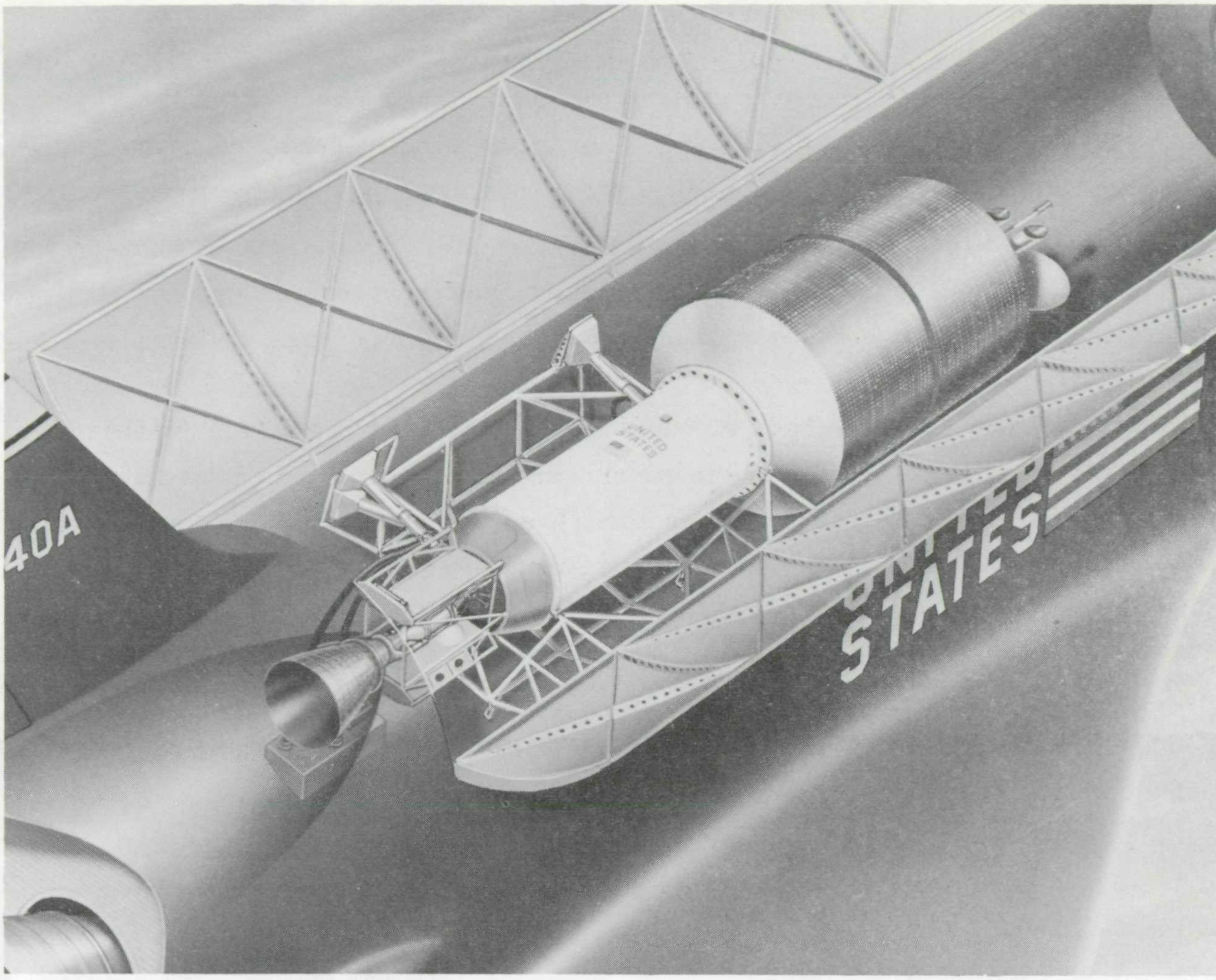
The complete physical interface between the Agena space tug/payload combination and the space shuttle orbiter cargo bay consists of a support structure and three interconnections between the Agena vehicle and the Agena/payload service panel (Fig. 2-5). The three interconnections are the Agena oxidizer emergency dump, the Agena fuel emergency dump, and the Agena main electrical umbilical disconnect (J-100).

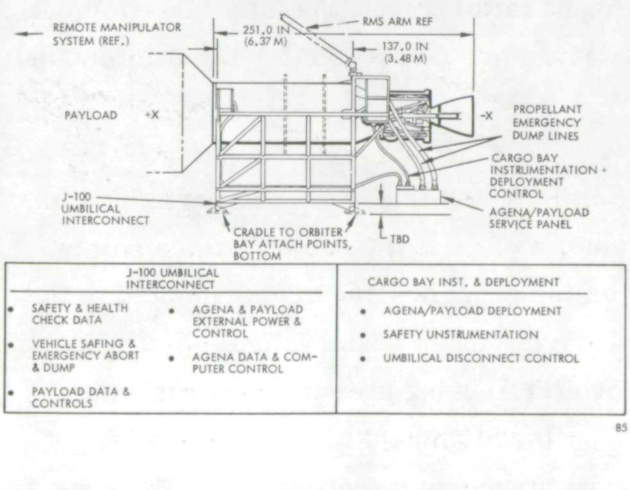
Both payload and Agena power, data, command, and control functions are routed to the orbiter through the Agena J-100 interconnect. The payload functions are wired direct to the J-100 connector through an Agena/payload interface cable. No other payload interconnect is required. The three interconnects to the Agena vehicle are existing types of flyaway umbilical disconnects used at the launch bases for Agena flights.

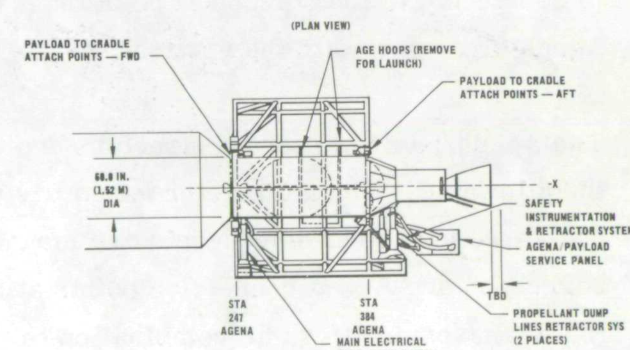
These disconnects are mated during the Agena/payload installation into the orbiter and remain connected until just before orbital deployment. The two propellant emergency dump disconnects are dry at the time of connection and remain dry, eliminating any spillage problem during deployment disconnect. If propellant dump occurs as a result of a mission abort, the disconnects and lines will be wet; however, the disconnects will not be activated, since deployment will not occur.

Two GSE handling rings installed around the Agena tanks permit the fully tanked Agena to be handled in the horizontal position. These rings are removed after the orbiter (and Agena) are erected to the vertical.

The Agena/payload support structure depicted in Fig. 2-5 is designed to remain within the allowable 15-foot-diameter cargo bay volume, except at the orbiter attach points. The three umbilical disconnects are mounted on the support structure and mated to the corresponding Agena connection points at the time of launch base systems test. Mating the Agena/payload/cradle combination to the orbiter, during prelaunch operations, therefore requires only one precision operation – the alignment of the cradle with respect to the orbiter by shimming at the support structure mounting pads. The connection of the two emergency dump lines, the Agena main electrical umbilical (J-100), and the cargo-bay instrumentation and deployment control cable completes the mating of the Agena/payload combination to the orbiter.







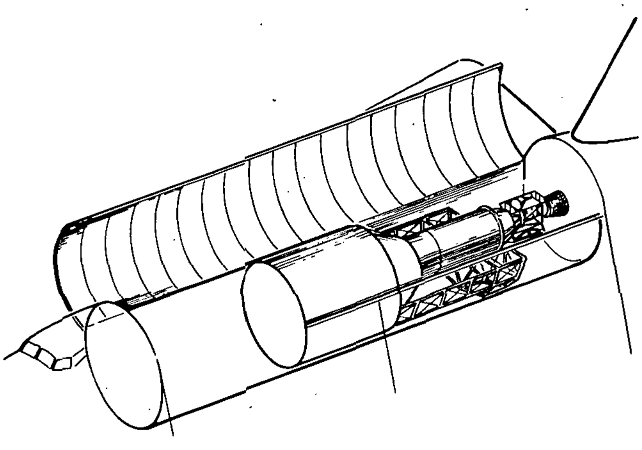
Side View

Plan View

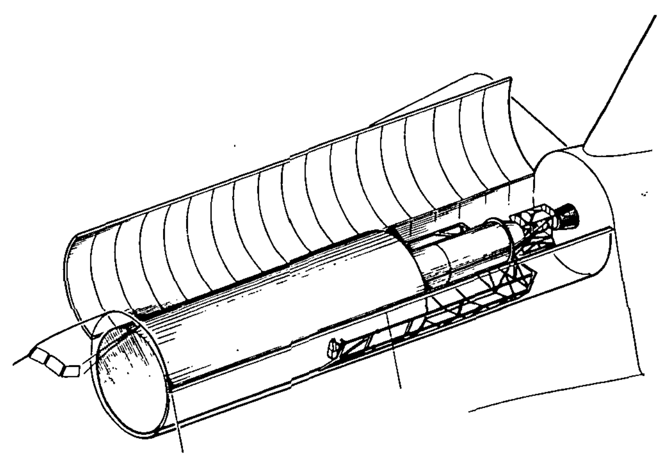
Fig. 2-5 Space Shuttle/Agena Space Tug Interface

Figure 2-6 presents two alternative support structure configurations for those payloads with weight and/or CG location that results in loads exceeding the Agena capability for the fully cantilevered support structure. For medium loads such as the Mars-Viking spacecraft, the payload adapter cantilevered support structure will be used. For very long and heavy payloads, the extended support structure that supports the payload at its CG can be used.

All Agena/orbiter interface connections will be routed through the Agena/payload service panel (Fig. 2-7). Although this panel is an Agena-supplied item, along with the umbilical connections and retraction mechanisms, for Agena missions all connections on the orbiter side of the panel can be fixed, installed equipment. The service panel is designed for easy access to permit maintenance and repair on individual components without the need to disconnect and remove the panel from the orbiter.

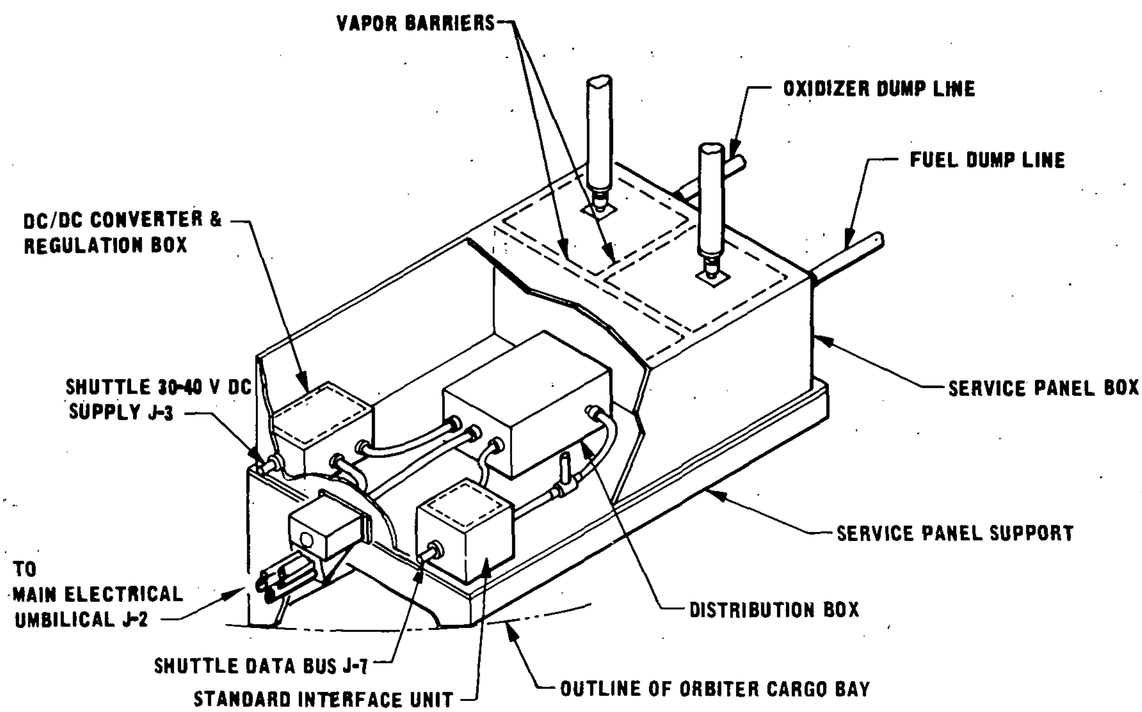


Payload Adapter Cantilevered Support

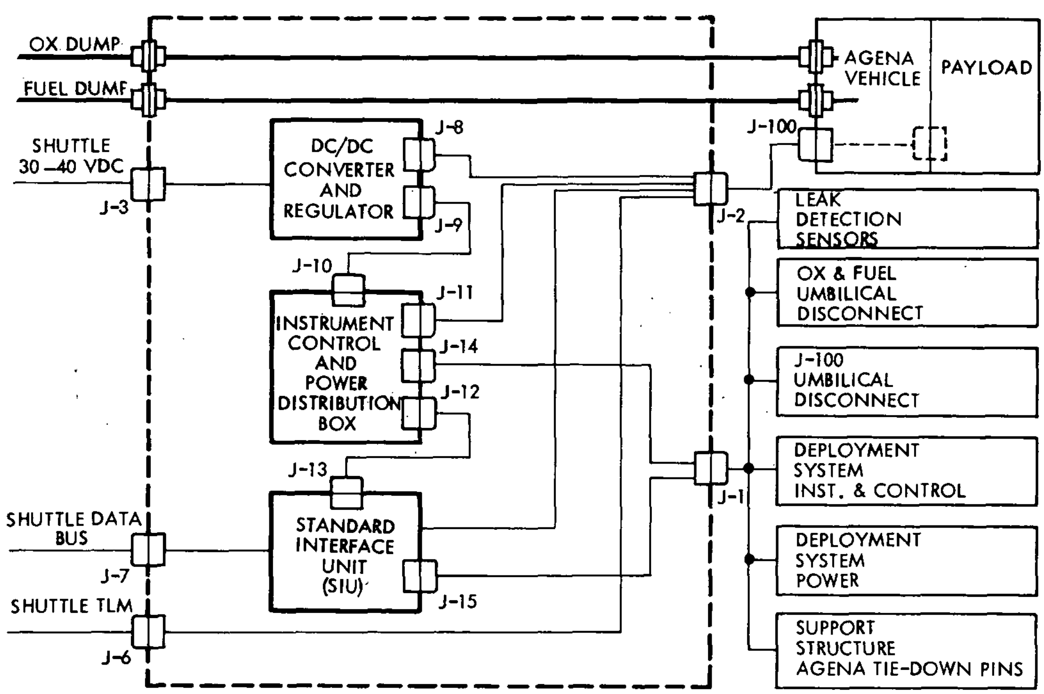


Extended Support Structure

Fig. 2-6 Alternative Support Structure Configurations



Cutaway View



Schematic Diagram

Fig. 2-7 Agena/Payload Service Panel

The service panel serves as a junction and distribution box for the various electrical connections. The three interconnects between the Agena space tug and orbiter are shown in the panel schematic,Fig. 2-7. The service panel also serves as a coupling point between the fixed installed dump lines within the orbiter structure and the flexible lines connected to the Agena. All cargo bay functions are routed through panel connector J-1, Agena and payload electrical functions through panel connector J-2. If early space shuttle models do not have a data bus, the standard interface unit will be replaced by two signal conditioning boxes, one for Agena functions and one for payload.

The Agena space tug can be installed in the space shuttle as long as 15 days prior to launch. The cargo bay safety instrumentation will be activated and continuously monitored until the Agena is deployed in orbit. Approximately 24 hours before liftoff, the Agena guidance system will be activated for warmup and completion of the prelaunch flight-readiness check. This check, which requires approximately 30 minutes to complete, can be conducted in parallel with the space shuttle countdown on a noninterference basis. Once activated, the guidance system remains active through Agena deployment. The required Agena power profile is depicted in Fig. 2-8.

The Agena space tug will be tanked before it is installed in the orbiter cargo bay. This procedure simplifies the tanking operation and the fluid interface between the Agena and the orbiter. This pretanking procedure was finalized after a thorough in-house analysis and was reviewed with both Lockheed and NASA operations personnel at Cape Kennedy and Vandenburg Air Force Base. The conclusion reached after completing these reviews was that the Agena pretanking procedure was feasible and could be performed as safely as existing vehicle tanking procedures. The design requirement for propellant dumping is satisfied by two fluid lines between the Agena and the service panel (Fig. 2-9). These two dump lines connect to the existing Agena fill couplings and extend beyond the service panel, through the orbiter interior to an exit point on the orbiter exterior skin surface. The dump lines will be connected immediately after the tanked Agena is installed in the cargo bay and remain connected until just before deployment. The dump lines and Agena interconnect will always be dry except in the case of an emergency dump.

The Agena vehicle is generally qualified to a more severe environment than it will experience during space shuttle flights. The guidance computer and inertial sensor assembly are currently qualified to the using program required acoustic level, which is lower than the space shuttle acoustic level. However, a second using program has started a program to requalify this equipment to a level approximately equal to that of the space shuttle.

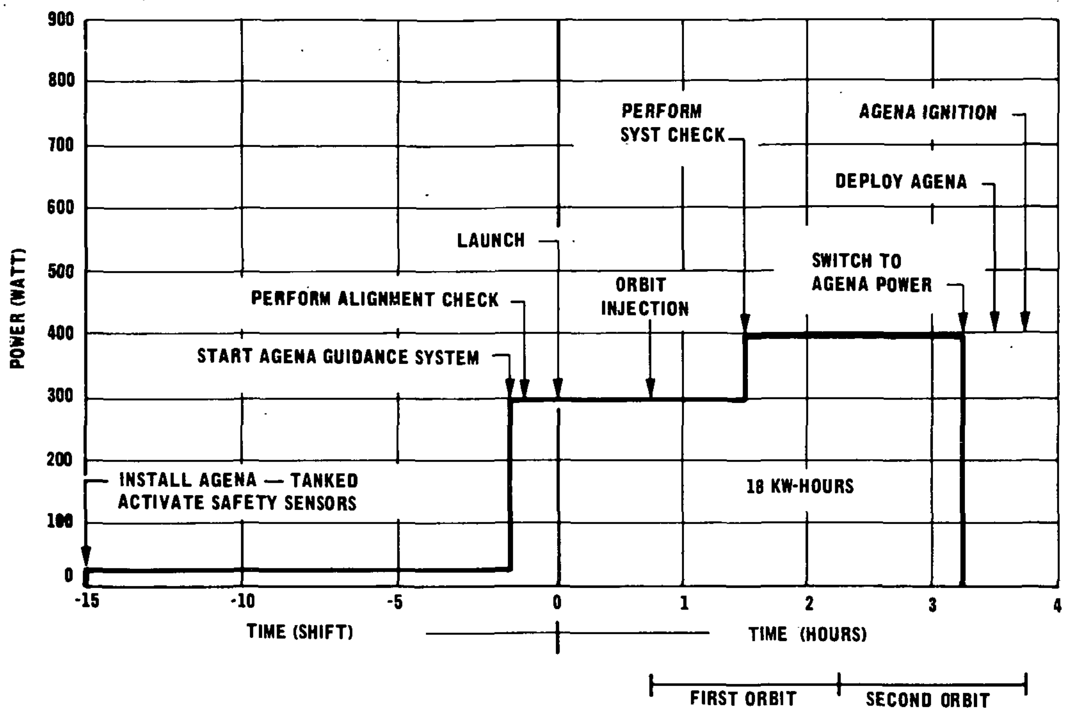


Fig. 2-8 Agena Space Tug Power Requirement

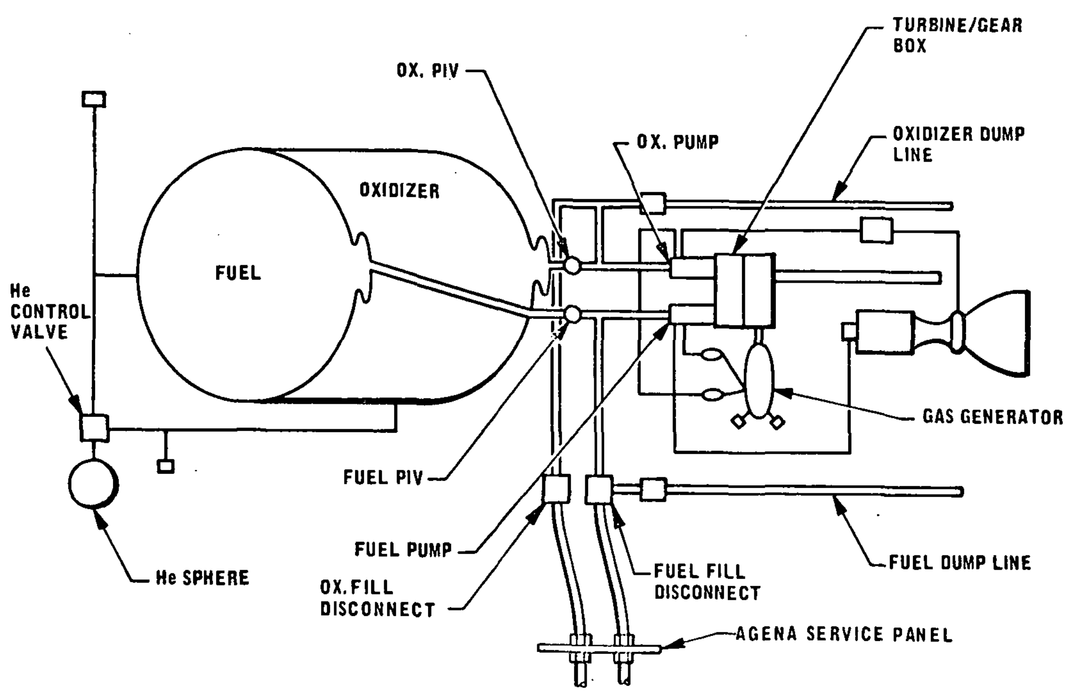


Fig. 2-9 Agena Propellant Dump Lines

The thermal limit of 75°F is an arbitrary design limit to fix propellant load factors in support of performance calculations. The higher temperature was selected to permit the loss of pad cooling without causing concern for either bulk propellant temperature rise or increase in tank ullage pressures.

The Agena support equipment includes all cargo bay equipment required by the Agena from the time of installation into the cargo bay through deployment. All elements of this equipment are included in the following weight statement. The variations in support structure weight are caused by variations in structure length to accommodate different payload weights and CG locations.

	Cantilevered Support System	Extended Cradle System	Cantilevered Support with P/L Adapter
Agena/Payload Support Structure	508	1083	642
Agena Service Panel and Electrical Components and Cables	97	97	97
Dumplines and Retraction Mechanism	120	120	120
J-100 Disconnect and Cables	71	71	71
Total	796	1371	930

2.2 AGENA SPACE TUG LAUNCH OPERATIONS

The milestone schedule (Fig. 2-10) shows a conservative span of 26 days from arrival of an Agena space tug at the launch base to liftoff from the pad. This span is based on an assumed one-shift per day operation until the Agena/payload is mated with the orbiter. The final 3 days before liftoff are virtually passive for the Agena, except for safety monitoring, final flight readiness check, and an optional guidance system azimuth alignment. The Agena, with the mated payload and support structure, can be stored for up to 14 days between Agena tanking and mating with the orbiter.

The three major space shuttle payload elements – Agena space tug, support structure, and payload – are brought together at the Payload Processing Facility (Fig. 2-11). Each undergoes the following checks:

- Identification and damage receiving inspection
- A compatibility check with its respective ground support equipment
- Final checkouts before assembly to an Agena/payload/support structure combination

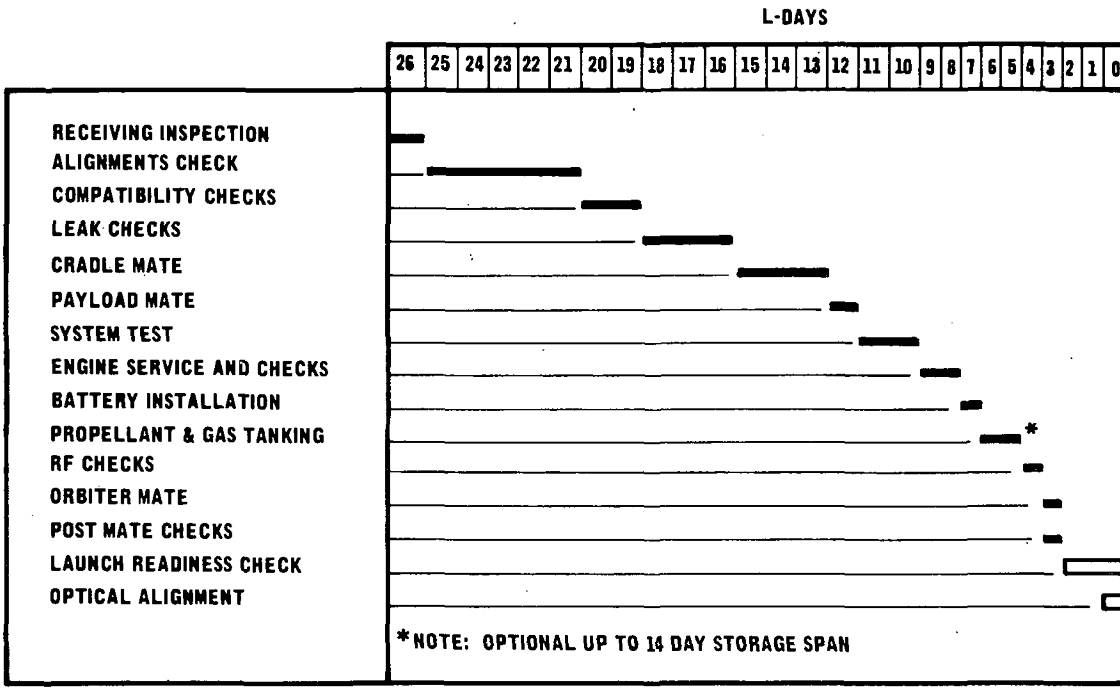


Fig. 2-10 Milestone Schedule

New support structures not previously flown would not pass through the refurbishment cycle, but would move directly to alignment checks after receiving inspection.

After the payload, support structure, and Agena have been mated, a complete Agena system test (Fig. 2-12) will be performed. This comprehensive test is run in two parts. First, the integrity of all functional interfaces and the proper operation of all Agena equipment is verified; then the payload and support structure are similarly tested. In the second part of the test, the Agena's capability to perform the mission is checked by operating the vehicle to simulate the actual flight functional sequence. The flight program is loaded into the computer, the computer memory is dumped, and a word-by-word verification is made that the program was loaded correctly. The assimulated flight program (with shortened time spans) is then loaded, and the vehicle is operated in a flight-simulated manner. All discretes and mission-required functions are verified, both as to function and operation time.

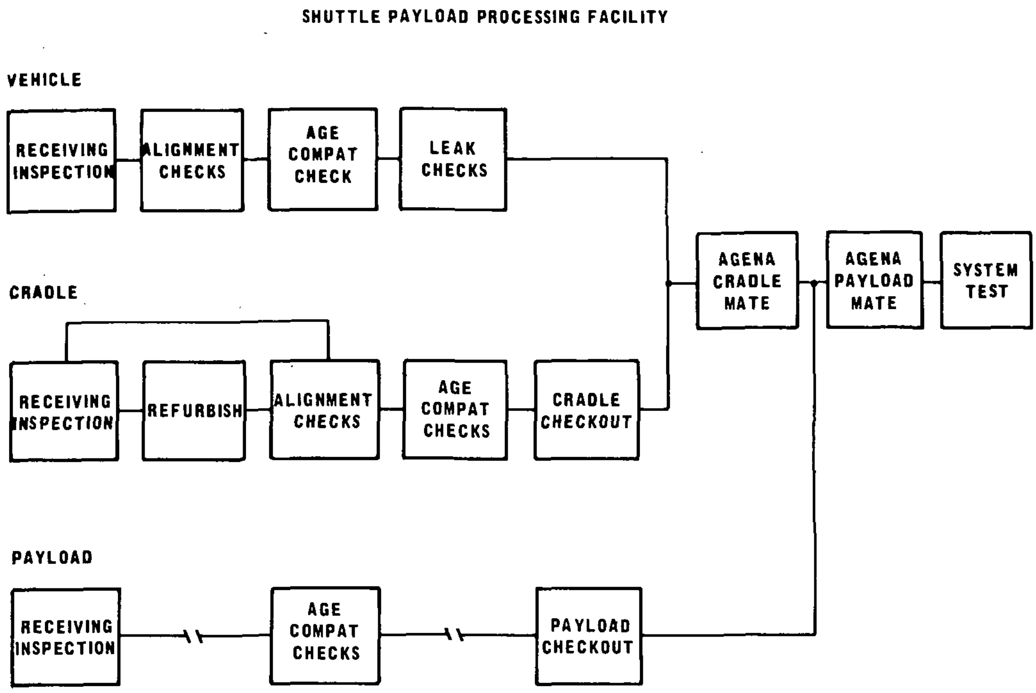
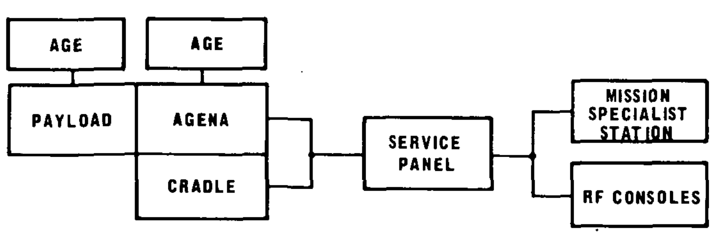


Fig. 2-11 Agena/Payload Operations



COMPLETE SYSTEMS TEST	FLIGHT READINESS TEST
VEHICLE ● ALL DISCRETES ● FLIGHT CONTROLS ● ATTITUDE CONTROL ● ELECTRICAL POWER ● TLM ● COMPUTER LOAD AND DUMP ● STATIC NAVIGATION CHECK ● EMERGENCY DUMP ● VEHICLE SAFING CRADLE ● REMOTE AND MANUAL DISCONNECTS ● DEPLOYMENT CONTROL AND INST PAYLOAD ● COMPLETE CHECKOUT ● AGENA/PAYLOAD COMPATIBILITY	VEHICLE ● LOAD FLIGHT PROGRAM ● COMPUTER DUMP ● SIMULATED FLIGHT SEQUENCE ● EMERGENCY DUMP ● VEHICLE SAFING CRADLE ● REMOTE AND MANUAL DISCONNECT ● DEPLOYMENT CONTROL AND INST PAYLOAD ● SIMULATED FLIGHT SEQUENCE ● AGENA/PAYLOAD COMPATIBILITY ● SEPARATION (SIGNAL ONLY)

Fig. 2-12 System Test

The service panel and mission specialist station are the functional equivalent of the actual flight hardware.

After system test, the Agena/payload is moved to the Agena tanking and storage area. The existing Agena GSE installation at Pad 13, Cape Kennedy, can be used for Agena space tug tanking with no changes except for the physical accommodation of the support structures and the addition of a safety console (Fig. 2-13) to handle and display the Agena safety instrumentation. Emergency dump and Agena safing can be controlled from either the propulsion or the safety console. During a storage span following tanking, the Agena would remain in the tanking facility.

Before the Agena/payload and orbiter are mated, the Agena response to RF commands to and from the orbiter will be verified. This procedure checks out the RF link between the Agena and orbiter in the post-deployment mode. After the Agena is moved to the orbiter facility and installed in the orbiter cargo bay, all interfaces are checked through the Agena/payload service panel to the mission specialist station.

The orbiter is then moved to the pad, erected, and mated to the booster. On pad, no external GSE connections to the Agena are required except for the emergency dump system and the optional inertial sensor assembly alignment optical path (Fig. 2-14). Agena safety monitors will be displayed at the mission specialist station. The Agena computer can be updated as required after Agena activation on T-1 day.

2.3 AGENA SPACE TUG SAFETY

A preliminary hazards analysis was completed on the Agena space tug vehicle and its required operations; three significant problem areas and potential approaches for overcoming them have been identified:

- The Agena propellants must be handled with proper safeguards; proven techniques developed during 320 Agena launches over a period of 13 years will be used.
- Reversal of the integral propellant tank bulkhead must be avoided; there are proven techniques to prevent this.
- The handling of a fully tanked Agena will require some new safeguards; however, the procedures involved do not require the development of new techniques or equipment.

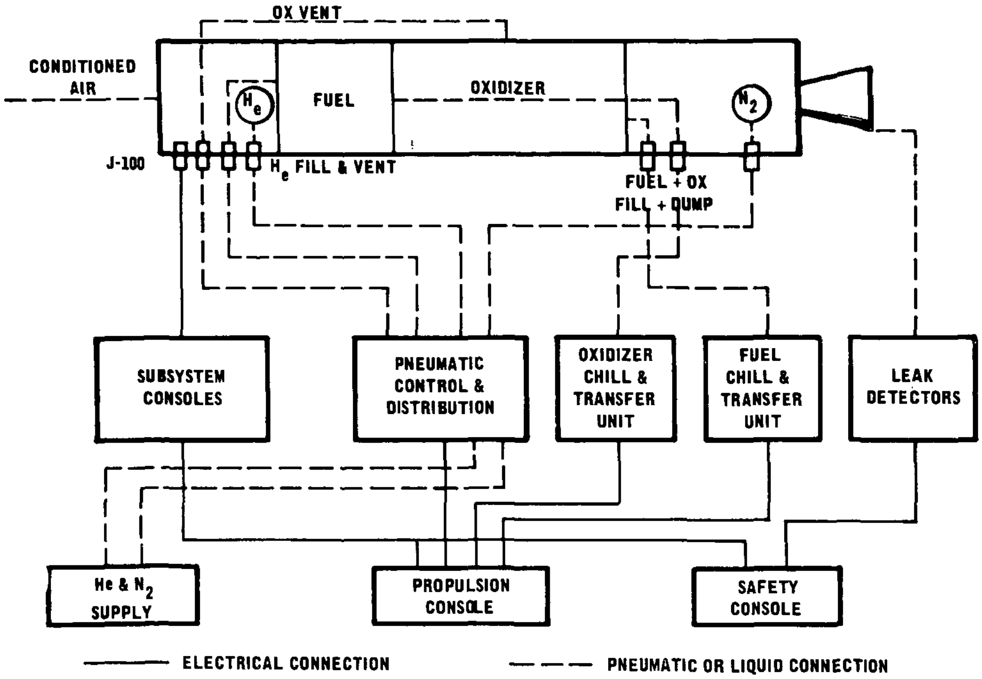
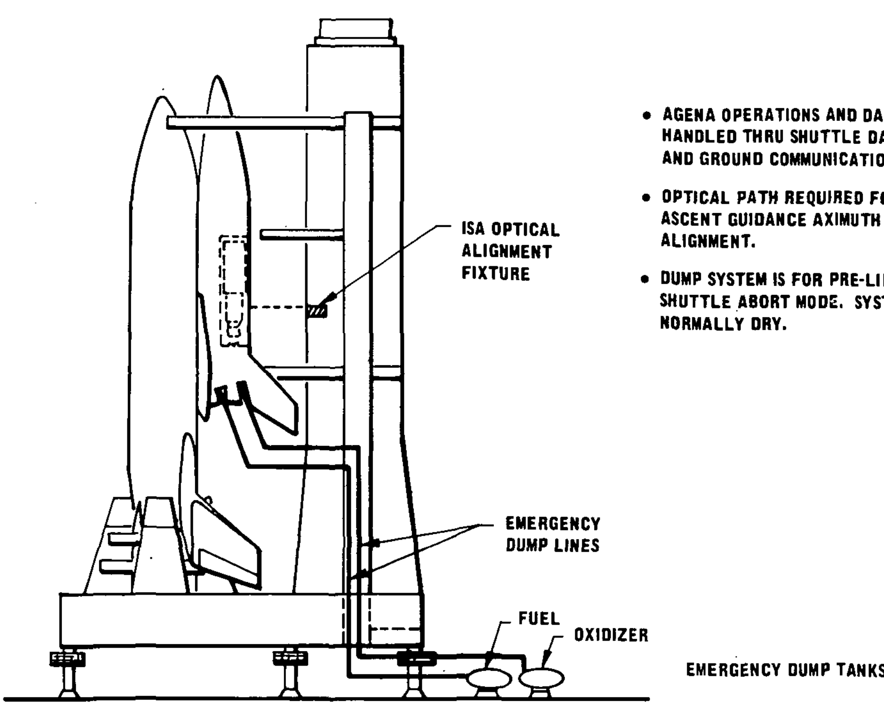


Fig. 2-13 Agena Tanking and Storage Interface



- AGENA OPERATIONS AND DATA ARE HANDLED THRU SHUTTLE DATA BUS AND GROUND COMMUNICATIONS LINKS.
- OPTICAL PATH REQUIRED FOR AGENA ASCENT GUIDANCE AXIMUTH ALIGNMENT.
- DUMP SYSTEM IS FOR PRE-LIFTOFF SHUTTLE ABORT MODE. SYSTEM IS NORMALLY DRY.

Fig. 2-14 Shuttle Pad Operations

In the 236 Agena launches since 1962, from both WTR and ETR, there has been no Agena propellant leakage. Neither have any leaks occurred in the GSE since 1962.

It is also significant that in a number of vehicle hot-fire tests at Santa Cruz, during which the Agena engine, tanks, and pressurization system were subjected to operational pressures and dynamic conditions, there were no vehicle propellant leaks. The techniques and procedures used in achieving this record are directly applicable to the Agena space tug; they have been incorporated into the launch base test plans.

To detect propellant leakage, and to monitor the status of the propellant tanks, propellants, and high-pressure gases, certain safety instrumentation (Table 2-2) for the Agena and the orbiter cargo bay have been identified. These parameters are displayed on the Agena console at the orbiter mission specialist station, and they could also be displayed at the pilots' console. The same safety instrumentation and display would be required during the optional capability for 14-day storage of the tanked Agena. Display would be at the Agena GSE control or safety monitor station.

Table 2-2
AGENA SPACE TUG SAFETY INSTRUMENTATION

Measurement	Location	Instrument Range	Acceptance Readings	Action Required if Reading Out of Range
Fuel Tank Pressure	Pressurization Control Valve	0 to 100 psi	0 to 34.5 psi	Reduce Fuel Temperature, or Dump
Oxidizer Tank Pressure	Pressurization Control Valve	0 to 100 psi	0 to 34.5 psi	Reduce Oxidizer Temperature, Vent, or Dump
Fuel Tank Temperature	Exterior Tank Skin	30 to 90°F	≤75°F	Reduce Fuel Temperature, or Dump
Oxidizer Tank Temperature	Exterior Tank Skin	30 to 90°F	≤75°F	Reduce Oxidizer Temperature, Vent, or Dump
Oxidizer Differential Pressure	Between Oxidizer and Fuel Vent Lines	±10 psi	Fuel Minus Oxidizer ≥0 psi	Cool, Vent, or Dump Oxidizer
Cargo Bay Temperature	Shuttle Cargo Bay	TBD	TBD	TBD
Presence of Fuel or Oxidizer	Shuttle Cargo Bay	Function of Instrument Type	Negative	Assess Leak Rate, and if out of Acceptable Range Either Deploy Agena or Dump Propellant
He Tank Pressure	He Control Valve	0 to 4000 psi	≤2880 psi	Cool or Vent
N_2 Tank Pressure	N_2 Control Valve	0 to 4000 psi	≤2880 psi	Cool or Vent

Emergency dump of Agena propellants is possible during Agena tanking, storage span, on the pad, or in orbit. In all cases the Agena dump system and controls are the same. The Agena onboard pressurization system is activated and the appropriate isolation valve is opened. In storage or on-pad, both propellants can be dumped simultaneously in a maximum dump time of 8 minutes. Simultaneous dump is feasible, since the propellants are isolated throughout the dump system, including the receiving tanks.

On-orbit dumping requires sequential dumping, oxidizer first. In addition, a shuttle-supplied thrust vector of 1×10^{-2} to 1×10^{-3} g is required throughout the dump span of 14 minutes.

A safety design recommendation that will automatically maintain a positive ΔP across the propellant tank bulkhead involves placing a differential pressure transducer and vent valve across the two tanks. The transducer senses the differences between the fuel and oxidizer tank pressures. If this difference changes below 5 psid, the vent valve vents the oxidizer tank to achieve the desired differential pressure. The oxidizer tank vent is plumbed into the overboard oxidizer tank emergency dump line. Thus, even the complete loss of all orbiter and Agena power would not jeopardize the Agena tank bulkhead integrity.

The problem of handling the fully tanked Agena space tug can be safely carried out by stringently following established Agena handling procedures and observing certain safeguards, as illustrated in Fig. 2-15. An Agena stress analysis has shown that the structure has sufficient margin to meet these handling requirements with the Agena fully tanked, with a cantilevered payload, and with the supporting cradle.

Existing procedures would be used to tank the Agena in the vertical position. Agena space tug safety instrumentation and emergency dump capability would be activated and available. Lifting, tilting, and lowering the Agena/payload/cradle onto a transporter would require a dual crane setup, with dual cables, hoists, and hooks. An additional static (nonhoisting) safety cable support could also be used.

The Agena would be transported with an acceleration/shock cushioned transporter and with a full complement of safety instrumentation. The Agena/payload would be moved at night to minimize exposure to other traffic. The Agena/payload would be lifted from the transporter and placed into the cargo bay of the horizontally positioned orbiter with a crane setup similar to that used to place the Agena/payload on the transporter. The orbiter service building would be evacuated, leaving only the minimum of personnel required for the mating operation.

A summary of preliminary safety guidelines that have been established for the Agena space tug vehicle and associated launch base and flight operations follows:

- All GSE shall be required to be fail-safe
- Safety instrumentation shall be continuously monitored after tanking
- Shuttle design factors shall be an Agena space tug design requirement
- All Agena space tug subsystems shall be fail safe or be capable of safing by remedial action
- Orbital deployment hardware shall be designed for fail operational/fail safe operation
- Agena space tug safing shall be controlled by command from Agena control console/pilot's console
- Automatic control of propellant tank integral bulkhead Δ pressure shall be provided

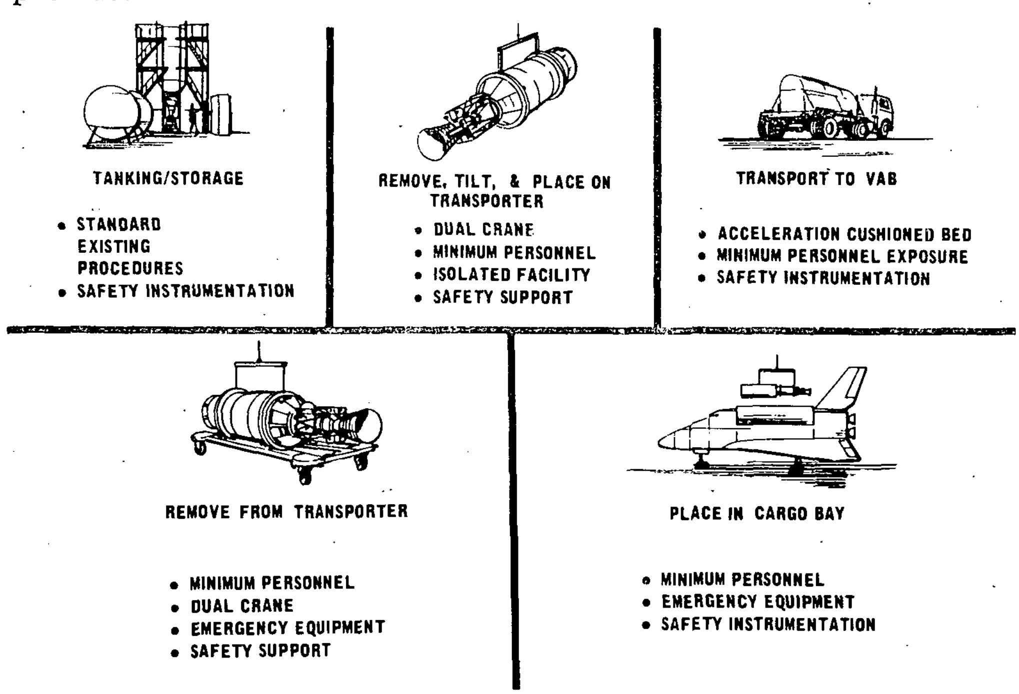


Fig. 2-15 Handling Tanked Agena

2.4 EVOLUTIONARY STAGE DESIGN

The Agena space tug guidelines are also applicable to the evolutionary stage Agena. The same guidance, power, and communication subsystems are used in both configurations. Improvements defined by the Lockheed Agena Improvement Plan were reviewed and planned improvements were selected in the propulsion subsystem areas that are nearly certain to be flight proven before the first space shuttle flight. Performance and propellant tankage were optimized to the baseline synchronous equatorial mission, since it is the performance design driver.

After the propellant tank configuration was established and a propellant loading of 48,800 pounds was selected, a point detail design for the evolutionary Agena space tug (Fig. 2-16) with a diameter of 120 inches and a length of 275 inches was completed. The inboard profile shows the major subsystems and principal components. Basically, the evolutionary Agena space tug is comprised of three major sections, i.e., the forward equipment section, the intermediate propellant tank section, and the aft propulsion section. There is a strong resemblance to the present Agena space tug vehicle.

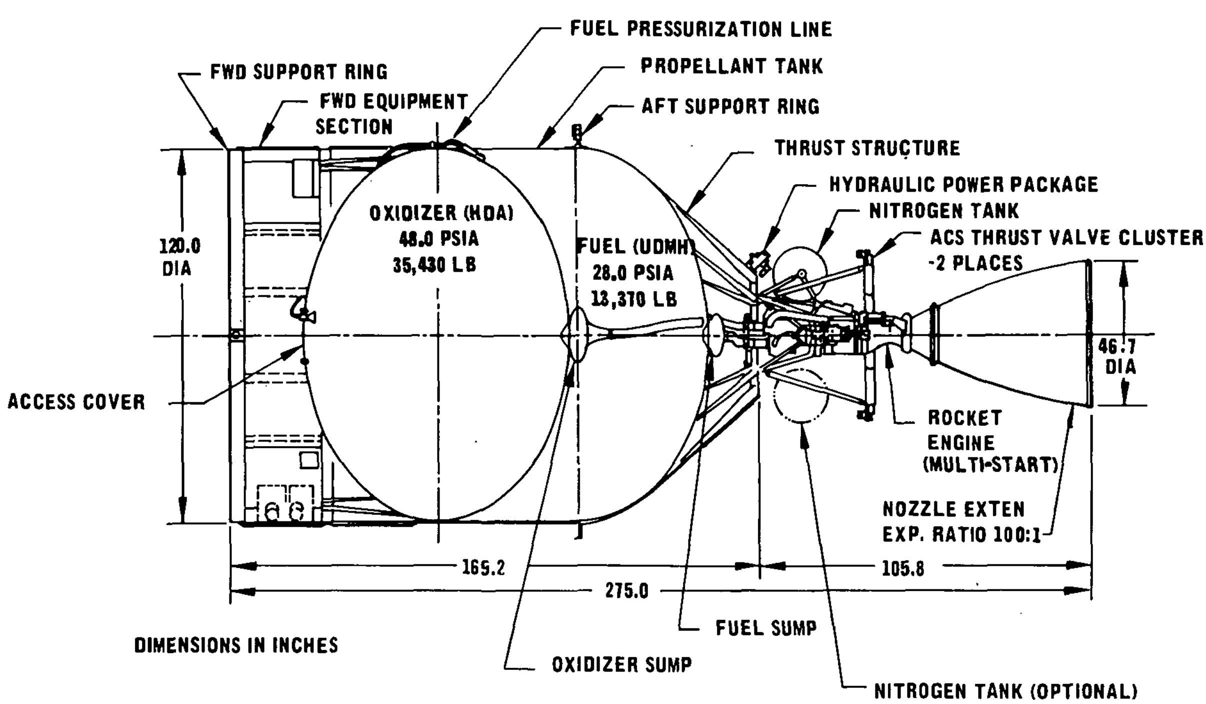


Fig. 2-16 Evolutionary Stage (Inboard Profile)

All of the guidance, electronics, power, propellant tank pressurization, and telemetry systems are installed in the forward section. The structure for this section is semi-monocoque, utilizing external trapezodial stringers and internal beams that provide structural stiffness as well as mounting bases for the functional equipment installed in this section.

The forward oxidizer tank is a true $\sqrt{2:1}$ ellipse; the lower head provides a common bulkhead for both tanks. The aft head of the fuel tank is $\sqrt{2:1}$ semi-ellipse. A cylindrical section joins the two tanks at a Y-ring near the equator of the oxidizer tank. The membrane, as well as other tank components, will be made of 2021 aluminum alloy.

The aft propulsion section is comprised of an engine thrust cone attached to the fuel tank head, the rocket engine accessories, and supporting truss. The attitude control thrusters and nitrogen storage tanks are also mounted in the aft section. Figure 2-17 presents an external view of the evolutionary stage, with appropriate cutaways to show interior design details.

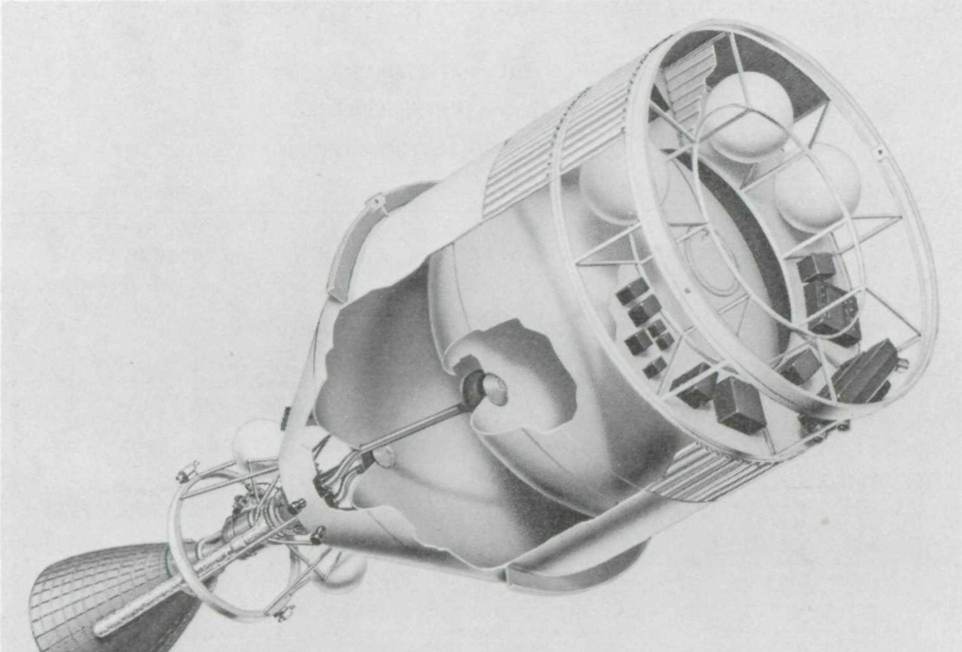


Fig. 2-17 Evolutionary Stage (Cutaway View)

The evolutionary stage impact on the established space shuttle/Agena space tug interface is minimal. The cargo bay support cradle structure requires redesign to accommodate the larger stage diameter. The weight tradeoff between the reduction in size of the support structure and the consequent increase in tubing wall thickness results in a weight decrease of 30 pounds. Large-diameter emergency dump lines may be required to compensate for the increased propellant load if the dump time is considered to be excessive.

Since the evolutionary stage incorporates the same electronics as the Agena space tug, no changes are required in the Agena/payload service panel or the Agena console located in the orbiter mission specialist station. Safety instrumentation, propellant tanking techniques, and vehicle flight operations also remain the same.

The synchronous equatorial mission configuration was selected for both the Agena space tug and the evolutionary stage for comparison of pertinent stage characteristics (Fig. 2-18). A measure of tank efficiency (L/D) for the evolutionary stage Agena is evident when it is shown that this stage is only 27 inches longer and has a tankage capacity three and one-half times greater than that of the Agena space tug. Moreover, 17 inches of the length is attributable to the longer engine nozzle associated with the 100:1 expansion ratio of the nozzle used on the evolutionary stage. A high mass fraction of 0.963 is further evidence of the improved efficiency of the larger diameter stage.

2.5 PERFORMANCE CAPABILITY

In determining Agena space tug performance capability, four general areas produce the basic guidelines for deriving the actual payload weight values. The mission definition specifies the initial and final orbit conditions, ΔV schedule, and associated coast times. Vehicle weights specify the impulse propellant loading and determine the difference between vehicle burnout weight and payload weight; propulsion characteristics define specific impulse and thrust levels. The primary performance constraint is a maximum Agena space tug plus payload ignition weight limitation corresponding to the 65,000-pound space shuttle delivery capability due east at a 100 nm circular orbit.

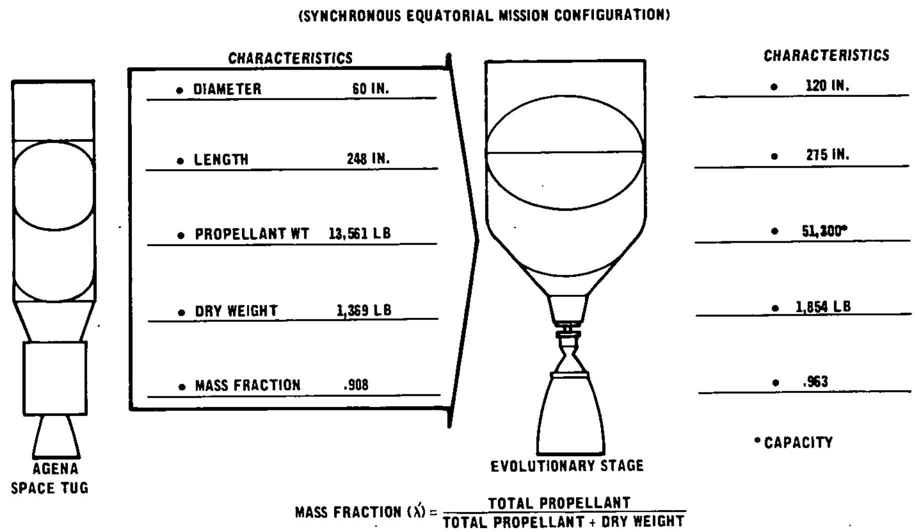


Fig. 2-18 Agena Space Tug/Evolutionary Stage Comparison

The Agena space tug performance capability under the above-mentioned guidelines follows:

Mission	Payload Weight (lb)	
	I_{SP} = 290.8 sec	I_{SP} = 310.0 sec
• Synchronous-Equatorial	2257	2,804
• Interplanetary	3540	4,225
• Low Earth Sun-Sync Orbit*	9770 (each orbit)	10,053 (each orbit)

*Agena space tug payload performance is constrained by space shuttle payload capability for polar orbit.

A summary of the payload capability for the evolutionary Agena space tug configurations presented below shows a five- to six-fold increase in maximum performance for the synchronous-equatorial mission when compared to the Agena space tug configurations.

The 1982 Viking interplanetary mission reflects an approximate four- to five-fold increase but the low earth, sun-synchronous orbit shows a loss in payload capability. This decrease in performance results from the improved Agena space tug propellant offloading required to satisfy the space shuttle delivery constraint for polar orbits. The increased inert weight of the evolutionary Agena space tug configurations associated, for this mission, with the unusable propellant loading, generates a decrease in payload weight when compared to the smaller Agena space tug. The absolute payload values shown for the synchronous-equatorial mission differ from the values shown in the parametric propellant loading figures by virtue of the point design scar weights and actual mission sequence of events used in simulating the reference mission performance capability.

Mission	Payload Weight (lb)	
	HDA/UDMH I_{SP} = 310.0 sec	N_2O_4/MMH I_{SP} = 322.0 sec
• Synchronous-Equatorial	13,234	13,956
• Interplanetary	16,512	17,276
• Low Earth, Sun-Sync Orbit*	9,504 (each orbit)	9,695 (each orbit)

*Agena space tug payload performance is constrained by space shuttle payload capability for polar orbit.

The curves of ΔV versus payload capability for the Agena space tug and evolutionary stage point designs illustrate their potential mission capability. Payload weights for ignition weights equal to or less than 65,000 pounds are shown in Fig. 2-19, along with the capability reflecting no ignition weight constraint. It should be noted that the evolutionary stage can provide a 2,000-pound spacecraft with more than 25,000-foot per second ΔV in support of high-energy, deep-space scientific missions. This is equivalent to a total characteristic velocity of over 50,000 feet per second.

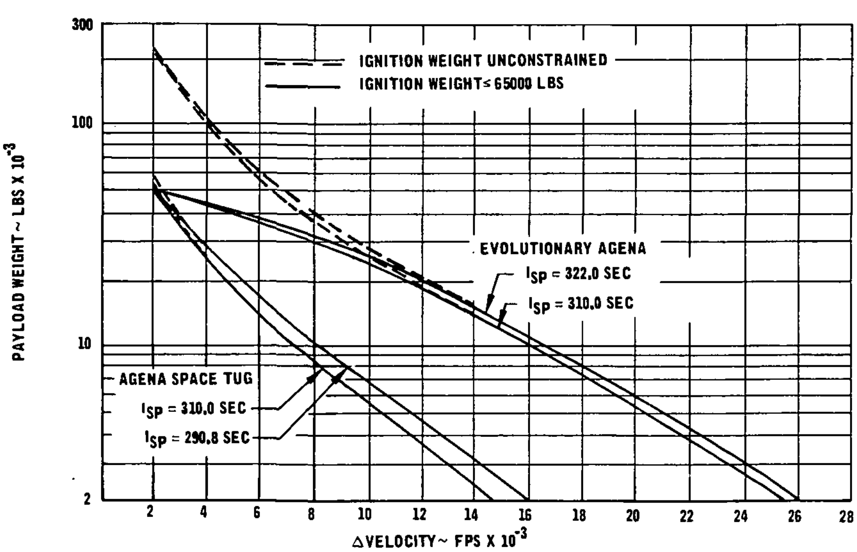


Fig. 2-19 Agena Space Tug Performance Capability

2.6 COST ANALYSIS

Important programmatic assumptions made in deriving the Agena space tug costs are as follows:

- A production rate of six per year over a program duration of 12 years was assumed in deriving the unit costs. It is anticipated that these costs will drop appreciably for higher launch rates, which might be anticipated in a full-scale space shuttle program.
- It was assumed that the Agenas will be purchased by NASA directly from LMSC. No dual-agency program management, such as was experienced on the Gemini-Agena program, would be incorporated on the Agena space tug.
- The development program for the Agena space tug was assumed to include one flight test; consequently, costs of one flight test article and its associated operations are included; however, no charge was made for the use of the space shuttle during this flight test.
- It was assumed that six sets of shuttle interface equipment to accommodate the Agena space tug would be purchased; five of these would be for flight purposes and one set would be used as backup.
- A 4-year development span was assumed.
- All costs in current dollars

The Agena space tug development program includes the design, integration, systems engineering, and test of the mission-peculiar and shuttle compatibility required changes. Interface design includes all cargo bay hardware, interfaces with the space shuttle, all GSE, and the shuttle/Agena software interface. The development test program verifies the functional and operational readiness of Agena and shuttle interface hardware and software.

As mentioned above, a 4-year development span is anticipated. The peak annual funding level is $16 million.

Important cost elements included in the Agena tug costs are as follows:

- Services and software that are mission peculiar; that is, those services that enable the Agena space tug to fly a particular mission with a particular payload (Such services would include guidance software, documentation, and mission plans.)
- Launch costs for the Agena only; that is, the costs of sustaining the Agena launch crew and any facilities and GSE required to support Agena operations only

Specific cost elements omitted from this analysis were prime contractor fee (however, subcontractor fees were included), Government program management costs, Government costs for mission control, and costs incurred for space shuttle launch operations and launch site operations.

The estimated average recurring-production cost for an Agena space tug vehicle is approximately $3.4 million at a production rate of 6 per year. Figure 2-20 presents vehicle costs for higher production rates. The $3.4 million cost was derived by first creating a work breakdown structure (WBS) incorporating all the major hardware elements and services common to the Agena space tug. This WBS detailed Agena tug hardware down to the seventh level. The WBS was used as a guide in estimating a bottom-up cost for the lowest indentured levels in the WBS. These input cost data were in the form of labor hours by classification, material dollars, and subcontract dollars. The sources of information used to generate these costs included a historical study of the Gemini Agena Target Vehicle (performed for NASA/MSC by LMSC under contract NAS9-10902) as well as other more contemporary Agena vehicle costs.

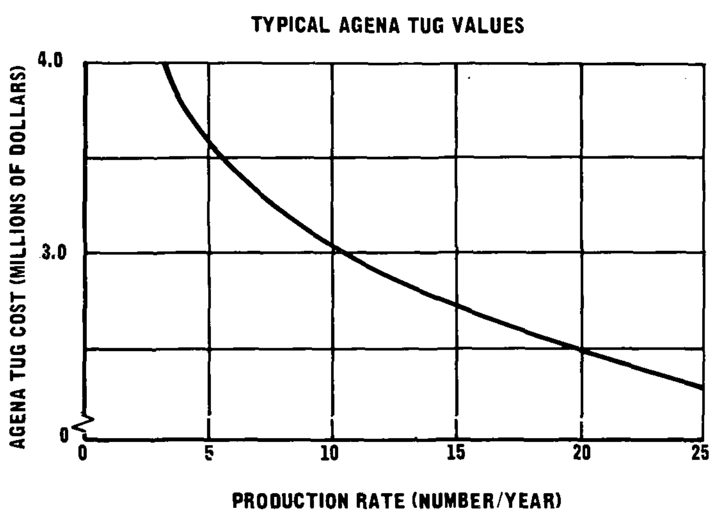


Fig. 2-20 Agena Space Tug Cost Vs Production Rate

Bottom level cost inputs were key punched and supplied as inputs to LMSC's computer program DBANK. The DBANK program then converted the elements of cost to dollar costs by WBS entry using current rates and applicable ratios (such as the ratio of quality assurance to manufacturing and test planning to test operations). Finally, the logic of the DBANK program summed the costs upward by levels to give a total recurring production cost at level three.

To cross-check the Agena space tug recurring cost estimate, a special analysis was conducted to compare the historically derived costs of the Gemini Agena Target Vehicle (GATV) with those of the Agena (Table 2-3). This reconciliation was performed by averaging the total recurring costs for six GATVs to get a per unit cost. These costs, in 1964 to 1966 dollars and rates, were converted to current-year dollars through use of typical inflationary factors for the aerospace industry between the years 1965 to 1971. The next step in the analysis was to subtract all of the costs of hardware carried on the GATV that were not applicable to the Agena space tug version. These included such items as the secondary propulsion system and the complex communications system of the GATV. It was also necessary to subtract the costs of assembling and testing the GATV. In place of these costs, appropriate values based on current Agena costs were added to represent the hardware, assembly, and test costs peculiar to the Agena space tug. Finally, the management, engineering, and support costs for the GATV were reduced in proportion to the ratio of tug hardware costs to GATV hardware costs.

As Table 2-3 indicates, the reconciled unit cost for the Agena space tug came out to within $10,000 of the estimated cost. This represents a difference of a fraction of 1 percent and thus adds credence to the estimates.

Table 2-3

RECURRING PRODUCTION COST RECONCILIATION

	($ Millions)
Calculate Average GATV Cost	$\frac{29.409}{6} = 4.901$
Convert to Current Dollars	4.901 x 1.4 = 6.861
Subtract Inapplicable GATV Hardware Costs	6.861 - 1.4 (1.560) = 4.677
Subtract Inapplicable GATV Assembly and Test Costs	4.677 - 1.4 (0.414) = 4.097
Subtract Proportionate Share of GATV Management, Engineering, and Support Costs	4.097 - 0.47 (3.267) = 2.562
Add Agena Space-Tug-Peculiar Hardware/Assembly/Test Costs	2.562 + 0.677 + 0.184 = 3.423
Compare to Derived Agena Space Tug Estimate	Δ = 3.423 - 3.413 = 0.010

Recurring operations costs for the Agena space tug vehicle are broken into two major categories: launch operations and services, and flight operations and services.

The launch operations costs, reflecting the prelaunch sequences defined during the study, are estimated to cost approximately $640,000 for an average unit, on the basis of six launches per year. Higher launch rates will reduce this figure. The methodology used in deriving these costs is very similar to the approach used in deriving the recurring-production costs. Detailed costs on the GATV, as derived under contract NAS9-10902, were used in estimating the launch operations and associated base support functions. These costs were adjusted downward to account for the fact that the Agena space tug prelaunch operations would be simpler than the GATV and would require less facilities and GSE support.

The flight operations costs of $135,000 were based on GATV experience adjusted for the fact that the Agena space tug would require support only during ascent whereas the GATV required 5 days of mission operations support. As noted earlier, the mission operations support costs include only the participation of Lockheed personnel at the Mission Control Center. Government costs for this operation are not included, nor are costs for the manned space tracking network.

2.7 NONRECURRING COSTS

It is estimated that the nonrecurring (RDT&E) costs for the Agena space tug vehicle and its supporting equipment will total approximately $40 million, as shown in Table 2-4. This analysis is based on the development and qualification plans for the Agena space tug outlined elsewhere in this presentation. The methodology used in deriving the estimate was similar to that for the recurring costs. Special emphasis was placed on identifying the major tasks, the major test hardware and operations, and the shuttle interface equipment required to bring the Agena space tug to an operational status. A bottom-up costing methodology was applied and the DBANK program was used to sum costs in an indentured WBS format.

Table 2-4
NONRECURRING COSTS

Agena Space Tug Vehicle System		($ Millions)
Structures		0.451
Propulsion		0.631
Electrical Power		0.216
Guidance and ACS		0.361
Communications		1.082
GSE		5.533
Systems Engineering Integration		12.970
Program Management		2.741
Facilities		0.731
Test Hardware and Operations		9.550
Tooling and STE		2.667
Support		1.665
	Subtotal	38.598
Shuttle Orbiter Interface Equipment		1.871
	Total	40.469

For the Agena space tug costs, the subsystems development costs are relatively low. This reflects the fact that the Agena space tug requires relatively few new items of hardware. The systems engineering and integration costs are fairly high. This is because systems integration, particularly integration of the Agena with the shuttle, requires considerable analysis and documentation. Reliability and quality functions must take into account the necessity to operate inside the cargo bay of the manned space shuttle vehicle. Engineering and manufacturing support services must generate new drawings and procedures. Engineering analyses must also reflect the change from expendable launch vehicles to the space shuttle. Test plans must be written to cover shuttle-peculiar tests. The line item of systems engineering and integration also includes the design (but not the fabrication) of the shuttle orbiter interface equipment; the fabrication of this interface equipment is broken out as a separate item below.

In the same way that the recurring costs were reconciled against the GATV unit costs, an analysis has been conducted to relate the nonrecurring costs of the Agena space tug to those of the GATV (Table 2-5). The methodology used in this reconciliation was to convert the nonrecurring costs of the GATV to 1971 dollars. Then the costs for subsystems developments made under the GATV program, such as the Model 8247 engine and the Model 8250 secondary propulsion system, were subtracted from this total. After GATV subsystem developments had been removed, the tug subsystem development costs were added back. The costs for designing and fabricating the shuttle interface equipment were also added, as were the costs for the single flight test of the Agena space tug (there was no comparable flight test of the GATV).

The difference between this reconciled estimate and the derived estimate for the Agena space tug amounts to approximately $1.7 million, or roughly 4 percent. This appears to be a very reasonable correlation.

Table 2-5
NONRECURRING COST RECONCILIATION

	($ Millions)
Calculate GATV Nonrecurring Cost in Current Dollars	52.741 x 1.4 = 73.837
Subtract Inapplicable Subsystem Developments (e.g., Propulsion, TT&C) and Services	73.837 - 43.284 = 30.553
Add Tug Subsystem Development	30.553 + 4.757 = 35.310
Add Shuttle Interface Equipment Design and Fabrication	35.310 + 2.772 = 38.082
Add Flight Test Hardware and Operations	38.082 + 4.070 = 42.125
Compare to Derived Agena Tug Estimate	Δ = 42.125 - 40.469 = 1.683 ($\approx$+4%)

2.8 EVOLUTIONARY STAGE COSTS

For the improved Agena vehicle, recurring production costs were derived by using the same methodology that was used with the baseline Agena space tug. The cost difference between the improved Agena and the baseline configuration is approximately $450,000, making the total cost of the improved Agena approximately $3.86 million. Principal differences in hardware costs between the improved Agena and the baseline version occur in the structures cost; this includes the cost for a larger propellant tank and a larger forward equipment rack. Electrical power system costs differ by virtue of the increased amount of wire harness required on the improved Agena. Other cost differences between the improved Agena space tug and the baseline version are in subsystems installation and checkout (predominantly the final assembly), sustaining engineering/program management, and GSE and facilities maintenance costs.

The improved Agena space tug recurring-operations costs of $845,000 per average unit differ by only about $60,000 from the operations costs of the baseline Agena vehicle. Cost differences are experienced in the vehicle servicing operations required for the larger improved Agena vehicle and in logistics costs (specifically the cost of propellants). There are no differences in flight operations and services costs between the improved Agena and the baseline Agena space tug.

The estimated nonrecurring cost of $47.7 million for improved Agena space tug development reflects a program in which tug evolution incorporates those relatively small costs required to increase the diameter of the Agena vehicle and to upgrade its propulsion system to a specific impulse of 310 sec. The increase in costs for going directly to the improved Agena space tug rather than to the baseline version amounts to only about $7.2 million. WBS entries principally affected by the incorporation of the improved Agena space tug include structures, tooling, GSE, and systems engineering and management. Specific cost items covered include the design of a large propellant tank and forward rack; the design and fabrication of the tooling necessary to build these items and to assemble the increased size vehicle; the cost of ground support equipment to service and handle the vehicle; and costs for documenting and analyzing the new configuration.

2.9 COST COMPARISON

The improved performance capability of the evolutionary stage can be obtained (Table 2-6) on a recurring cost basis for less than a 10 percent increase in price over the Agena space tug recurring cost. Similarly, the development costs for this stage are only about 15 percent more than the development costs for the Agena space tug.

In both categories, the cost difference is because of the larger tanks and diameter of the evolutionary stage. All other key items, such as the subsystems, propellants, operational procedures, and space shuttle interface, are common to the two stages.

It is recognized that the evolutionary stage will require a modified support cradle for cargo bay mounting. However, this cradle will be only a modification of the one designed for the Agena space tug. The design conditions for the two cradles are the same, since the space shuttle cargo bay load constraint of 65,000 lb, due east, applies equally to both vehicles.

Table 2-6
AGENA SPACE TUG VERSUS EVOLUTIONARY STAGE COSTS
($ Millions)

	Agena Space Tug	Evolutionary Stage	Cost Difference
Recurring			
Recurring Production Cost (Average Unit)	3.413	3.858	0.445
Recurring Operations Cost	0.645	0.709	0.064
Flight Operations and Services	0.135	0.135	0
Nonrecurring			
Vehicle System	38.598	45.791	7.193
Shuttle Orbiter Interface Equipment	1.871	1.871	0

Section 3
SPACE SHUTTLE DESIGN REQUIREMENTS

The following key space shuttle/Agena space tug interface requirements are equally applicable to the evolutionary stage. The support structure for both vehicles is based on the same design approach, with the major difference being the accommodation of the larger, 10-foot-diameter evolutionary stage. Four structural hardpoints are required in the cargo bay to provide for attachment of the support structure. If different length support structures are required to accommodate various payload configurations, several sets of hardpoints will be needed. However, only four would be used for each space shuttle flight.

The requirement for on-pad and on-orbit emergency propellant dump makes it necessary to route overboard lines through the orbiter aft section structure to exit points in the primary engine area. These dump lines should be between 1-1/2 and 2 inches in diameter.

A small thrust vector is required to provide for propellant settling during on-orbit emergency dump. This vector must be along the X-axis of the space shuttle, with a magnitude of 1×10^{-2} to 1×10^{-3} g. This vector could be supplied by operation of either the space shuttle OMS or ACS systems.

The combined prelaunch and flight electrical energy need is nominally 18 kw-hr at a maximum of 400 watts of steady-state power. This energy and power requirement is well within the orbiter capability.

On the pad and prior to liftoff the cargo bay ambient temperature should be no more than 75°F. This temperature level was established to allow for a cargo bay cooling system failure on the pad. The Agena environmental qualification document (LMSC 61170, dated 25 February 1969) gives an upper temperature limit for ambient conditions of 125°F under full solar irradiation conditions. The Agena space tug design is in full compliance with LMSC 61170.

A signal conditioning interface is required between the Agena space tug computer and the orbiter data bus or other data management system. This interface is needed to provide for checkout and safety monitoring and control at the Agena console at the mission specialist's station and to provide for an Agena stage vector update by the orbiter just prior to Agena/payload deployment.

If mission trajectory or orbit injection accuracies require it, optical windows must be provided in the cargo bay door to permit on-pad azimuth alignment of the Agena computer. This could be accomplished by direct line of sight if the cargo bay doors were open prior to liftoff.

Section 4
RECOMMENDED FOLLOW-ON STUDIES

During the course of the study, the possible follow-on tasks enumerated below were identified.

Atmospheric Abort: The space shuttle may be required to abort a mission at any time between liftoff and Agena/payload deployment in orbit. Possible abort modes include flybacks, downrange landings, and once-around maneuvers. The implications of the presence of the Agena space tug as part of the payload in the cargo bay need to be identified and assessed and the resulting interface and vehicle design requirements identified.

Minimum Interface: Since the Agena uses earth storable propellants, it is conceivable that the Agena could be transported in the space shuttle cargo bay with no plumbing interface between the Agena and the space shuttle. The primary areas of concern are the safety effects on shuttle operations of no provisions for Agena propellant vent or dump and the structural considerations for landing with a fully loaded Agena following a mission abort.

On-Orbit Checkout and Deployment: Checkout of the Agena space tug and its deployment involves several different sequences and interfaces. These include deployment sequences and timelines, crew involvement, orbiter software effects, and Agena checkout timelines.

Support Equipment Conceptual Design: Several items of equipment for operational support of the Agena space tug have been identified. This equipment would be installed either in the cargo bay or in the orbiter itself. The present study has established conceptual feasibility and has produced the preliminary design for the equipment to be located in the cargo bay. A firm study guideline limited Agena/shuttle interface definition beyond the Agena/payload service panel. Therefore, additional work is needed in such areas as emergency dump line routing, preliminary design of the Agena service console located in the mission specialist station, and the Agena/payload software interface with the orbiter.

Agena Space Tug Payload Support: Of the more than 320 Agena flights, over 80 percent have been in a spacecraft configuration performing earth orbit missions of from 2 weeks to more than 1 year. In the spacecraft configuration the Agena has furnished continuous support to the payload. Such support typically included orbit insertion and maneuvers, guidance and attitude control, navigation, electrical power, data management, discrete commands, and communications.

For application to space shuttle operations the Agena could, in addition to the above-listed functions, support the payload during flight readiness and predeployment checks. This task would identify items of equipment and functions that are common between the payload and the Agena for both orbital checkout and flight operations. The payload weight and cost savings would be determined for these Agena/payload combinations and the utilization by the payload of available Agena functional capability.

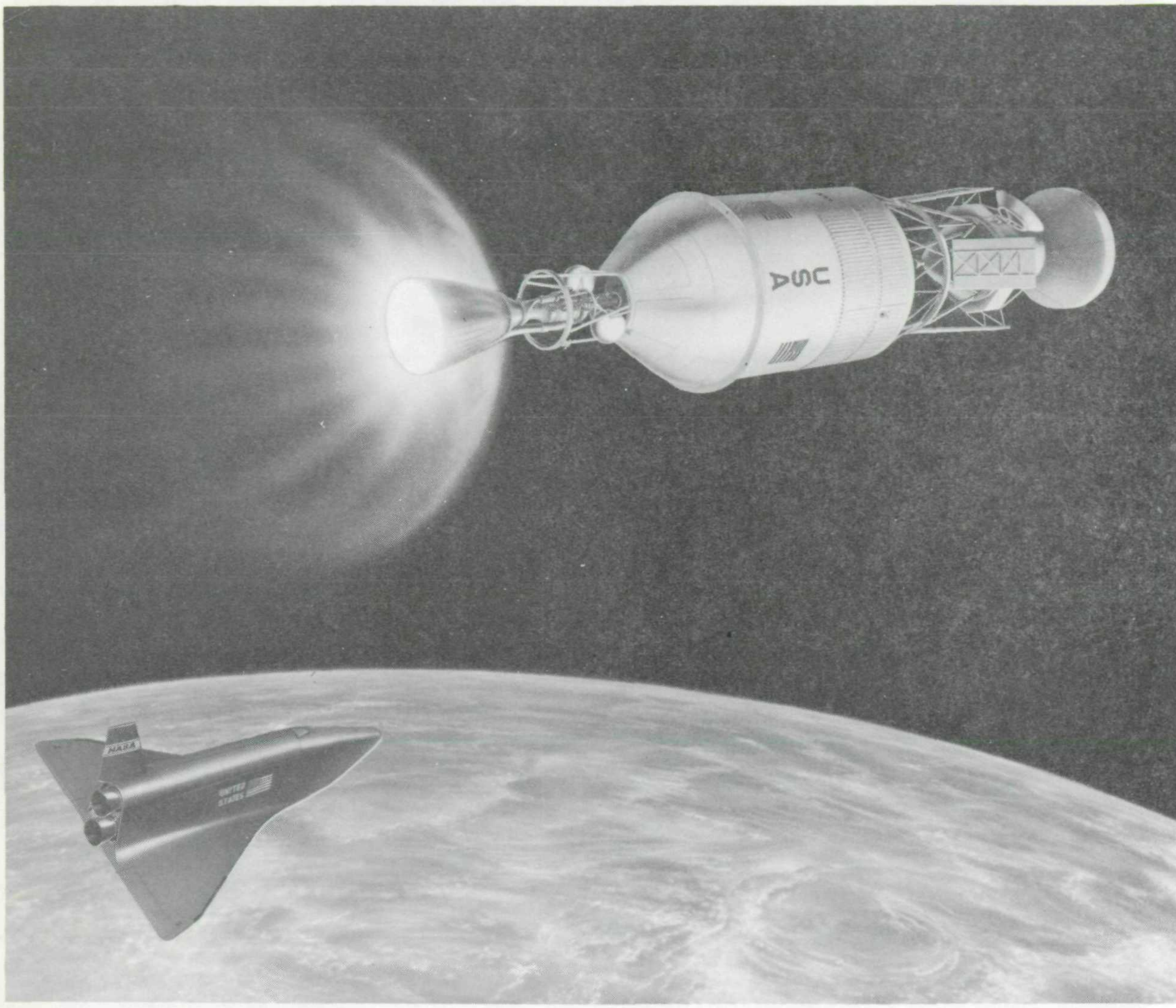
Safety Analysis: A more detailed safety analysis is needed to identify all critical hazards and to establish feasible remedial or corrective measures. This analysis should include all ground operations through liftoff, ascent, and orbital deployment. Hazards incident to mission abort and the corresponding Agena safing requirements should also be included.

Mockup Support of Orbiter Design: As the orbiter design work moves into Phase C it will be necessary to establish certain cargo bay interface requirements more firmly. Among these are Agena/payload support structure attachment point locations and loads, the location of the Agena/payload service panel, routing of emergency dump lines, accessibility both on pad and on orbit, and vehicle installation and alignment problems. The above data and resulting orbiter design requirements can be developed with the aid of structural mockups and cargo bay layouts.

Tandem Agena Space Tug: A preliminary investigation shows that a marked payload capability increase can be obtained by utilizing a fully configured and stripped Agena in a tandem arrangement. Two tandem Agena space tugs and a payload can be mated and carried in the cargo bay and inserted into a 28.50-degree inclination, circular, 100-nm altitude orbit. Only one shuttle flight is required. The evolutionary stage also shows the same potential for payload performance gain by a tandem stage arrangement. Candidate configurations should be established and evaluated in terms of performance and cost.

Improved Agena Space Tug: A firm guideline for the existing study was to utilize existing hardware and technology with no allowance for improvements or technology development. The introduction of 1976-1980 technology advances and higher energy storable propellants will produce even higher Agena space tug and evolutionary stage payload performance. The tradeoff between these performance advances and the resulting cost increases should be evaluated and promising concepts introduced into the Agena space tug and evolutionary stage designs. Space shuttle interface effects would then be determined and final recommended concepts established.

Agena Retrieval and Refurbishment: The economic advantages of retrieval, refurbishment, and reuse of the Agena space tug and evolutionary stage should be determined. This task would involve identification of any required Agena changes, determination of any effects on the established shuttle interface, definition of retest needs, determination of the reliability and safety impact, and definition of economic advantage.



Evolutionary Stage With Mars-Viking Payload

LOCKHEED MISSILES & SPACE COMPANY, INC.
A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

LMSC
SPACE SYSTEMS
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