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THE SOVIET SURFACE-TO-SURFACE GUIDED MISSILE SCUD (SS-1B)(C)

S-9428

MIS 24-63
MAY 1963

PREPARED BY

U.S. ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA

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SENSITIVE SOURCES AND METHODS INVOLVED

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(S) FOREWORD (U)

(S) This report is an analysis of the SCUD SS-1b Surface-to-Surface Guided Missile System, and represents an evaluation of intelligence information available through May 1963. This document was prepared by the Directorate of Missile Intelligence, U. S. Army Missile Command.

25X1C [redacted]

(U) Comments or queries regarding the material contained in this report should be submitted to the Commanding General, U. S. Army Missile Command, ATTN: AMSMI-Y, Redstone Arsenal, Alabama.

(S-NOFORN) TABLE OF CONTENTS (U)

1 [redacted] LIST OF GRAPHICS (U)

X1 [redacted] LIST OF TABLES (U)

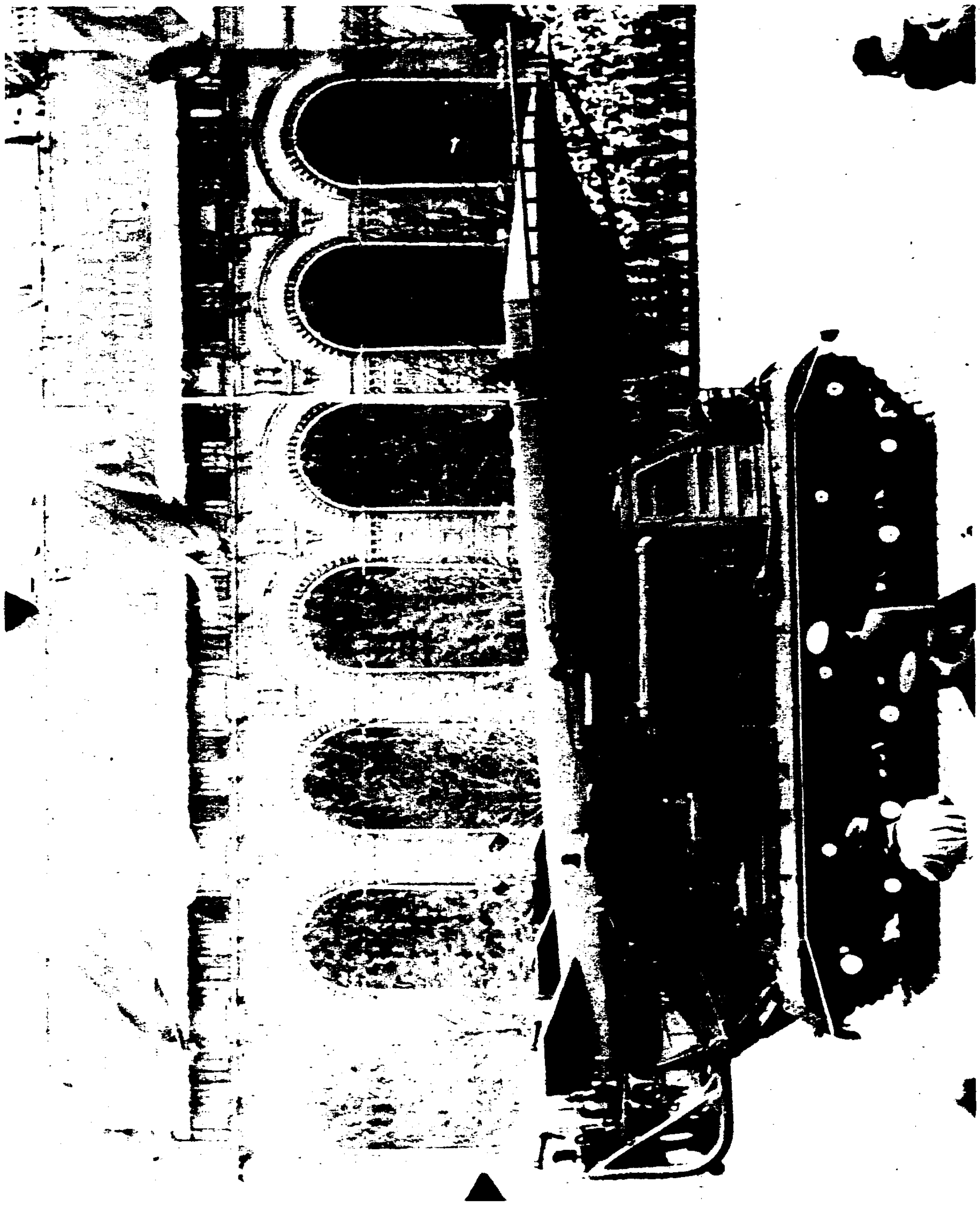

Figure 1. (CONFIDENTIAL) Moscow Parade Photograph, 1 May 1960 (U)

I. [redacted] GENERAL SYSTEM DESCRIPTION (U)

A. [redacted] Introduction (U)

The Soviet Union has developed a second generation 150 nm missile system identified as the 8A61. This missile is designated the SS-1b and has been nicknamed SCUD A by western intelligence. It is a replacement for the Soviet V-2 type 150 nm missile.

[redacted] The SCUD A was first seen in the 1957 May Day parade. This probably dates the beginning of the development period in the 1953-1954 time period.

[redacted] Intelligence information verifies that the SCUD A is heavily deployed in the Soviet Union, lightly deployed in GSFG and possibly deployed in other Bloc countries.

[redacted] The SCUD missile is a highly mobile, extremely reliable, tactical weapon. It is transported, erected and launched from a transporter-erector-launcher.

B. [redacted] System Characteristics (U)

The SS-1b (SCUD A) is a single-stage, surface-to-surface, all-inertial, guided ballistic missile. It employs a storable propellant combination of red fuming nitric acid (containing 18-22% N_2O_4) and kerosene. In addition, a starting fuel, "Tonka", is used (50% ksilidin and 50% triethylamine). The trajectory for the all-inertial system is determined from a preset program and cutoff is determined by a velocity seeker. The tankage section is a full-monocoque welded construction, while the aft skirt and fins are of semi-monocoque riveted construction.

[redacted] Three types of warheads exist for the SCUD: chemical, high-explosive, and nuclear. The warheads are attached to a structural member at the forward end of the tankage section. When fired with the 1550 lb high-explosive (HE) warhead, the missile has a maximum range of 160 nm. With a nuclear warhead, the missile has approximately half range capability. The nuclear warhead weighs approximately 2500 lbs and has a 10 to 15 kiloton yield. In future references within this study, it will be assumed that the 1550 HE warhead is in the missile, unless otherwise indicated. (i.e., with reference to lift-off weight, burnout weight, etc.)

[redacted] A brief summary of missile characteristics and performance data is listed below. The photographs (Figures 1 and 2) taken in the 1 May 1960 parade were used, along with other intelligence information, in determining system description and performance characteristics.

Missile length	34.4 ft
Diameter	2.85 ft
Range (max)	160 nm
Thrust (vac)	21,500 lbs
Specific impulse (vac)	256

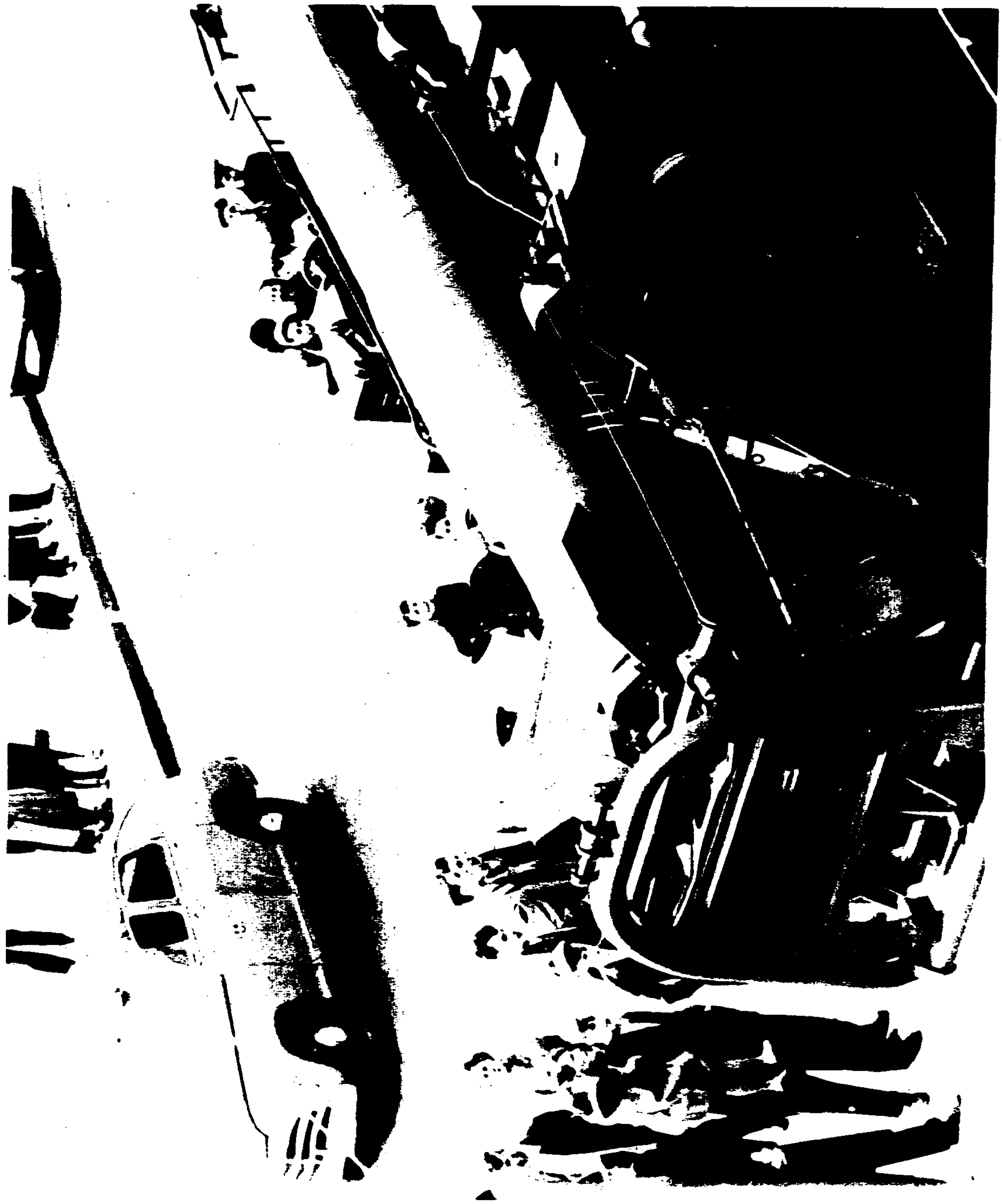

Figure 2. (CONFIDENTIAL) Photograph of Aft End of SCUD Missile in Moscow Parade, 1 May 1960 (U)

Propellant flow rate	84 lb/sec
Duration of thrust	92 secs
Lift-off weight	11,728 lbs
Burnout weight	4000 lbs
Cutoff acceleration	4.6 G's
Apogee	41 nm
Flight time	315 secs
Cutoff velocity	4958 ft/sec
Cutoff angle	36.5 degrees

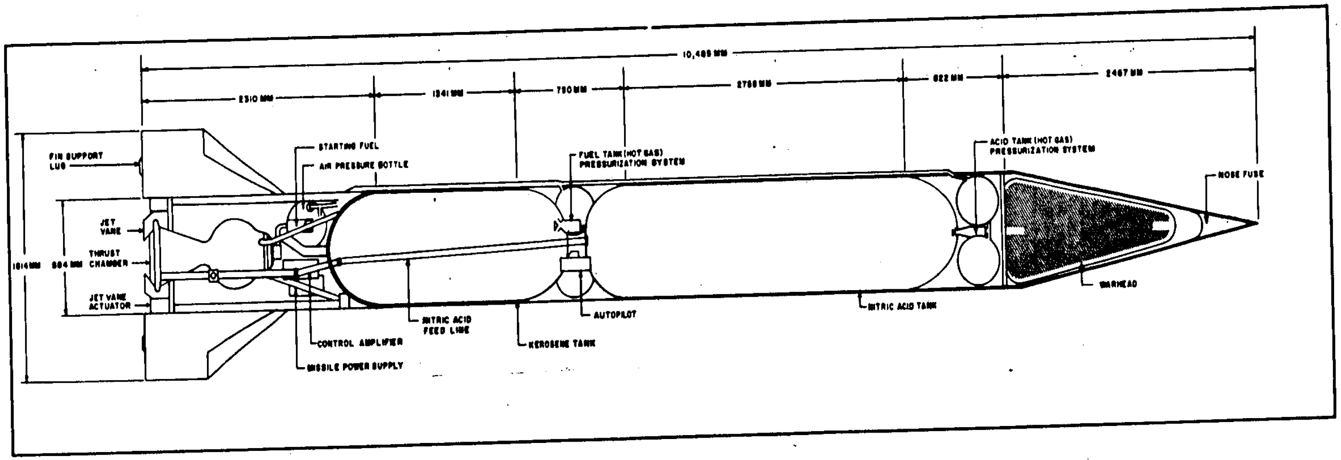

Figure 3. (SECRET-NOFORN) Inboard Profile (U)

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II. [redacted] MISSILE CHARACTERISTICS (U)

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A. [redacted] General (U)

SCUD A employs an all-inertial guidance system that remains inertially fixed to the local horizontal and azimuthal orientations of the launch point. It has four carbon vanes, located in the jet exhaust, which are mechanically deflected by steering motors, for control purposes. The missile developes a vacuum thrust of 21,500 pounds and burns for a total of 92 seconds. The carrier vehicle consists of several main subsystems; the airframe, guidance and control, propulsion, propellant systems, missile power, and pneumatic systems.

1

B. [redacted] Airframe (U)

1 [redacted] The SCUD airframe can be divided into the following sections: (a) nose, (b) forward tank (oxidizer), (c) instrument compartment, (d) rear tank (fuel), and (e) tail section. (See Figure 3 for schematic.) The nose section houses the warhead and fuse assembly.

1 [redacted] The forward transition section houses the hot gas pressurization system of the oxidizer pressure tank.

1 [redacted] The forward and aft tank sections contain the missile propellants. Stainless steel (0.081 inch thick) is used to withstand the 500 psi tank pressure of the hot gases from the gas generator pressurization systems. The tankage section is a full-monocoque structure consisting of a shell and additional frame support members. The missile skin serves as the tank wall. The tanks are separated by a center transition section. All subsections of the tankage are welded together to form a complete unit. An oxidizer line runs through the fuel tank to the tail section. A conduit is located on the outside of both tanks to carry the electrical cables and pneumatic lines to center and nose sections.

1 [redacted] The center transition section contains an access door. Part of the missile guidance and the hot gas pressurization system of the fuel pressure tank are contained in this transition section.

1 [redacted] The tail section skirt is a semi-monocoque riveted structure consisting of a structural frame and a thin sheetmetal covering. The loads of this section are carried by the framework, and the skin acts mainly as an aerodynamic cover. The thrust is transmitted from the engine through a welded frame mount of steel tubing to the aft support ring which is bolted to the aft skirt and to the tankage section. The tail section **encloses** the propulsion unit and provides fin surfaces and trim tabs for the missile. In addition, the tail section houses the electrical components of the control system, part of the guidance system, and the main power supply unit.

1 [redacted] The engine uses a liquid bi-propellant, has a sea level thrust of 18,500 lbs, and is assumed to be an uprated German Wasserfall type.

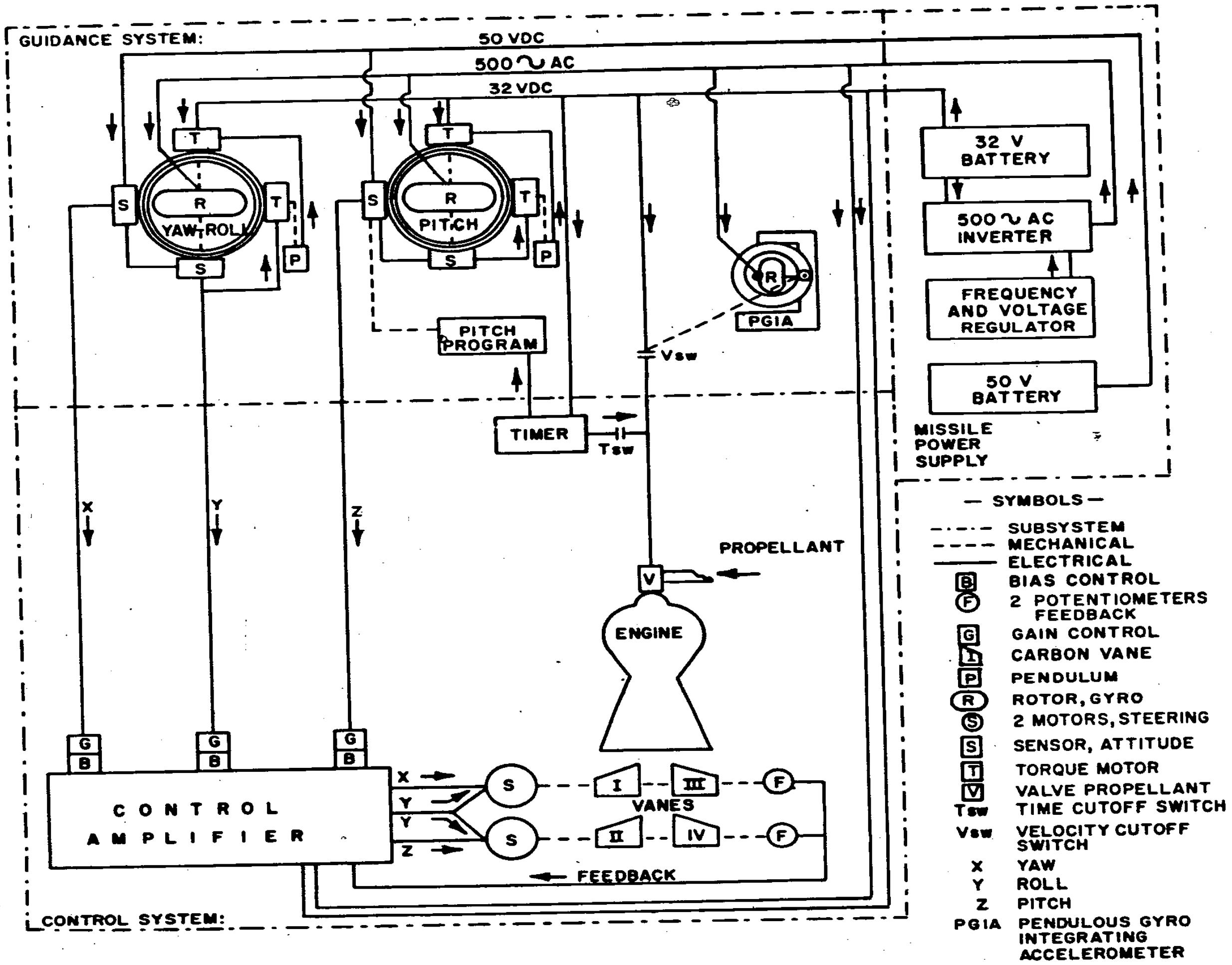

Figure 4. (SECRET-[redacted] Block Diagram of SCUD Guidance and Control System (C)

C. ([redacted] Guidance and Control (U)

1. [redacted] General (U)

The SCUD employs an all-inertial guidance system that remains inertially fixed to the local horizontal and azimuthal orientations of the launch point. During the thrust phase these orientations are inertially maintained. All outside control is removed at launch. Attitude deviations are detected by an autopilot, cutoff velocity is detected by an integrating accelerometer, and attitude and trajectory control are maintained by a control amplifier through steering motors and jet vanes. For a graphic description of the guidance and control system see the block diagram (Figure 4).

2. [redacted] Guidance System (U)

The autopilot consists of a baseplate, two gyros, a pitch gyro programmer, and an integrating accelerometer. The baseplate is mounted to the airframe in the instrument compartment between the propellant tanks. This baseplate contains reference flanges for the mounting alignment to the airframe, missile vertical erection, and inertial component alignment.

a. [redacted] Gyros (U)

The two gyros of the SCUD autopilot are basically copies of those used on the German LEV-3 (V-2) autopilot; that is, they are a two-degree-of-freedom, non-synchronous, ball bearing type.

(1) [redacted] Yaw-roll Gyro (U)

The yaw-roll gyro is mounted on the baseplate with its spin axis perpendicular to the local vertical and to the firing azimuth. (This spin axis orientation permits the missile to program in pitch without affecting the yaw-roll reference.) An electromechanical pendulum and torque motor align the outer gimbal parallel to the local vertical. The spin axis is aligned perpendicular to the outer gimbal by a torque motor and bridged potentiometers. The inner gimbal potentiometer provides the roll attitude signal and the outer gimbal potentiometer provides the yaw attitude signal.

(2) [redacted] Pitch Gyro (U)

The pitch gyro is mounted on the baseplate with its spin axis perpendicular to the local vertical and parallel to the firing azimuth. An electromechanical pendulum and a torque motor erect the outer gimbal parallel to the local vertical. A torque motor and inner gimbal bridged potentiometers align the spin axis perpendicular to the outer gimbal. (This alignment eliminates yaw cross-coupling while roll cross-coupling can be tolerated to the mechanical limit of the gimbal freedom, approximately ± 20°.) The bridged potentiometer of the outer gimbal axis is programmed around the pitch axis of the autopilot by a pulsed d-c motor.

1 b. [redacted] Pitch Gyro Programmer (U)

The pitch gyro programmer consists of a step motor, sliprings, and bridged potentiometers. Pulses of d-c current from a timer energize the step motor and the pitch attitude potentiometer body is mechanically displaced around the pitch axis of the autopilot. (The potentiometer wiper is attached to the outer gimbal of the gyro.) Programming of this potentiometer does not affect the gyro's ability to detect missile pitch attitude deviations, but this displacement introduces an attitude signal in the pitch control circuits. This attitude signal will cause the missile to pitch over until this sensor is nulled. The pitch program, during the thrust phase, is controlled by this timer and the rate and duration of the program is based upon the selected range.

1 c. [redacted] Integrating Accelerometer (U)

The integrating accelerometer of the SCUD autopilot is a pendulous gyro integrating type. This thrust cutoff device is a velocity seeker that measures acceleration, integrates acceleration for velocity information, and initiates cutoff. This device is so mounted on the baseplate that longitudinal missile acceleration is sensed and, at a predetermined velocity, the cutoff circuits initiate thrust termination in a single command.

1 d. [redacted] Baseplate (U)

The baseplate of the SCUD autopilot is somewhat triangular in shape, has an adjustable capability on at least two of the three points of support, and contains two machined flanges that are used for plumbing the missile after erection. The gyros and the accelerometer are initially aligned to these flanges and these machined surfaces are used as a reference for aligning the autopilot to the firing azimuth.

1 3. [redacted] Control System (U)

The control system consists of the control amplifier, four steering motors for the carbon jet vanes, four jet vanes, four feedback potentiometers, the timer, the propellant cutoff valve and trim tabs. The control system uses d-c attitude signals from the autopilot to control steering rudder movement by a magnetic control amplifier.

1 a. [redacted] Control Amplifier (U)

The magnetic control amplifier consists of a preamplifier, mixer, and power amplifier for each of the three attitude signals. Provisions are made to utilize rudder position signals (feedback). The attitude and feedback signals are mixed and amplified by the preamplifiers to provide sufficient amplitude for mixing with a constant phase source in the mixer. Integrating networks of the preamplifier also provide rate and displacement information for the mixer. The mixer determines the amplitude by comparing the incoming signal with a constant phase source and the amplitude is the result of rectification and filtering. The mixer output is amplified by the power amplifier to energize the control relay of the steering motors.

X1 b. [redacted] Steering Motors (U)

The four steering motors are electrically-driven oil pumps controlled by a polarized control valve. The control valve is synchronized with the polarity of the attitude signals to provide vane deflection needed for yaw, roll, and pitch. The steering motor consists of a d-c motor, an oil pump, and a free-floating piston. The motor runs continuously and provides an oil pressure through the oil pump to the piston cylinder. The piston's position, through linkage, determines the angular deflection of the carbon vanes. The control valve is a polarized relay that provides directional control of the oil flow to the cylinder. The control amplifier output is applied to each of the four control valves and the polarity of the controlling voltage determines the direction while the amplitude determines the angular deflection of the carbon vanes.

1 c. [redacted] Carbon Vanes (U)

The carbon vanes, located in the jet exhaust, are mechanically deflected by the steering motors. The carbon vanes control the missile in yaw, roll, and pitch; Vanes I and III in yaw, Vanes II and IV in pitch, and all four in roll. Two potentiometers are spindle connected to each of the four carbon vanes to provide a position signal for the control amplifier and also for test purposes prior to launch.

1 d. [redacted] Timer (U)

The timer supplies the time reference for the pitch program and the burning time limit for the engine. (This timer is believed to be synchronized to the inverter frequency; that is, the 10th subharmonic of 500 cps.)

e. [redacted] Propellant Cutoff Valve (U)

The cutoff valve terminates propellant flow on command of the velocity switch (PGIA) or the time switch (timer). Normally the velocity switch terminates propellant flow after the missile obtains cutoff velocity; however, should the PGIA fail to detect cutoff velocity, the timer terminates propellant flow prior to depletion.

f. [redacted] Trim Tabs (U)

The use of trim tab control on the aerodynamic fins has not been ascertained, but their utilization would be desirable. A close examination of the SCUD photographs indicates trim tabs on the rear portion of the fins; however, this is not positive because of the detail of the photography. During the thrust phase, carbon vane erosion will introduce false torques into the control system. The guidance and control system is capable of detecting and correcting these torques, but if trim tabs are used, the correction torques needed for the carbon vanes would be reduced.

1 4. [redacted] Guidance and Control Checkout (U)

1 [redacted] The SCUD guidance and control system undergoes many tests, alignments, and checkouts before launching.

1 [redacted] Components of the guidance system are tested individually and as a system. The gyros and accelerometer are removed from the missile during horizontal checkout, but replaced before the missile is erected on the launch table. The guidance system functioning is tested with the control system to insure proper polarization, gain, and synchronization. The integrating accelerometer's capability to terminate thrust is also tested prior to and after the missile is erected on the launch table. For further checkout procedures see **Section** V.

1 [redacted] The control system does not correct for lateral and slant range errors during the thrust phase. Lateral errors due to wind shear forces are determined from firing tables and met data and corrections in azimuth are made prior to launch. Slant range errors are minimized by a nearly constant engine thrust; therefore, providing a flight trajectory that closely approximates the desired trajectory. A test sequence program is applied to the overall control system to insure that:

(a) The polarity of the attitude signals is correct.

(b) The synchronization of the carbon vanes provides roll control.

(c) The pitch program is started, locked-in, and terminated for the selected range.

(d) The emergency shutdown circuits are actuated.

(e) The **fuze**-arming signals occur at the predetermined time after lift-off.

(f) The thrust is terminated by an on-board timer (92 seconds after lift-off) if the integrating accelerometer has not detected cutoff velocity.

(g) The necessary final **fuze**-arming signals are applied to the warhead.

5. [redacted] Autopilot Erection and Alignment (U)

When the missile is erected on the firing table with Fin I aligned downrange, two levels are placed on the autopilot baseplate reference flanges. The missile is leveled by a triangular leveling frame of the firing table (see Figure 26). The final aiming procedure employs the reference flanges of the autopilot and a collimator (Section V, paragraph E). A prism is employed to transfer (optically) the autopilot reference to the carbon vanes.

[redacted] The final aiming procedure requires that the autopilot be energized and erected; that is, the gyros running and the gimbals aligned to their preset positions. The control amplifier must also be operating to center-position the carbon vanes. The pendulums of the gyros detect the local vertical and maintain the autopilot earth-fixed; therefore, the control system will center-position the carbon vanes. This guidance and control system's holding capability is remotely observed. A prism is mounted on and aligned with Fins I and III and the collimator is employed to monitor the fin's reference. After the autopilot compartment is closed, the autopilot's erection capability is remotely observed by the collimator and the prism. This observation is conducted throughout pre-launch checkout and up to the moment of launch. The prism mounted on Fins I and III may be removed before ignition; however, the prism is believed to be expendable.

D. [redacted] Propulsion System (U)

The power plant of the SCUD missile is a bi-propellant liquid rocket engine. The thrust is generated for a period of 92 seconds. The desired thrust is maintained by a chamber pressure loop. Energy for this thrust is provided by red fuming nitric acid (containing 18-22% N_2O_4) and kerosene. Iodine is added to the acid to inhibit corrosion. A small concentration of iodine additive results in a negligible decrease in performance.

[redacted] The combustion chamber cooling system consists of point connections for distribution of the nitric acid within the chamber walls. The chamber has a combined cooling system (circulation cooling and internal cooling -- a vapor curtain). This cooling system permits the maintenance of 930-1110°F temperature.

[redacted] The pressure in the compressed air tank located in the engine compartment (Figure 3) is equal to 3000 psia. A reducer lowers this pressure to 550 psia (this pressure is used to force the hot gas components into the gas generator, and the starting fuel into the injector).

[redacted] The propellants are pressurized and transferred from the missile tanks to the engine combustion chamber by gases from two hot gas pressurization systems. (See paragraph E below.)

[redacted] In summary, the propulsion system consists of the following components:

1. Combustion chamber.
2. Fuel tank.
3. Fuel feed assembly.
4. Oxidizer tank.

5. Oxidizer feed assembly.

6. Distribution net.

7. Tank pressurization assemblies.

8. Engine control assembly (pyrovalves, diaphragms, pressure relays, throttle unit, and the like).

9. Engine assembly (piping system, delivery discs, and feed and drainage valves).

10. Atomizers (ball-valve type, jet and centrifugal). The orifice diameters are from 0.002 to 0.079 inches.

1 E. [redacted] Propellant System (U)

The propellant system transfers the fuel (kerosene) and oxidizer (nitric acid) from the missile tanks to the thrust chamber under pressure. The systems consist of two hot gas generator systems, two tanks, two on-off control valves, a throttling control valve, piping, and the engine passages.

1 [redacted] The two tanks are made from high strength stainless steel. The oxidizer tank is located above the fuel tank. The oxidizer passes through the fuel tank (by way of a pipe) to the main on-off valve. After passing through this valve, the oxidizer enters the coolant manifold. This section directs the engine coolant fluid (the oxidizer in this case) around the nozzle and up through the engine wall to the injector. Fuel flow is direct to the injector head through the main on-off valve. The engine temperature and chamber pressure variations operate the automatic throttle to vary fuel comsumption.

1 [redacted] A propellant tank pressurization system supplies a pressure of about 500 psia for the oxidizer and fuel tanks. An investigation of a simple compressed air pressurized propellant feed system was conducted in an effort to determine the applicability of such a system. The study revealed that a simple on-board pressurized feed system would impose severe weight penalties on the SCUD missile. In addition it was found that the missile does not have the necessary free volume to carry the required pressure bottles. A minimum of 24.9 cubic feet is necessary as a gas volume requirement. This also imposes a weight penalty of approximately 500 pounds. Therefore it is felt that two hot gas generator pressurization systems are the best candidates for a propellant pressure feed system.

1 [redacted] It is assumed that a hydrogen peroxide gas generator is used for the acid tank. The steam and oxygen gases from this reaction are compatible with the nitric acid at tank gas temperatures of 500-700°F. At lower temperatures the steam would condense to water and dilute the acid. At higher temperatures a prohibitive tank wall thickness would be required to contain the pressure. Higher temperature would also cause decomposition of prohibitive amounts of N_2O_4 in the acid.

[redacted] An ethylene oxide gas generator is assumed to be used for the fuel tank. The methane and carbon monoxide gases from this reaction are compatible with the kerosene fuel. A heating coil is attached to the head of this gas generator, near the injector, for ignition of the ethylene oxide.

[redacted] Nitrogen is used for pressurizing gas for the hydrogen peroxide and ethylene oxide containers. The nitrogen gas is stored in a sphere in the engine compartment.

[redacted] It is also a possibility that fuel could be used as a coolant. There is enough fuel left as residuals for this purpose. However, nitric acid was chosen as a coolant based on U.S. state-of-the-art and also on the fact that the German Wasserfall and Soviet R-113 engines use nitric acid to cool the engines. (There is a great similarity between the Wasserfall, R-113 and SCUD). The missile parameters would be altered very little if fuel was used.

F. [redacted] Main Power and Pneumatic Systems (U)

A main missile power supply (MPS) is utilized in the SCUD missile to supply electrical power for the guidance system and hydraulic power for pneumatic valves. Alternating current is supplied by a rotary inverter, while hydraulic power is supplied by a d-c motor-pump combination. The MPS is located in the engine compartment along with part of the guidance system and pressurization system. Hydraulic and nitrogen pressure lines and cables are routed to intertank and nose section through the outside cabling duct.

G. [redacted] Performance Analysis (U)

1. [redacted] General (U)

[redacted] The initial phase of the missile performance analysis consisted of calculating the design parameters of the SCUD A missile that would be required for a trajectory analysis. The results of this trajectory analysis were required to perform an aerodynamic heating analysis, to determine the drag coefficient, and to provide "g" loadings for use in the airframe stress analysis.

[redacted] For the trajectory, an estimate of the propellant weight was made and thrust chamber parameters were determined. Using these estimated values, the propellant tank pressure needed was calculated. Estimates were then made of the weight of the propulsion components, tank pressurization system, main power supply, guidance system, and warhead. Calculations were performed (see Appendix II) to determine the aerodynamic heating during re-entry of the entire vehicle.

[redacted] The results of this analysis, together with the estimated component weights and thrust level, were used as a basis for the first estimate of the airframe weight. Figures 1 and 2 were used to determine the skin thickness based on wrinkles and dents in the skin, the locations of riveted and welded sections of the skin, and the size of the welded joints. The trajectory analysis (Appendix I) was performed utilizing the preliminary performance parameters, weights, and an estimated drag coefficient. Ranges of 150 and 80 nm were obtained for the SS-1b (SCUD) using the conventional and the nuclear warheads, respectively (see **Figures 21 and 22**).

1 2. [redacted] Propellant Weight (U)

Utilizing the propellant tank arrangement (see Figure 3), the nitric acid weight in the forward tank and the kerosene weight in the aft tank were determined to be 6200 lbs and 1750 lbs, respectively.

1 3. [redacted] Propulsion System (U)

1 [redacted] The thrust level used as the basis for the performance calculations is considered as an approximation of the actual value. The effect of not knowing the precise thrust level of the SCUD A is not significant since missile range is not too sensitive to the exact thrust level. A thrust level of 18,500 lbs has been calculated from propulsion parameters.

1 [redacted] The only known engine available to the Soviets with a thrust in this class is the World War II German Wasserfall engine, which has a sea-level thrust of 17,600 lbs and a chamber pressure of 300 psia. However, it is doubtful that the basic Wasserfall engine is used because of the rather large size of the engine in relation to its thrust level. It is possible, however, that the Soviets have continued the development of the Wasserfall engine -- increasing the performance, and reducing the length of the engine to make it more compact. On the other hand, it is also possible that the Soviets have not made use of the Wasserfall engine and have developed a completely new engine for use in the SCUD A missile. However, it is felt that the SCUD A engine would utilize a low chamber pressure in order to use thinner chamber walls and reduce the cooling requirements. Low chamber pressures were used in the Wasserfall, the German V-2 and its Soviet counterpart, and the Soviet K-102 engine which operated at 310 psia.

1 [redacted] For the SCUD A, the thrust chamber performance calculations were based on the use of inhibited red fuming nitric acid and kerosene at an injector mixture ratio of 3.4, a chamber pressure of 355 psia, and an expansion ratio of 5.15. The corresponding nozzle exit pressure is 10.3 psia, which results in good performance, considering the burnout altitude of about 100,000 feet. The nozzle throat area was chosen to provide a sea-level thrust of about 18,500 lbs. The motor has both regenerative and film cooling systems to maintain a wall temperature of 930-1110°F.

TABLE 1. [redacted] PROPULSION SYSTEM DATA (U)

ITEM	UNITS	VALUE
Sea-level thrust	lb	18,500
Vacuum thrust	lb	21,500
Propellant flow rate	lb/sec	84
Sea-level specific impulse	sec	220
Vacuum specific impulse	sec	256
Expansion ratio	--	5.15
Mixture ratio	lbs	3.4
Chamber pressure	psia	355
Nozzle exit pressure	psia	10.3
Duration of thrust	sec	92

4. [redacted] Aerodynamic Heating (U)

A heat transfer analysis was performed (see **Appendix II**) in order to help determine the kind of material used and its required thickness to withstand the temperatures encountered by aerodynamic heating. The analysis revealed the maximum temperatures over a range of various skin thicknesses for locations along the missile beginning at the tip of the nose cone. A study of the SCUD A trajectory and its velocity revealed that aerodynamic heating was not severe until re-entry. Re-entry velocity of about 5,000 ft/sec results in an overall body skin temperature of approximately 700-900°F, and the nose skin temperature of about 1,000°F. These temperatures are critical for aluminum; therefore, stainless steel is probably used.

5. [redacted] Airframe (U)

The width of the welds seen in the photography (Figures 1 and 2) tends to support the use of stainless steel. The waviness of the aft skirt skin is indicative of thinner materiel compared to the tank sections. The heat transfer analysis (Appendix II) and the airframe stress analysis (Appendix III) support the use of stainless steel for the SCUD missile airframe.

[redacted] The airframe weight analysis was based on the assumption that the SCUD airframe is constructed of stainless steel of series type 300. Flight loads were estimated by making use of the propellant and component weights and their distribution, tank pressures, and the "g" loading curve from the preliminary trajectory. The skin temperatures at various locations along the missile were obtained from the heat transfer analysis.

[redacted] A general description of the structure of the SCUD airframe will help to clarify the results of the airframe stress analysis. The structure consists of three distinct sections; the aft skirt, the tankage section, and the nose cone (Figure 3). The aft skirt is a semi-monocoque riveted structure consisting of a structural frame and a thin sheetmetal covering. It is felt that most of the loads on this section are carried by the framework, and that the skin acts mainly as an aerodynamic cover. The thrust is transmitted through a thrust frame to the aft support ring which is riveted to the aft skirt and to the tankage section. The tankage section is a full-monocoque structure consisting of a shell and ring frames with no additional support members. The section consists of the two integral propellant tanks (the missile skin serves as the tank wall), an **intertank** transition, and a short transition section on either end. The aft transition section connects the fuel tank to the thrust unit, and the forward transition section connects the oxidizer tank to the nose cone. All the subsections of the tankage section are welded together to form the complete unit. The aft end of the warhead is attached to a conical support which, in turn, is attached to a support ring at the forward end of the tankage section. The nose cone is a metal shield which provides the proper aerodynamic configuration and protects the warhead from the heat generated during re-entry. The nose cone is connected to the tankage section just ahead of the warhead support ring.

1 [redacted] For the stress analysis, the weights of the support rings, the aft skirt, and the fins were estimated by using previous experience with similar structures constructed of steel. The weights of the tankage section and nose cone, however, were determined from the skin thickness which provided adequate margins of safety for the most critical load on the section. For the tankage sections, it was assumed that the entire section was welded up from the same thickness of stainless steel. This facilitates construction of the section, results in good welded joints, and provides adequate although not excessive margins of safety for all points along the missile. The resulting thickness for the skin and bulkheads of the tankage section is 0.081 inch, while the nose cone thickness is 0.080 inch.

1 6. [redacted] Range (U)

1 [redacted] The computation of range is based on the estimated overall missile weight breakdown as tabulated in table 2.

1 [redacted] The zero-lift drag coefficient as a function of Mach number was based upon preliminary trajectory analysis to obtain the skin friction contribution. The final trajectory analysis was performed by making use of the estimated propulsion system data, missile weight breakdown, and drag coefficient. It is seen that for the 150 nm range, the most likely warhead weight is 1550 lbs. The design characteristics of the SCUD are presented in table 2.

1 TABLE 2. [redacted] MISSILE CHARACTERISTICS (U)

Length	34.4 ft
Diameter	2.85 ft
Missile dry weight	3,778 lbs
Nose cone	1,550 lbs
(Nuclear)	2,500 lbs
Range	150 nm
(Nuclear)	80 nm
Apogee	41 nm
Burning time	92 sec

TABLE 2. [redacted] MISSILE CHARACTERISTICS (U) (CONT'D)

Flight time	315 sec
Cutoff velocity	4,958 ft/sec
Cutoff angle	36.5 degrees
Cutoff acceleration	4.6 G's
Lift-off weight	11,728 lbs*1
Fueled weight	11,775 lbs*2
Burnout weight	4000 lbs*3
Thrust	18,500 lbs
(Vacuum)	21,500 lbs
Specific impulse	220 sec
(Vacuum)	256 sec
Oxidizer	6,200 lbs*4
Flow rate	66.3 lbs/sec
Residue	100 lbs
Fuel	1,750 lbs*5
Flow rate	17.7 lbs/sec
Residue	122 lbs
Propellant flow rate	84 lbs/sec*6
Starting fuel	47 lbs

TABLE 3. [redacted] WEIGHT BREAKDOWN (U)

*1 Lift-off Weight

Airframe and nose cone weight		3,778 lbs
Oxidizer flight weight		6,200 lbs
Fuel flight weight		1,750 lbs
	TOTAL	11,728 lbs

*2 Fueled Weight

Lift-off weight		11,728 lbs
Starting fuel		47 lbs
	TOTAL	11,775 lbs

*3 **Burnout Weight**

Airframe and nose cone weight		3,778 lbs
Oxidizer and fuel residue		222 lbs
	TOTAL	4,000 lbs

*4 Oxidizer

Oxidizer flow rate: 66.3 lbs/sec

Total oxidizer burned in 92 sec		6,100 lbs
Residue		100 lbs
	TOTAL	6,200 lbs

---

*See weight breakdown (Table 3).

TABLE 3. [redacted] WEIGHT BREAKDOWN (U) (CONT'D)

*5 Fuel

Fuel flow rate: 17.7 lbs/sec		
Total fuel burned in 92 sec		1,628 lbs
Residue		122 lbs
	TOTAL	1,750 lbs

*6 Propellant Flow Rate

Oxidizer burned during flight/sec		66.3 lbs
Fuel burned during flight/sec		17.7 lbs
	TOTAL	84 lbs

H. [redacted] Warhead (U)

The SCUD missile is designed with a non-separating warhead. This warhead may be one of two existing types, i.e., a conventional HE charge or an atomic charge designated as a special warhead 8K11. These special warheads have 10 and 15 kiloton yields.

[redacted] The HE warhead consists of the nose fuze, the detonator, the explosive material, the base fuze, cables, and the fuze arming device.

[redacted] The explosive material consists of 60% trotyl (trinitrotoluene), 25% hexogen (RDX) (trimethylenetrinitroamine), and 15% aluminum. In addition to this 100% mixture, the explosive material has a 5% covering of chloronapthalene. Overall weight of the explosive charge is 1175 lbs, and the shell container of the warhead has three layers; a steel jacket - (0.1 in.), an asbestos carton, and a steel jacket (0.04 in.). By means of this protective arrangement of the warhead, the temperature at the surfaces of the explosive material does not exceed 175°F.

[redacted] The nose and base fuzes are installed and the warhead joined with the missile at the assembly point in the technical area.

III. [redacted] GROUND SUPPORT EQUIPMENT (U)

A. [redacted] General (U)

[redacted] Ground support equipment (GSE) includes all equipment used to transport, handle, test, service, and launch the missile.

[redacted] The smallest self-sustaining operational unit for this system is the battalion since the three launching batteries are dependent on the headquarters battery, the missile transport battery, and the technical battery for support. For this reason, equipment is presented by area of employment on battalion level rather than at battery level, and only vehicles and equipment that have a technical function are included.

[redacted] GSE for the SCUD missile system is both road and rail transportable. In addition, there is a capability for air resupply of missiles by either helicopter or conventional cargo aircraft.

[redacted] The basic vehicle used in ground support of the SCUD missile is the ZIL-151. The standard cargo version of this vehicle is shown in Figure 5 and the van body version in Figure 6. The ZIL-157 (standard cargo version shown in Figure 7) is used interchangeably with the ZIL-151.

B. [redacted] Missile Ground Transporter (U)

The purpose of this vehicle is to transport the SCUD A missile from the depot to the technical position; to serve as a dolly through test, checkout, fueling, and warhead installation; and to transport the ready missile to the storage area. The vehicle is a two-axle trailer consisting of chassis, front and rear cradles with rubber liners and straps, draw bar, guard rails, undercarriage, and brake mechanism. This vehicle has the following characteristics:

Load capacity	6 tons
Weight	3.2 tons
Length	32.2 ft
Width	8.9 ft
Height	5.9 ft
Ground clearance	9.8 in

[redacted] A variety of prime movers could be used to tow this trailer; however, the most likely candidate is the ZIL-151 shown in Figure 5.

[redacted] Figure 8, which shows a trailer transporter carrying a SCUD missile, is based on a photograph that was taken during a transport helicopter demonstration at the Tushino air show in 1961. The ground transporter described above is of the same general configuration but of more rugged construction.

1 [redacted] ZIL-151 STANDARD CARGO TRUCK (U)

1 [redacted] CHARACTERISTICS (U)

1.	Weight	6 short tons
2.	Wheel base	191 inches
3.	Overall length	22 ft, 9 in.
4.	Width	7 ft, 7 in.
5.	Engine	92 HP 6 cyl gasoline
6.	Speed	41 mph
7.	Cruising range	413 miles
8.	Payload	5.2 short tons
9.	Towed load	4 short tons

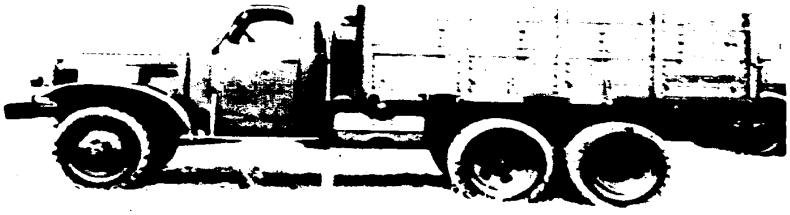

Figure 5. (UNCLASSIFIED) ZIL-151 Standard Cargo Truck (U)

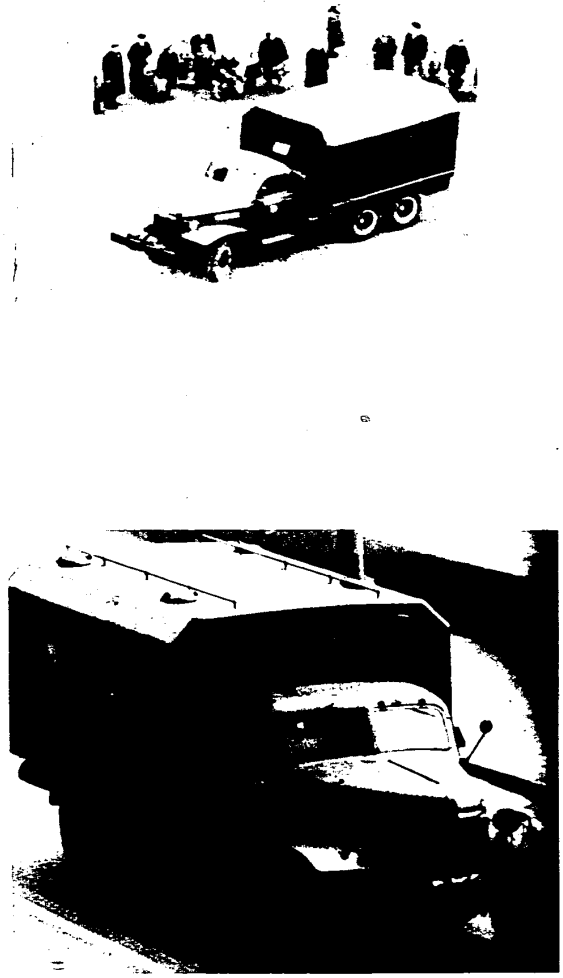

Figure 6. (UNCLASSIFIED) ZIL-151 Van Body Truck (U)

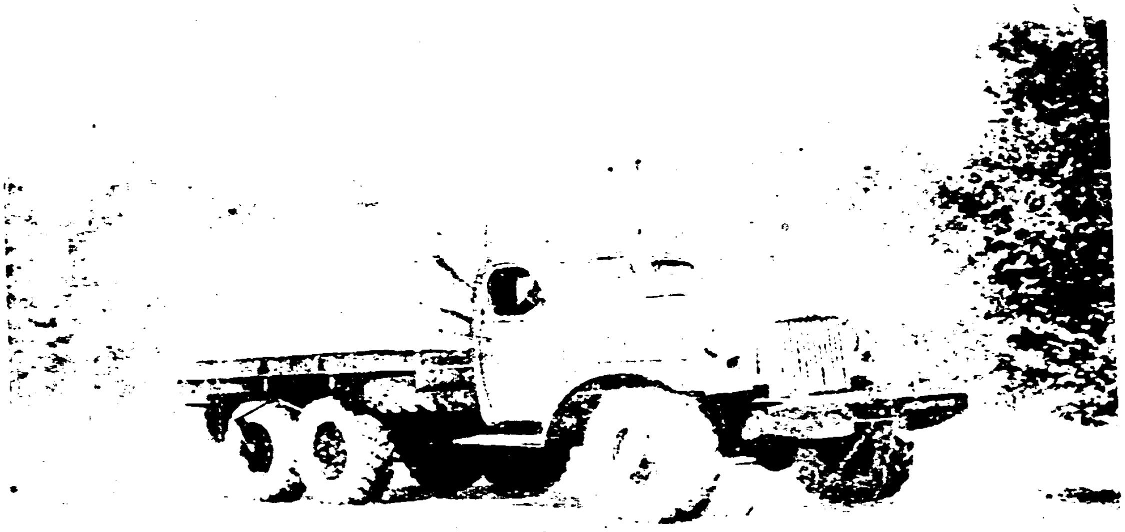

Figure 7. (UNCLASSIFIED) ZIL-157 Standard Cargo Truck (U)

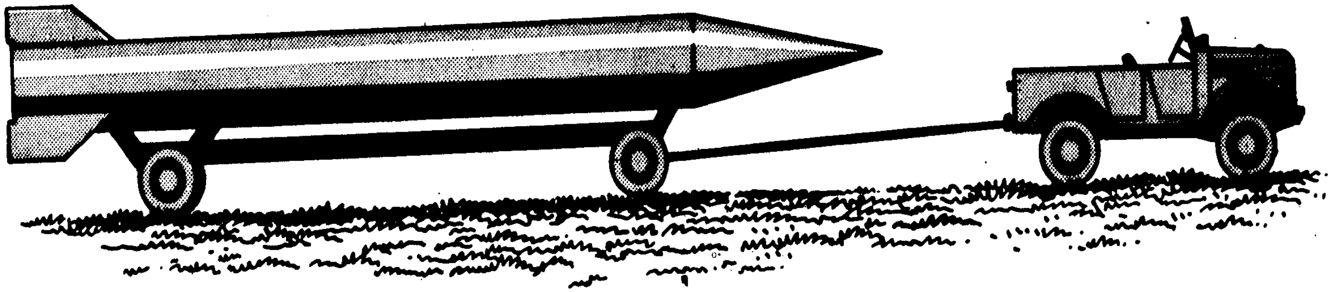

Figure 8. (CONFIDENTIAL) Missile on Transporter, Line Drawing (U)

1 C. [redacted] Propulsion System Test Equipment (U)

This equipment is mounted in the van body of a ZIL-151 truck similar to that shown in Figure 6. The purpose of the equipment is to provide a capability for a complete pressure testing of the propulsion system and its components. The equipment consists of manometers, a voltmeter, and an ammeter. Also included is equipment for filling the spherical tanks in the missile with compressed air to check the correct setting of the reducer, stands, piping, valves, etc.

1 D. [redacted] Electrical System Test Equipment (U)

The electrical system test equipment, like that for the propulsion system test, is mounted in the van body of a ZIL-151 truck similar to that shown in **Figure 6.** Included in this van is a console and a mock-up of the missile electrical system for checkout of guidance system components, and a console for checking insulation of the cable net. Guidance system checkout includes check of pickup current of steering motors, check of functioning of the autopilot, and check of accelerometers.

E. [redacted] Air Compressor Unit (U)

This unit is used for filling the missile propellant tanks with compressed air and for pressurizing the air bottles on the transporter-erector-launcher (TEL) (230 to 350 atmospheres). The unit includes the power plant, compressor, air system, cooling system, regenerating unit, oxygen-water condenser, moisture absorber, and control panel. The unit is mounted on a ZIL-151 truck and has the following characteristics:

Overall weight	10 tons
Weight w/o ZIL-151	3.5 tons
Air delivery	53 cu ft/min
Engine	55 to 60 HP
Compressor speed	1250 to 1800 rpm
Maximum speed of vehicle	25 mph
Range (governed by fuel)	400 miles

[redacted] A photoelectric automatic moisture indicator is used to control the humidity of the air delivered by the compressor or from the bottles. It consists of a measuring head with cooling system, an electronic unit, a power unit, and a front cover. The measuring head consists of a measuring mirror, illuminating bulbs, two photoelements, two objectives, and diaphragms. The cooling system consists of a throttle, a coil, a preheater, and a heat transfer unit. The power unit is fed with a 220 volt source.

[redacted] Also included as part of the air compressor unit is an air preheater consisting of an electric motor driven blower, a gasoline burner, and grids through which the air is blown. The exhaust air temperature is 250°F.

X1

F. [redacted] <u>Electrical Power Supply</u> (U)

The electrical power supply for the SCUD requires two pieces of equipment in the test area. A gasoline electric generator similar to that shown in Figure 9 is used as the basic power source of 220 volt alternating current and probably has a capacity rating of 25-30 kw. The rotary converter or transformer trailer similar to the one shown in Figure 10 is used in conjunction with the generator as a source of direct current supply.

X1

G. [redacted] <u>Fuel Transporter</u> (U)

The purpose of this vehicle is to transport kerosene for the SCUD missile to the fueling site and there transfer it to the missile tank by means of the integral pumping system mounted in a compartment on the vehicle. Kerosene tanks are constructed of steel with a zinc coating. The tank and pumping system are mounted on a ZIL-151 truck chassis. This vehicle is shown in Figure 11 and has the following characteristics:

Weight loaded	10 tons
Capacity	800 gallons
Working capacity	780 gallons
Weight of contents	3 tons
Method of transfer	Pump
Maximum working capacity	95 gpm

X1

H. [redacted] <u>Oxidizer Transporter</u> (U)

The purpose of this vehicle is to transport nitric acid for the SCUD A missile to the fueling site and there to transfer it to the missile oxidizer tank by means of the integral pumping system mounted in a compartment on the vehicle. Nitric acid tanks are constructed of aluminum and aluminum alloy. The tank and pumping system are mounted on a ZIL-151 truck chassis and in general appearance would be similar to the kerosene transporter shown in Figure 11. This vehicle has the following characteristics:

Weight loaded	10.6 tons
Capacity	810 gallons
Working capacity	740 gallons
Weight of contents	3.4 tons
Method of transfer	Pump
Maximum working capacity	95 gpm

X1

I. [redacted] <u>Washdown and Neutralizing Vehicle</u> (U)

The purpose of this vehicle is to provide equipment to remove and/or render harmless any propellants spilled during transfer to the missile tanks. The unit consists of a tank and integral pumping system with hoses mounted on a ZIL-151 truck chassis. Its general appearance would not be too unlike that of a fuel transporter, and it has the following characteristics:

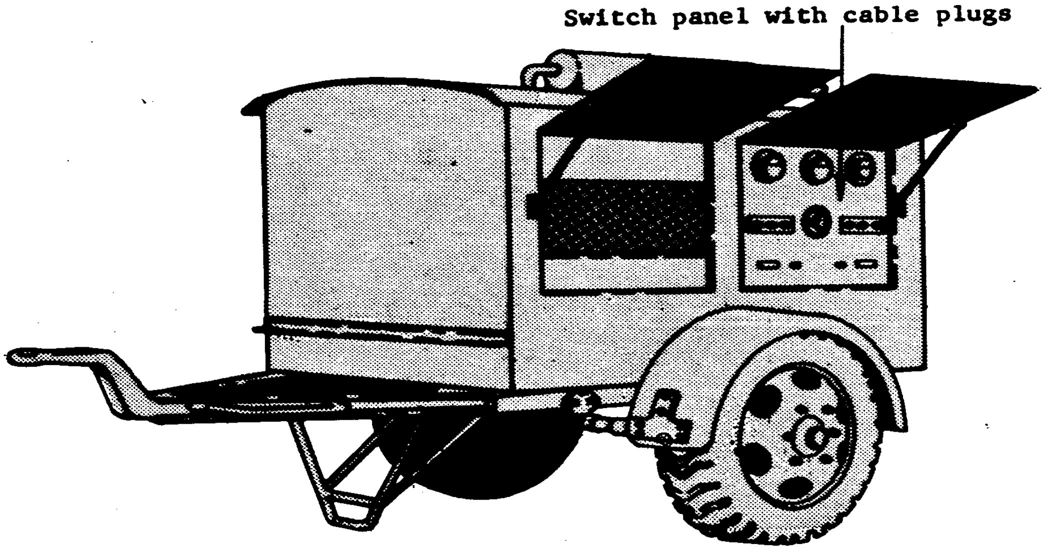

Figure 9. (UNCLASSIFIED) Electric Generator (Generator Trailer) (U)

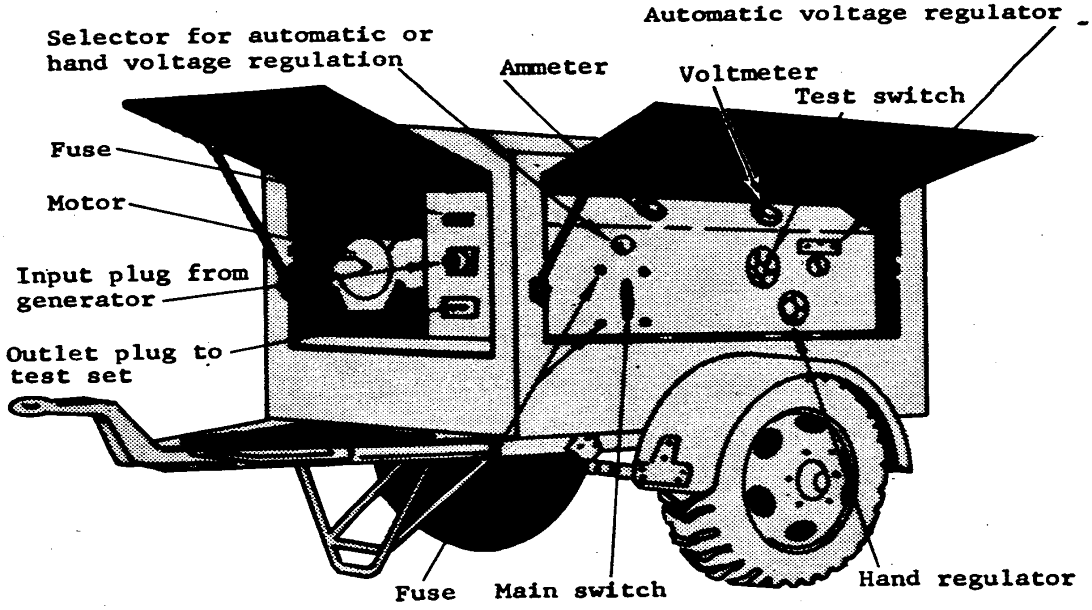

Figure 10. (UNCLASSIFIED) Rotary Converter (Transformer Trailer) (U)

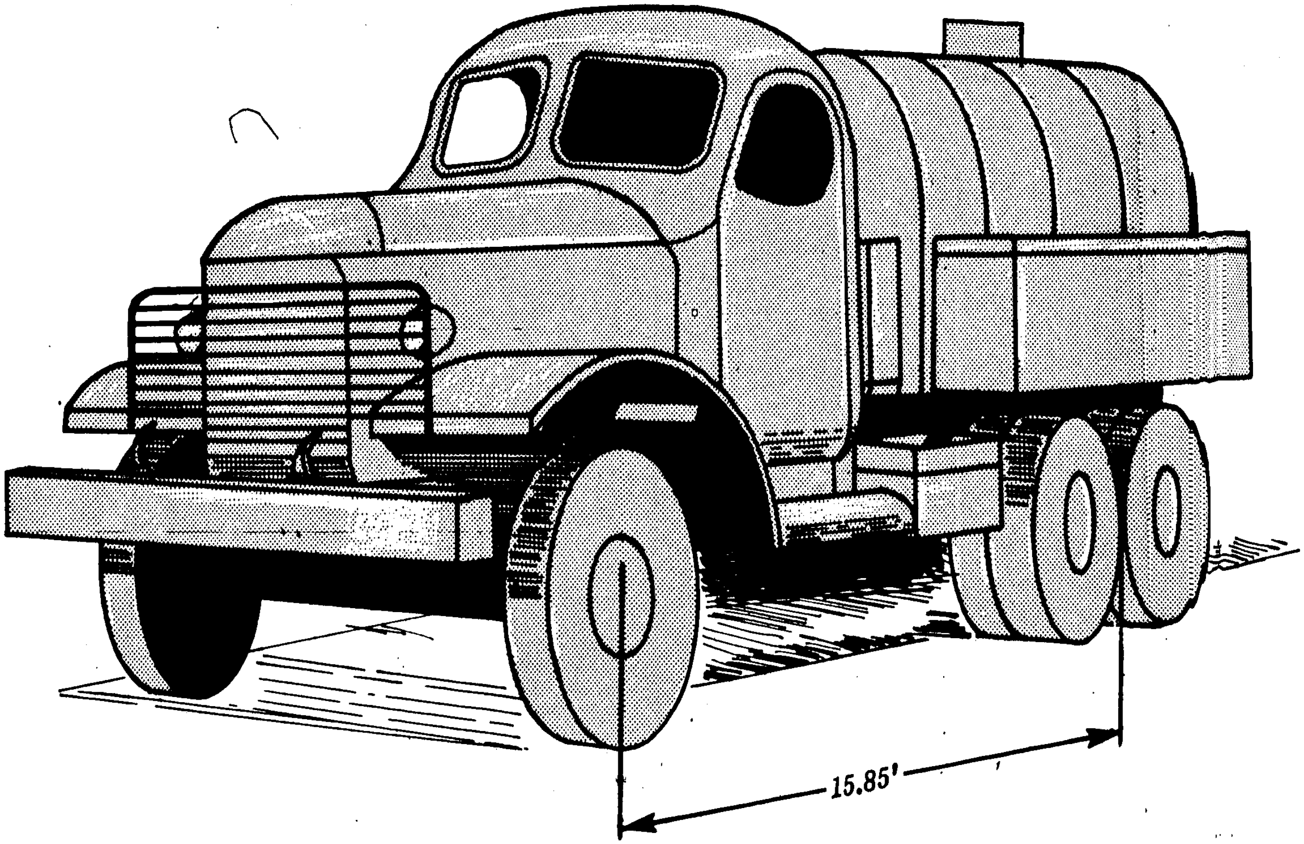

Figure 11. (UNCLASSIFIED) Fuel Transporter, Line Drawing (U)

Weight loaded	10.1 tons
Capacity	500 gallons
Working capacity	500 gallons
Weight of contents	4200 pounds
Pumping rate	250 gpm

1 J. [redacted] Fire Fighting Vehicle (U)

The purpose of this vehicle is to provide equipment for fire protection for the technical area. The unit consists of a tank, integral pumping system for filling and emptying the tank, and suction and discharge hoses mounted on a ZIL-151 truck chassis. It has the following characteristics:

Weight loaded	9.8 tons
Capacity	515 gallons
Working capacity	515 gallons
Weight of contents	4300 pounds
Pumping rate	250 gpm

1 K. [redacted] Crane (U)

The crane is a truck-tractor and semi-trailer combination as shown in Figure 12. It has a 30 kw alternating current generator and two electrically-driven motors. One motor is used to power the winch that controls the boom, and the other is used to power the winch for the hook. The crane has the following characteristics:

Weight of semi-trailer	7.8 tons
Weight of truck-tractor	14.9 tons
Length of combination	49.5 ft
Height in mobile condition	10.5 ft
Height in working position	28.2 ft
Width	11.5 ft
Maximum lifting capacity	13.7 tons
Hoisting speed	3.95 ft/min
Maximum elevation of hook	23 ft

1 [redacted] This crane is used at the assembly point in mating the warhead with the missile, and is also used to transload the missile from the ground transporter to the TEL.

1 L. [redacted] Transporter-Erector-Launcher (U)

The purpose of this vehicle is to transport the SCUD A missile from the ready missile storage area to the launch site, erect it on the launch pad, and provide facilities for final preparation and launching. It consists of: the body; engine mount; transmission; chain drive; suspension; missile booms; launch pad; test-launch equipment; aiming instruments complex; equipment for loading the missile with compressed air and starting fuel; the hoisting mechanism of the boom; general electric equipment; radio equipment, with a range of approximately 25 miles; and fire fighting equipment. The TEL

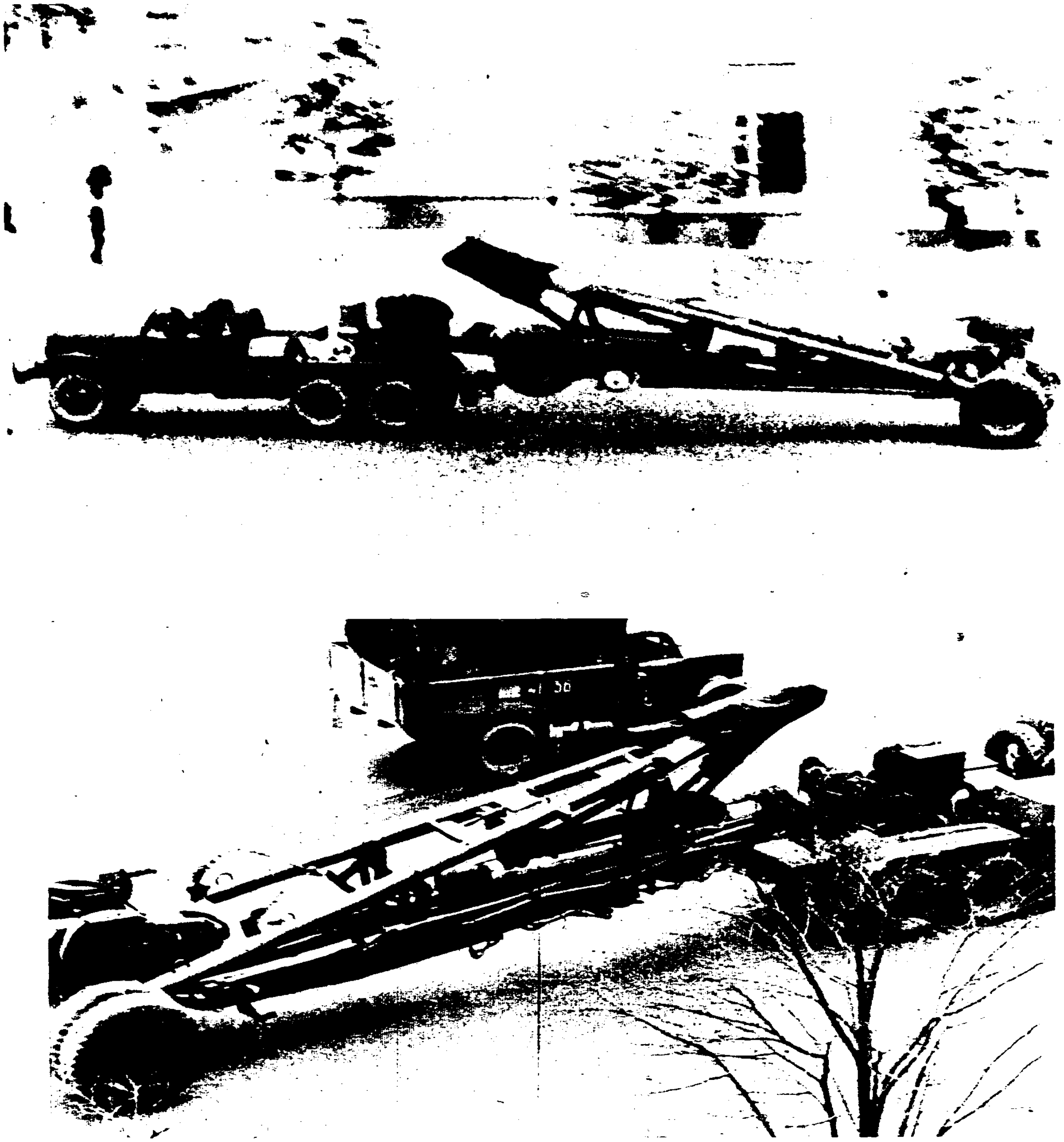

Figure 12. (CONFIDENTIAL) A-Frame Crane, Photographs (U)

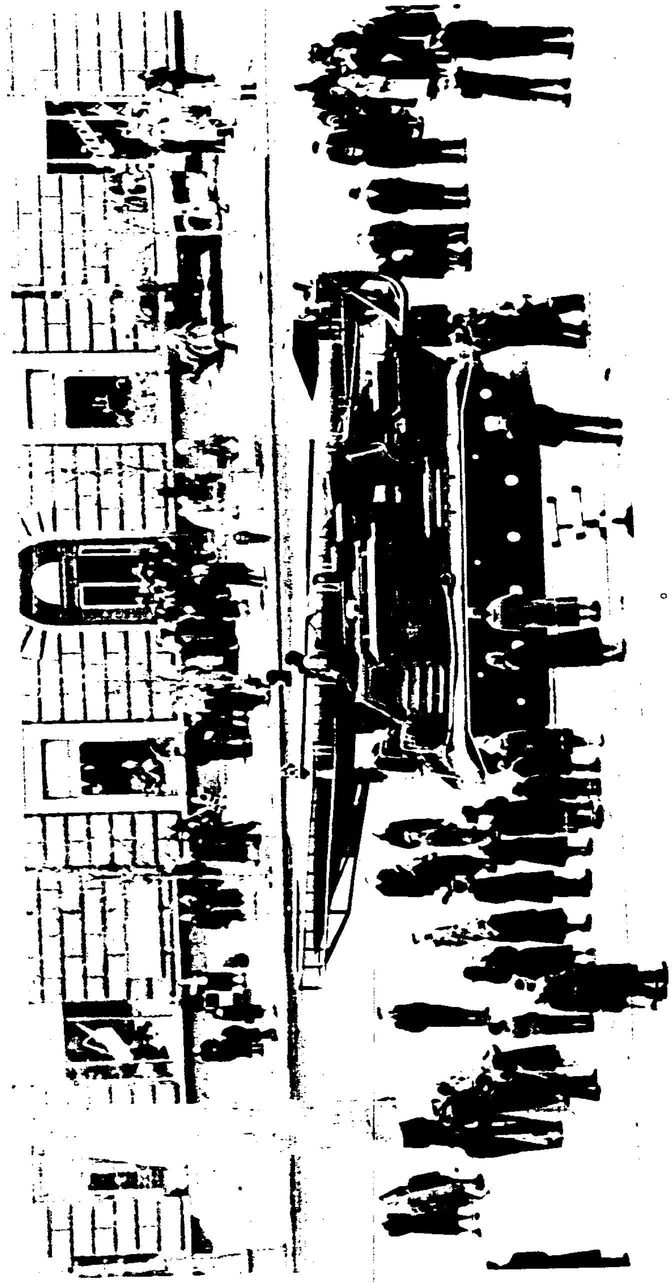

Figure 13. (CONFIDENTIAL) Transporter-Erector-Launcher, Photograph (U)

is shown in figure 13 as it appeared in a Moscow parade, and has the following characteristics:

Weight without missile	35 tons
Weight with missile	41 tons
Chassis length	23 ft
Length with boom	39.4 ft
Width	10.8 ft
Height in working position	39.4 ft
Maximum speed	26 mph
Cruising range	187 miles
Average specific pressure	0.046 lbs/sq in
Maximum ascent and descent	25 deg
Lateral angle of tilt without missile	20 deg
Lateral angle of tilt with missile	16 deg
Capacity of tanks - fuel	234 gals
Capacity of tanks - oil	34 gals
Capacity of tanks - water	22 gals
Engine - 12 cyl tank diesel	520 HP
Fording depth	4.6 ft

(U) Figure 14 shows the TEL with the missile in the launching position, with the boom in the vertical position.

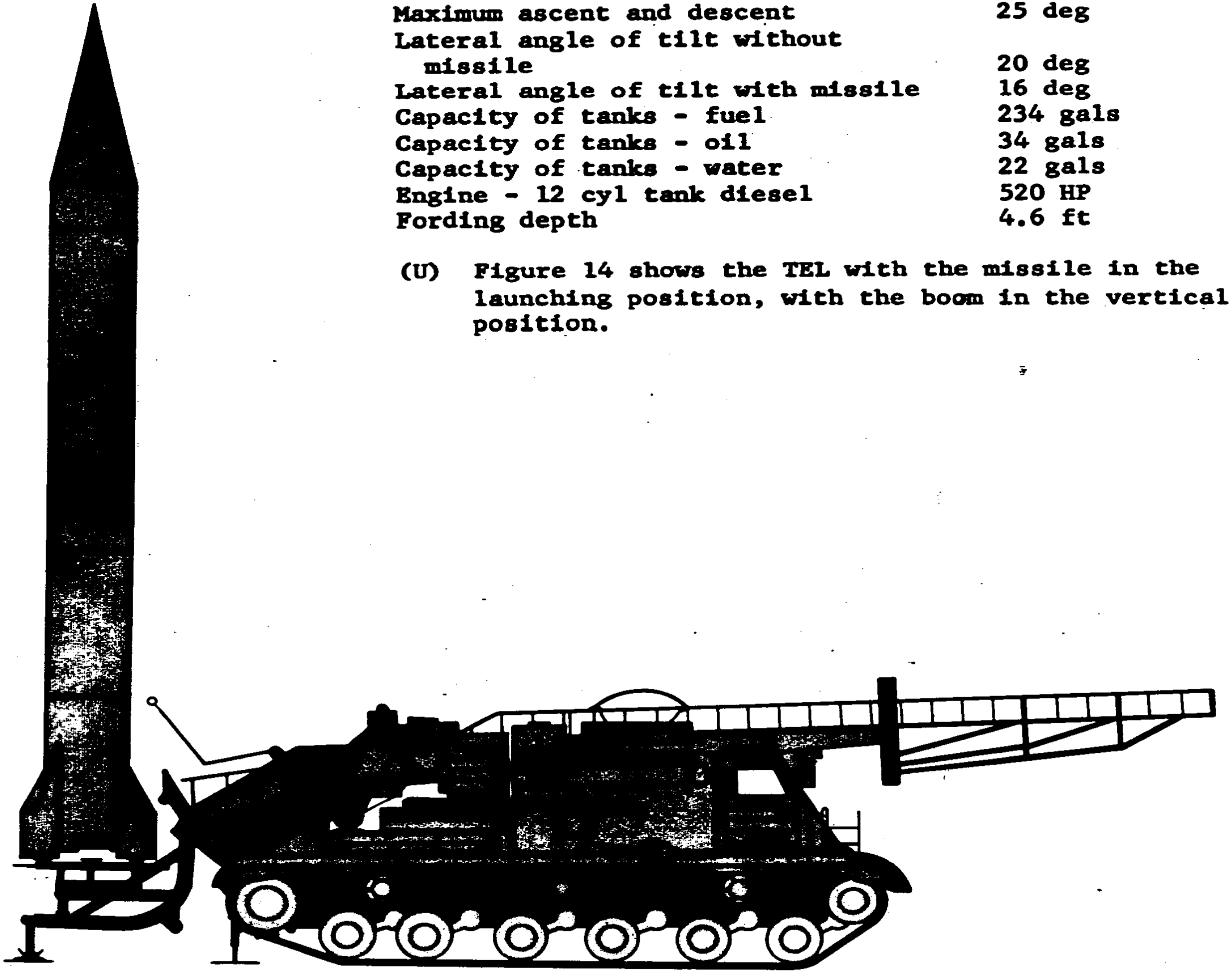

Figure 14. (CONFIDENTIAL) Transporter-Erector-Launcher with Missile in Launch Position (U)

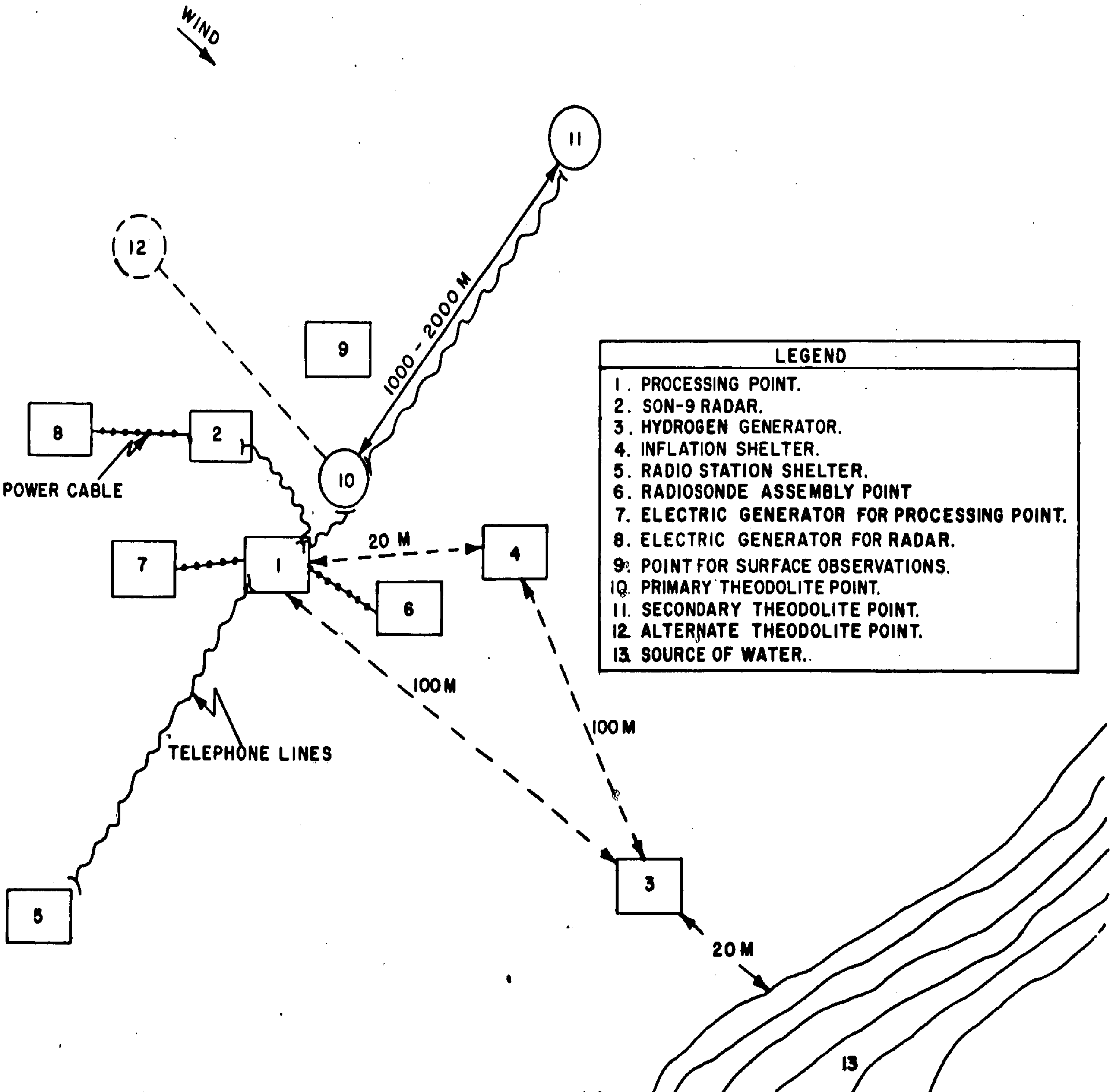

Figure 15. (SECRET) Typical Layout of Met Station (U)

5X1

M. [redacted] Meteorological Equipment (U)

The meteorological station of the SCUD missile system is part of the equipment operated by a platoon of the battalion headquarters battery. The basic equipment for this station is carried in a ZIL-151, with a van body similar to the one shown in Figure 6, and includes standard thermometers, psychrometers, aneroid barometers and wind measuring devices. This vehicle serves as a processing point and is designated as a mobile met office. Vehicles for a meteorological platoon probably include one mobile met office; two cargo trucks, each towing an electric generator; and a radar with prime mover. An assumed typical station layout is shown in Figure 15.

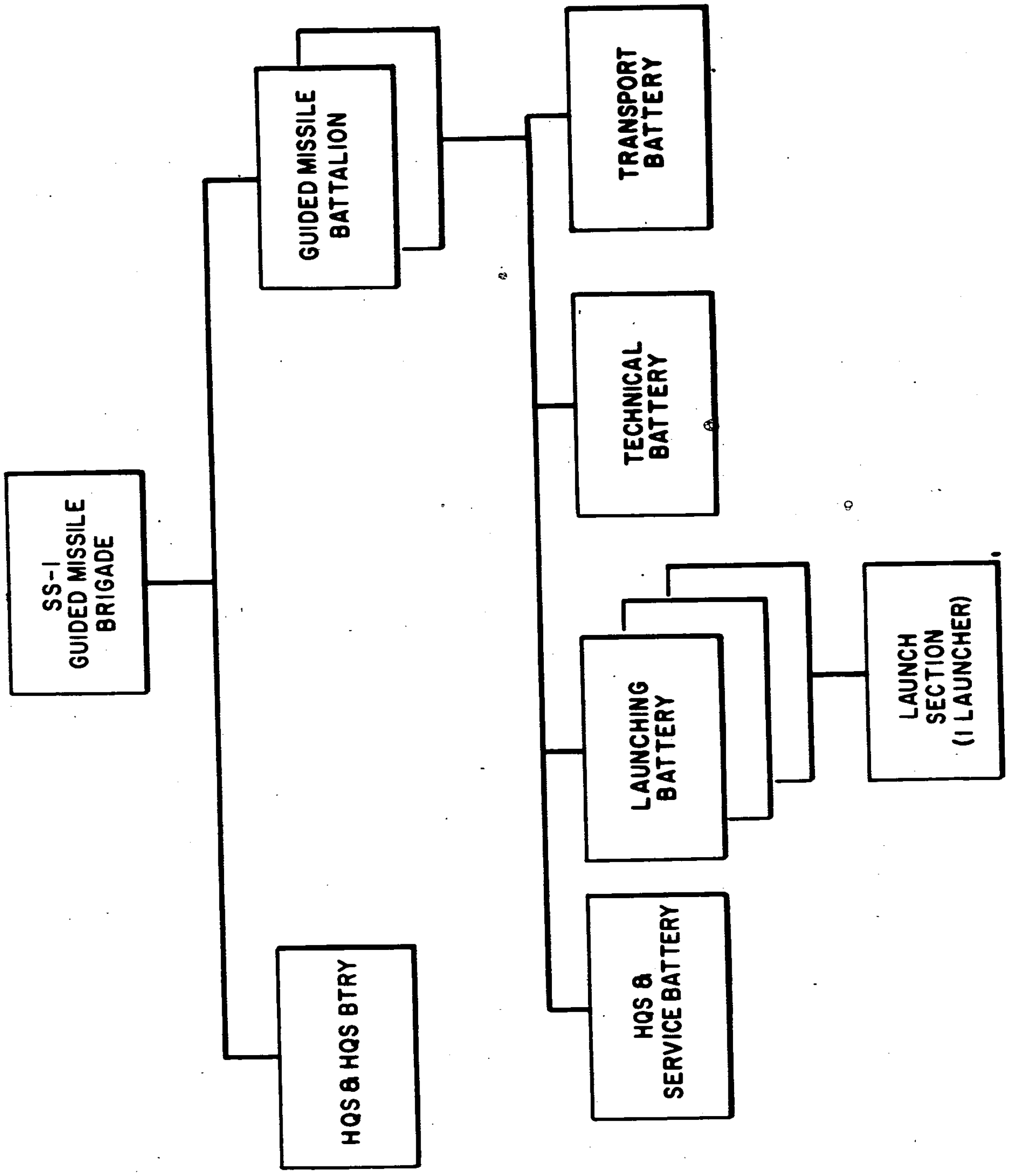

Figure 16. (SECRET-NOFORN) Organizational Structure of SS-1 (SCUD) Guided Missile Brigade (C)

IV. [redacted] ORGANIZATION AND FIELD OPERATIONS (U)

A. [redacted] General (U)

The tactical operational unit for the SCUD (8A61) system is the missile battalion. It is composed of a battalion command group, a headquarters battery, three launching batteries, a technical battery, and a missile transportation battery. The headquarters battery consists of a surveying platoon, two signal platoons, and a mobile meteorological artillery station. The launching battery consists of **a 20-man launching section,** one 12-man electrical firing section, and an 8-man compressor and battery charging station unit. The technical battery is composed of three missile testing stations, a section for handling special fuel, and one assembly section. The transport battery has two missile supply sections, one missile rigging platoon, one section for supply of special fuels, and a dry missile depot. **By utilizing the one launch facility in each battery, the battalion has a capability of launching three missiles simultaneously every 2 hours. The fueled** missile normally moves by road on its JSU tracked vehicle from the forward missile storage depot to the launch area. It has an off-road capability and is air transportable. It is integrated into all Soviet tactical forces and is employed in troop maneuvers and other training exercises for the achievement of combat effectiveness. Its relative short-range capabilities limit its use to front line objectives.

B. [redacted] Line of Vehicle March (U)

A typical convoy of a launch section moving within rear areas would include a command car followed by an instrument vehicle, a launching unit equipment vehicle, and the transporter-erector-launcher vehicles -- including a test launch set, a dry missile transporter, a neutralization and washdown vehicle, and personnel carriers. Only the amount of ground support equipment required to launch the missile would be moved beyond the forward dry missile depot storage area, which comprises part of an area known as the Technical Site.

C. [redacted] Processing the Missile (U)

The missiles are loaded in containers and moved by rail to a forward area supply depot -- 3 missiles per special car and up to 60 missiles on one train. Nose cones are transported separately -- five in 2-axle cars, and twelve in 4-axle cars. From the supply depot missiles are moved by vehicle to the Technical Site, approximately 50 km closer to the forward edge of the battle area (FEBA). Here the dry missiles are held temporarily in a storage depot until preparation of the missile for firing takes place, in which event it is processed through a series of testing points. These tests include the ground control equipment, the fuzing system, the propulsion unit, and the guidance system. These and other technical checkouts and services discussed elsewhere herein are made at the test points, the fuel loading point, and two points for the assembly of components (all within the Technical Site) -- including the warhead. The missile is then held at the ready missile storage point to be picked up by the using unit.

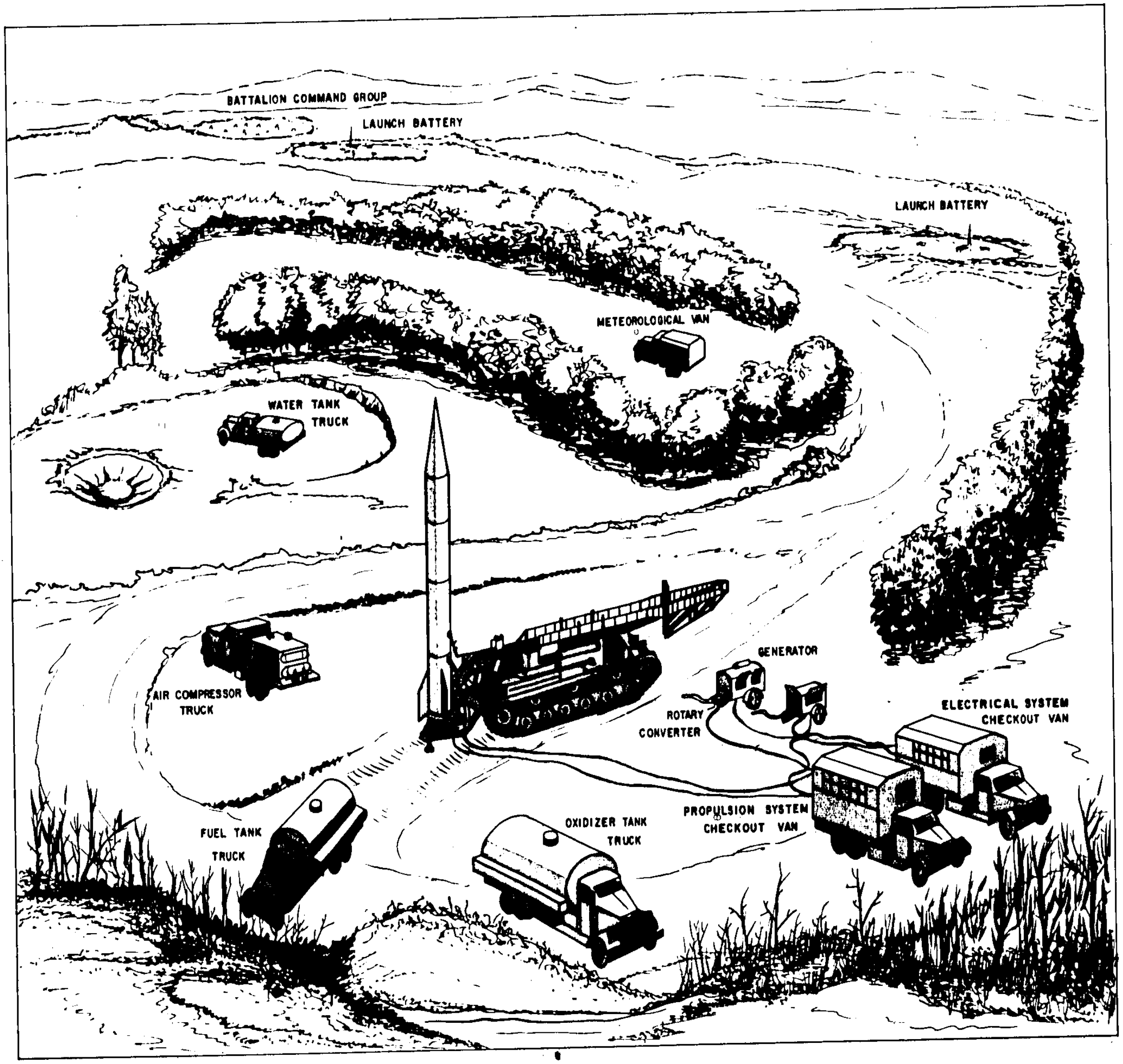

Figure 17. (SECRET-NOFORN) Typical Combat Formation of SCUD Missile Battalion (C)

D. [redacted] Field Deployment (U)

[redacted] Current doctrine for deployment of the SCUD missile battalion prescribes dispersion of two launch batteries along a front of 12 to 14 km. The Command Post, third launch battery, meteorological sites, and service units are echeloned in depth up to 8 to 10 km (**Figure 17**). This battalion area is normally located not closer than 30 to 40 km from the FEBA.

[redacted] Criteria for selection of the launch area is that it should provide for coverage of all assigned targets, deployment of all combat elements of the battalion, camouflage of all personnel and combat equipment, ease of control of fire, and convenient and concealed roads or trails.

E. [redacted] Launching Site (U)

[redacted] Batteries are normally held 15 to 20 km to the rear in a waiting area pending movement to the launch area.

[redacted] At this pre-surveyed position, little remains to be installed in the missile. Final operations include an inspection of the engine assembly and the guidance system, and a check of the insulation of the cable network. The missile is mounted vertically on the launch platform and the battery is installed. A collimator is fixed on a designated point and the missile is layed. Storm moorings are affixed when the wind velocity exceeds 20 mph, a gasoline generator and a quartz generator (a frequency control device) are started, and the missile is launched. Full geodetic preparation for firing the missile requires 3 days for completion.

F. [redacted] Deployment (U)

[redacted] Missile troops are deployed with the Group of Soviet Forces in Germany (GSFG), the Southern Group of Forces (SGF), the Turkestan Military District (Turk VO), the Transcaucasian Military District (Zak VO), and the Far Eastern Military District (DVO). It is likely that the SCUD is operational throughout all of these areas. The USSR has probably supplied the conventionally armed SCUD missile system in small quantities to both East Germany and Communist China. It has been produced in the USSR in large quantities, is an efficient weapon, and is well suited for training of troops with little or no missile experience.

G. [redacted] Comments (U)

[redacted] Tactical exercises involving Soviet missile troops during 1960 and 1961 revealed a weakness in combat readiness of missile technical units (Mobile Repair Technical Base - PRTB). At no time during these exercises were missiles delivered by the PRTB to the missile units in condition to be fired without undue delay. Soviet military leaders realize the necessity for developing close coordination and cooperation between missile units, missile technical units, and rear area service type units -- and they can be expected in the future to place extreme emphasis on correcting or at least greatly improving these shortcomings.

V. [redacted] ASSEMBLY AND CHECKOUT PROCEDURE (U)

A. [redacted] Introduction (U)

Possible deployment concepts of the SCUD have been presented in numerous publications since the missile's first public appearance. Although these various concepts cannot be verified, it is certain that the missile and its components must be thoroughly tested before launch. The actual deployment and checkout by troops in the field may be done in the following manner. The phases through which a missile must pass after manufacture are:

Storage. All components are held in a ready state at a supply depot for the troops.

Testing. After the troops are issued a missile system it is necessary to test all components together.

Loading and Assembly. The missile is moved to the fueling area and the assembly area.

Launch.

B. [redacted] Testing (U)

1. [redacted] General (U)

After being issued at the supply depot, the missile and all associated components are transported to the technical position, an area some distance away from the launch area, where testing and loading and assembly are accomplished. The equipment is disassembled and prepared for testing. Individual tests are made on every unit of the guidance system and fuzing equipment as well as the leak test on the rocket motor, fuel tanks and associated plumbing and valves. The missile remains in a horizontal position for these detailed tests or checks.

2. [redacted] Technical Position (U)

The testing position is divided into two work areas, work area one for propulsion system testing and work area two for electrical system testing, where special checkout consoles are erected for sequentially operating flight components of the missile in individually controlled simulated flight tests.

C. [redacted] Loading and Assembly (U)

1. [redacted] Operations at the Fueling Point (U)

Two working areas are organized at this point: one for fueling the missile with kerosene, the other for adding the oxidizer. The maximum loading speed is 250 liters per minute (66.25 gal/min).

1 2. [redacted] Assembly and Joining Procedure (U)

After fueling, the missile proceeds to the assembly and joining point on a carrier. The warhead is brought up in a special container. The fuzes are also delivered to this point in special packaging.

1 [redacted] The nose and base fuzes are installed in the missile. A crane is used to assist in joining the warhead to the missile. All connecting surfaces have been smeared with a fireproof substance. The entire missile is then placed on the **tracked erector-launcher** and moved to the launch area and turned over to the launching section of the firing battery.

1 D. [redacted] Launch (U)

After the missile arrives at the launching area there is a sequence of operations which is conducted to assure a successful launch. First, a thorough inspection is made of the engine assembly, the guidance system, and the gyroscopic instruments which are already mounted in the missile.

1 1. [redacted] Missile Alignment on Launcher (U)

The missile is erected at the designated launch point. A sight is taken on the previously surveyed point with a collimator, which has been placed upon a point designated by the geodetic personnel. The missile is aligned, with fin I in the direction of fire, and a vertical check is made. Leveling is probably accomplished by adjustments on the leveling frame on the launcher.

1 [redacted] Aiming the missile at the target requires more than just orienting the body of the missile. The gyro plate must be leveled and properly balanced and the missile must be perfectly vertical. Balancing the gyro plate implies the orientation of the gyro plate, together with the gyroscopes mounted thereon, with respect to the stabilizer fin surfaces.

1 [redacted] A rod and an optical quadrant which are designed for measuring the angle of inclination of the stabilizer surfaces to the horizontal are used to balance the gyro plate. The rod is fastened to the adapter of the gas-jet vanes. The optical quadrant, which consists of the body, a dial, and the traversing mechanism of the dial, is fastened on the control plate of the rod. A scale in degrees is painted on the dial. There is also a vernier of the dial which has a grid with 1-minute angular graduations. The optical quadrant provides a measurement of the angles ±120°. In aiming the missile at the target, an instrument set is used. The whole set is comprised of the collimator (as one unit of the set), a horizontal sight, two illuminated aiming stakes and two magnetic levels. These magnetic levels are for determination of the magnetic deviation peculiar to the particular launching site and will indicate the magnetic dip.

2. [redacted] Launch Area Tests (U)

Continuity checks are made of the cable networks by a megohmmeter. The main missile batteries are installed and the grounding

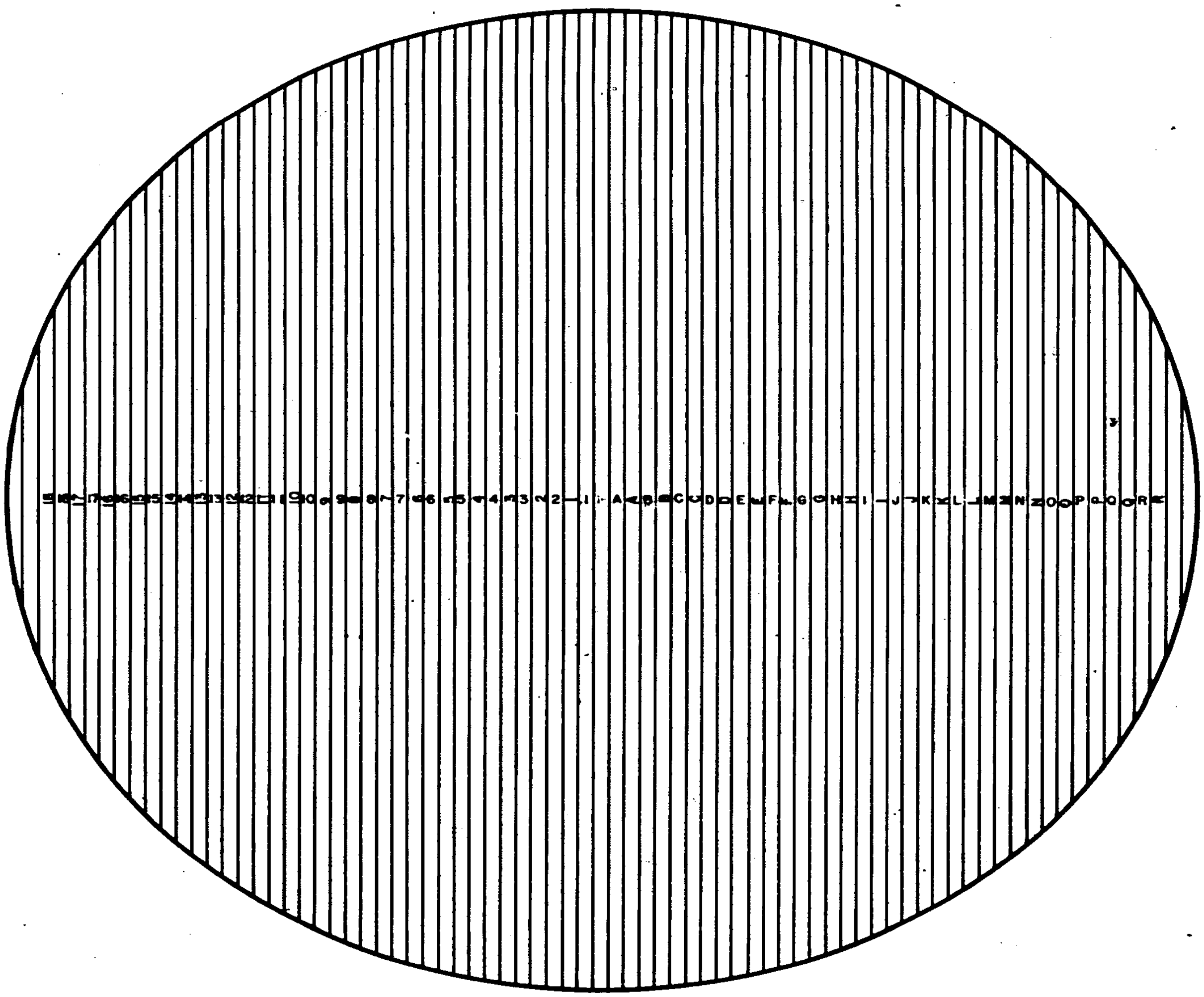

Figure 18. [redacted] Grid Circle of Collimator (U)

connection is made. Storm moorings are attached if the wind velocity exceeds 10 meters/sec.

1 [redacted] The final launch operations include a number of checks of the missile that cover the pyrocartridge circuit, the guidance system and a first and second general check. These checks are made with automatic test equipment and consist of a series of sequential events that are initiated by the test equipment; test results are indicated in a go-no-go display on the launching consoles.

1 [redacted] It would appear that no problems should exist for the launching crews after the missile is erected and aligned and the plug connections are made. The high-pressure feed connections appear to be an integral part of the erector launcher and are most likely connected at the time the missile is placed on the launcher. Otherwise the actual firing is automatic and controlled by a console.

1 E. [redacted] Aiming Requirement (U)

The geodetic survey of the launch point requires about 3 days which indicates that a first order survey is mandatory in order to achieve the target accuracy required of the guidance system. The use of a collimator, an instrument to measure horizontal and vertical angles and to determine the aiming point, in the survey supports the conclusion that this high-order geodetic survey is a necessary measure.

1 [redacted] The collimator consists of a tube, a sight, an upper plate, a dial (or angle-measuring ring), a lower plate with a fixed section, together with adjusting screws and auxiliaries. There is the usual tripod, small battery (2.4V), and a cover. The optical system of the collimator consists of an objective and a grid.

1 [redacted] Objective. The objective, consisting of three sections, is a converging lens at one of whose focal points is placed a small source of light. Rays diverging from this focal point emerge from the objective lens in a parallel beam.

1 [redacted] Grid. The grid is painted on the surface of the lens of the third objective section and is placed in the focal plane of the collimator objective. The grid circle is divided into 76 vertical stripes. On the left half of the grid, numbers are inscribed in a vertical and horizontal arrangement from 1 through 18. The right half is filled with 18 very narrow letters which are also arranged in the same manner as the numbers. (See **Figure 18.)** A ground glass provides uniform illumination of the grid. The grid is illuminated by a bulb when working under night conditions and is illuminated during the day by means of a reflecting mirror.

[redacted] Levels. A cylindrical level and two spherical levels are used to level the collimator horizontally. The cylindrical level is graduated to 1 minute; the spherical levels are graduated to 20 minutes.

X1 [redacted] Sight. A panoramic sight, consisting of an objective, a rotating prism, grid and eyepiece, is fastened to the body of the collimator tube and is used to aim the missile at the target. The angle of the field of vision is 10 degrees. The limit of the horizontal measurement is 60-00; the vertical angle is ±6-00. The grid has an upper row of numbers used for aiming at the target and a lower row of numbers for balancing of the horizontal. The horizontal sight is balanced when its optical axis, in the zero settings of the angular scale, is in the plane with the perpendicular control stripe of the table. For a horizontal balance, the collimator must be fastened to the control table so that markings on the collimator are superimposed on identical markings of the horizontal plate. The horizontal plate is turned with its head down (to 180°). By means of the angular scale of the horizontal, the identical markings of the collimator and the horizontal plate are superimposed. The reading of the angle is taken from the horizontal angular scale.

X1 [redacted] Screw clamp. A screw clamp, made up of a body with supports, a swinging mechanism, a telescope socket, two cylindrical levels and a control table, makes it convenient to balance the horizontal plate and install the collimator on either a tripod or the launcher.

X1 [redacted] The above aiming procedure is based primarily on the V-2 type procedure. (Reference: Operation Backfire.)

APPENDIX I [redacted] SUPPORTING ANALYSIS (U)

A. [redacted] Introduction (U)

This appendix includes all calculations used in the evaluation of the Soviet SCUD missile with the exception of the Heat Transfer Analysis and the Airframe Stress Analysis.

[redacted] Conclusions based upon these calculations are found in the body of the study.

B. [redacted] Discussion (U)

1. [redacted] Airframe Dimensions (U)

Figure 1 shows a side view of the SCUD missile taken at the 1960 May Day parade. This photograph was utilized to determine the distances between the major circumferential welded joints, the length of the nose cone, and other pertinent data needed for this analysis. The overall missile length and diameter were obtained from the photo intelligence study of the SCUD A missile seen at the 7 November 1957 Moscow parade.

2. [redacted] Tankage (U)

The tank volume calculations are based upon the end closure locations and missile diameter, as shown in figure 3. Two end closures, one on each tank, are assumed to be hemispheres. The remaining two closures are assumed to be of the 2 to $1\frac{1}{2}$ semi-elliptical type. The volume of the fuel tank (V fuel) is:

$$V_{fuel} = \frac{\pi}{4} D^2 L + \frac{\pi}{12} D^3 + \frac{\pi}{18} D^3$$

where:

D = Diameter, ft

L = Length, ft

$$V_{fuel} = \frac{3.14}{4} (2.8)^2 (4.4) + \frac{3.14}{12} (2.8)^3 + \frac{3.14}{18} (2.8)^3$$

$$V_{fuel} = 6.16 \times 4.4 + 5.7 = 27.1 + 5.7 + 4.2 = 37.0 \text{ ft}^3$$

From the 37 cu ft, one must subtract .75 for feed line volume through fuel tank, and 1.85 cu ft for unusable residue. Therefore, 34.4 cu ft is the usable fuel volume.
The volume of the nitric acid tank, V_{IRFNA}, is:

$$V_{IRFNA} = 6.16 \times 9.0 + 5.7 + 4.2 = 65.3 \text{ ft}^3$$

$$+ 0.75 \text{ for feed line volume} = 66.05 \text{ ft}^3$$

[redacted] Using a 4% ullage, the total weight of fuel is:

$$W = \rho \times V \times 0.96 = 53 \times 34.4 \times 0.96 = 1750 \text{ lb}$$

where:

W = Weight, lb

ρ = Density, lb/ft^3

Using an 7% propellant-tank-volume outage, the usable weight of fuel is:

$$W = 1750 \times 0.93 = 1628 \text{ lbs}$$

[redacted] By the same procedure, the total weight of nitric acid is calculated as:

$$W = \rho \times V = 93.9 \times 66.05 = 6200 \text{ lb (ullage included)}$$

Using approximately 1.6% propellant tank volume outage, the usable weight of nitric acid is:

$$W = 6200 \times 0.984 = 6100 \text{ lb}$$

It is felt that the Soviets could easily attain the ullage and outage figures quoted above; therefore, the analysis is conservative from a propellant utilization point of view.

[redacted] Since approximately 9% of the nitric acid flow rate is used for film cooling of the thrust chamber, the amount entering the injectors is:

$$W = 6100 \times .91 = 5551 \text{ lbs}$$

[redacted] The mixture ratio at the injectors is:

$$\text{M.R.} = \frac{5551}{1628} = 3.4$$

A summary of the propellant weights and volumes is provided in table IV.

TABLE 4. [redacted] CALCULATED TANK VOLUMES AND PROPELLANT WEIGHTS (U)

		OXIDIZER	**FUEL**	
	UNITS	(IRFNA)	(KEROSENE)	TOTAL
Propellant tank volume	ft^3	66.05	34.4	100.45
Total propellant weight	lb	6200	1750	7950
Usable propellant weight	lb	6100	1628	7728
Propellant flow through injectors	lb	5551	1628	7179
Film cooling	lb	549	0	549
Outage	lb	100	122	222

3. [redacted] Performance Calculations (U)

a. [redacted] Thrust Chamber (U)

The thrust chamber performance calculations are based upon the following values:

Chamber pressure (P_c) = 355 psia

Propellant combination = inhibited red fuming nitric acid/kerosene.

Mixture ratio (M.R.) = 3.4 (at injectors)

Throat diameter (D_t) = 7.118 in = 39.8^2 in (A_t)

Exit diameter (D_e) = 16.2 in = 205^2 in

Expansion ratio (ϵ) = 5.15

For a mixture ratio of 3.4 and a chamber pressure of 355 psia, the theoretical value of characteristic exhaust velocity (C*) is:

$$C^* = 5415 \text{ ft/sec} \left(C^* = \frac{P_c A_t}{\dot{m}} = \frac{P_c A_t g}{\dot{w}} = \frac{355\ (39.8)\ \ (32.2)}{84} = 5415 \text{ ft/sec}\right)$$

For the ratio of specific heats (k) of 1.18, and the expansion ratio of 5.15, the ratio of nozzle exit pressure (P_e) to chamber pressure (P_c) is:

$$\frac{P_e}{P_c} = 0.02901$$

Thus, the nozzle exit pressure is:

$$P_e = 0.02901 \times 355 = 10.3 \text{ psia}$$

For k = 1.18 and $\epsilon = 5.15$, the theoretical value of vacuum thrust coefficient ($C_{f_{VAC}}$) for a 15-degree, half-angle, conical nozzle is:

$$C_{f_{VAC}} = 1.522$$

The theoretical sea-level thrust coefficient ($C_{f_{SL}}$) is:

$$C_{f_{SL}} = C_{f_{VAC}} - \frac{P_a}{P_c}\epsilon$$

where:

P_a = Ambient pressure, psia

$$C_{f_{SL}} = 1.522 - \frac{14.7}{355} \times 5.15 = 1.522 - 0.213 = 1.309$$

The sea-level and vacuum specific values (I_{sp}) can be calculated as:

$$I_{sp_{SL}} = \frac{C_{f_{SL}} \; C^*}{g} = \frac{1.309 \times 5415}{32.2} = 220 \text{ sec}$$

$$I_{sp_{VAC}} = \frac{C_{f_{VAC}} \; C^*}{g} = \frac{1.522 \times 5415}{32.2} = 256 \text{ sec}$$

For the throat area (A_T) of 39.8 in^2, the thrust can be calculated from:

$$T = C_f P_c A_t$$

$$T_{SL} = 1.309 \times 355 \times 39.8 = 18{,}500 \text{ lb}$$

$$T_{VAC} = 1.522 \times 355 \times 39.8 = 21{,}500 \text{ lb}$$

The weight flow rate ($\dot{w}$) can be calculated as:

$$\dot{w} = \frac{T}{I_{sp}} = \frac{18{,}500}{220} = 84 \text{ lb/sec}$$

From the total propellant flow rate, mixture ratio at the injectors, and percentage of the nitric acid used to film-cool the thrust chamber, the oxidizer and fuel flow rates are calculated as:

$\dot{w}_{IRFNA}$ = 66.3 lb/sec

$\dot{w}_{fuel}$ = 17.7 lb/sec

TOTAL = 84 lb/sec

b. Performance Characteristics

(1) T_{SL} = 18,500 lb -- T_{VAC} = 21,500 lb

(2) For the usable propellant weight of 7728 lbs, the duration of thrust (t) is:

$$t = \frac{7728 \text{ lb}}{84 \text{ lb/sec}} = 92 \text{ sec}$$

(3) [redacted] The overall specific impulse is the net thrust divided by the tot propellant flow rate:

$$I_{sp_{SL}} = \frac{18,500}{84} = 220 \text{ sec}$$

$$I_{sp_{VAC}} = \frac{21,500}{84} = 256 \text{ sec}$$

(4) [redacted] A summary of the performance characteristics of the SCUD propulsion sy is shown in table V.

TABLE 5. [redacted] PROPULSION SYSTEM PERFORMANCE CHARACTERISTICS (U)

ITEM	UNITS	VALUE
Oxidizer	--	Red fuming nitric acid
Fuel	--	Kerosene
Mixture ratio at the injectors	--	3.4
Chamber pressure	psia	355
Total propellant flow rate	lb/sec	84
Sea-level specific impulse	sec	220
Vacuum specific impulse	sec	256
Sea-level net thrust	lb	18,500
Vacuum net thrust	lb	21,500
Duration of thrust	sec	92

4. [redacted] Propulsion System Weight (U)

The propulsion system weight can be calculated based upon current Unite tes state-of-the-art and multiplying this value by a factor which takes into account the differences between current United States and early 1950 Soviet state-of-the-art. The factor can be determined by comparing the calculated weight to the actual weight of a known Soviet propulsion system; for this comparison, the Soviet K-102 engine was chosen. It is believed that this engine is essentially a V-2 engine with the thrust increased from 56,000 lbs to 80,000 lbs at sea level. The increase in thrust was obtained by increasing the chamber pressure, maintaining essentially the structure of the original V-2 engine. Since the known Soviet engines produced during the development of the SCUD missile were of the same state-of-the-art as the K-102 engine, the calculated weight of the SCUD propulsion system could be approximately correct.

[redacted] Based on current United States state-of-the-art, the weight of the K-102 propulsion system, less turbopump, would be about 1140 lbs, while the actual weight (assuming that it is a V-2 engine) is 1360 lbs. Thus, the ratio utilized to convert current United States state-of-the-art propulsion system weights, less turbopump, to early 1950 Soviet state-of-the-art is:

$$\text{ratio} = \frac{1360}{1140} = 1.2$$

[redacted] Based upon current United States state-of-the-art, the weight of the SCUD propulsion system, less turbopump, is 460 lbs. Increasing this weight by 20% to convert to early 1950 Soviet state-of-the-art, the weight is:

$$W = 460 \times 1.2 = 550 \text{ lbs}$$

However, this weight is based upon an expansion ratio of 3.4, as used on the V-2 engine. For a more probable expansion ratio of 5.15, the weight would be increased by about 30 lbs. Thus, the estimated total propulsion system weight is approximately 580 lbs.

5. [redacted] Propulsion System Volume (U)

From the tankage location (**Figures 1 and 3**) the length of the propulsion compartment is 7.2 feet. The forward 1.4 feet of this length is occupied by the rear bulkhead of the fuel tank. The apparent nozzle exit is about 0.4 foot within the aft end of the missile. Thus, the usable length of the propulsion compartment is about 5.4 feet.

[redacted] With a sea-level thrust of 18,500 lbs, a chamber pressure of 355 psia, and a characteristic chamber length of about 100 inches (the same as that of the German Wasserfall engine), the approximate length of the thrust chamber is 4.0 feet. Subtracting the 4.0 foot thrust-chamber length from the 5.4 foot usable length of the propulsion compartment leaves 1.4 feet between the thrust chamber and tankage. There is adequate room between the thrust chamber and tankage to house the pressurization bottle, the MPS, and the autopilot amplifier.

[redacted] It is concluded that the available propulsion compartment is of the proper size to house a conventional pressure-fed thrust chamber with a sea-level thrust in the range of 18,000 lbs.

6. [redacted]) Tank Pressurization Systems Weights (U)

a. [redacted] Nitric Acid Tank Pressurization System (S)

The nitric acid tank is assumed to be pressurized by hot gases from a small hydrogen peroxide gas generator. The water and oxygen of these gases are compatible with the acid. These gases are produced in accordance with the following equation:

$$2\ H_2O_2 \rightleftharpoons 2\ H_2O + O_2$$

Therefore, two moles of liquid are required to produce three moles of gas. The resulting mole ratio is:

$$\text{mole ratio} = 2/3$$

The number of moles of gas required to pressurize the 66.05 cu ft acid tank to 500 psia can be determined from the following equation:

$$n = \frac{P\ V}{R\ T}$$

where:

P = Tank pressure, psia

V = Tank volume, cu ft

T = Tank gas temperature in ^{o}R

R = 10.73

A 93% hydrogen peroxide (H_2O_2) monopropellant is used in these calculations. It has a density of 88.7 lb/ft^3 and a chamber temperature of 1483°F. A tank gas temperature of 540°F (1000°R) is assumed.

Therefore:

$$n = \frac{500 \times 66.05}{10.73 \times 1000} = 3.08 \text{ lb moles}$$

Pound moles of H_2O_2 = 2/3 (3.17) = 2.05 lb moles

The weight of hydrogen peroxide required is:

$$W_{H_2O_2} = 3.05\ (35) = 71.8 \text{ lbs}$$

The volume of hydrogen peroxide required is:

$$V_{H_2O_2} = \frac{71.8}{88.7} = 0.81 \text{ cu ft}$$

The diameter of two spheres containing this volume is determined by the following expression:

$$D = \sqrt[3]{\frac{6\ V/2}{\pi}} = \sqrt[3]{\frac{6 \times 0.81}{3.14\ (2)}} = 0.918 \text{ ft}$$

Using a material similar to 321 or 347 austenitic stainless steel, with a yield strength of 180,000 psi and a factor of safety of 3.0 the design stress (s) or 60,000 psi is used. The thickness of the sphere is calculated as:

$$t = \frac{PD}{4s} = \frac{710 \times .918 \times 12}{4 \times 60,000} = 0.0326 \text{ in}$$

The total weight of the two spheres is:

$$W = 2\pi D^2 t\rho = 2 \times 3.14 \times (0.918)^2 \times \frac{.0326}{12} \times 489 = 7.03 \text{ lbs}$$

The weight of the hydrogen peroxide spheres is therefore estimated to be 10 lbs. The weight of the gas generator, which is 3 inches long and 3 inches in diameter, and the piping and control valve is estimated to be 5 lbs.

b. [redacted] Kerosene Tank Pressurization System (U)

[redacted] The kerosene tank is assumed to be pressurized by hot gases from a small ethylene oxide (C_2H_4O) gas generator. The methane and carbon monoxide from this reaction are compatible with the kerosene. These gases are produced in accordance with the following equation:

$$C_2H_4O \rightleftarrows CH_4 + CO$$

Therefore one mole of liquid is required to produce two moles of gas. The mole ratio is:

mole ratio = 1/2

The number of moles of gas required to pressurize a 34.4 cu ft fuel tank to 500 psia is determined by the following expression:

$$n = \frac{500 \times 34.4}{10.73\ (1000)} = 1.603$$

This calculation is based upon 1900°F chamber temperature for C_2H_4O and a tank temperature of 540°F, or 1000°R. The C_2H_4O has a density of 54.3 lb/ft^3 at 60°F.

Pound moles of C_2H_4O = 1/2 (1.603) = .802 lb mole

Weight of C_2H_4O = .802 (4.5) = 36.1 lbs

Volume of $C_2H_4O = \frac{36.1}{54.3} = .665$ cu ft

The diameter of two spheres containing this volume is determined by the following:

$$D = \sqrt[3]{\frac{6 \times .665}{3.14 \times 2}} = 0.866 \text{ ft}$$

The total weight of these two spheres, the gas generator, control valves, and piping is estimated to be 15 lbs.

c. [redacted] Summary (U)

The total pressurization system weight is 140 lbs. A detailed breakdown of this figure is given in table 6.

TABLE 6. [redacted] ESTIMATED TANK PRESSURIZATION SYSTEM WEIGHT BREAKDOWN (U)

ITEM	NITRIC ACID TANK	FUEL TANK	TOTAL
Monopropellant	71 lbs	39 lbs	110 lbs
Propellant bottles, valves, and gas generator	15 lbs	15 lbs	30 lbs
TOTAL	86 lbs	54 lbs	140 lbs

7. Propellant Tank Weights (U)

a. Nitric Acid Tank (U)

The tank wall (also the missile skin) is assumed to be constructed of a material similar to heat-treated 4130 austenitic stainless steel. This steel has excellent weldability; its joints and weldments are exceptionally tough and ductile. Heat-treated 4130 steel has a yield strength of 160,000 psi at 600°F. A factor of safety of 1.5 is used to get a design stress(s) of 106,600 psi.

The thickness of the steel cylindrical wall is calculated as:

$$t = \frac{PD}{2s} = \frac{500 \times 2.8 \times 12}{2 \times 106,600} = 0.0788 \text{ in}$$

The thickness of the steel domes are calculated as:

$$t = \frac{PD}{4s} = \frac{0.0812}{2} = 0.0394 \text{ in}$$

The total weight of the acid tank is:

$$W = \pi D^2 t \rho + \pi D L t \rho$$

$$W = 3.14 \times 2.8^2 \times \frac{0.0394}{12} \times 489 + 3.14 \times 2.8 \times 9 \times \frac{0.0788}{12} \times 489$$

$$W = 40 + 254 = 294 \text{ lbs}$$

b. Kerosene Tank (U)

The thickness of this tank is the same as the acid tank since it has the same diameter, is made from the same material, and contains the same pressure. The total weight of the fuel tank is:

$$W = 3.14 \times 2.8^2 \frac{\times 0.0394 \times}{12} 489 + 3.14 \times 2.8 \times 4.4 \times \frac{0.0788}{12} \times 489$$

$$W = 40 + 124 = 164 \text{ lbs}$$

8. Missile Power Supply (U)

The missile power supply (MPS) is assumed to be a battery-powered system comparable to the system on the V-2 missile; that is, alternating current is supplied by a rotary inverter.

For the guidance system, it is estimated that approximately 65 watts of power are required, 90% of which is supplied by an alternating current power supply. Thus, a-c power supplied by the rotary inverter is 65 x 0.90 = 58.5 watts. Rotary inverter efficiency is about 60%; therefore, the power input is (58.5 x 0.60 =) 75 watts. A separate 50 VDC command voltage supply is used for attitude sensor voltage, actuator feedback voltage and velocity cutoff circuits. The total current required will be 2 amperes or less. Power required for this supply is provided by the inverter (rectified and filtered). The power requirement for the missile command voltage is 100 watts. DC actuators for a missile of this range during this time period require peak currents of 100 amperes. An average current drain of 30 amperes is considered conservative; therefore, power needed for the actuators would be (32 volts x 30 amperes =) 960 watts.

The total battery output power is:

Power for autopilot		75 watts
Power for actuators		960 watts
Power for command voltage		100 watts
	TOTAL	1,135 watts

Using a 50% margin of safety for the battery, the total battery capacity should be at least (1,135 watts/32 volts =) 35 amperes for about 2 minutes. Batteries for this capacity during this time period are known to have weighed about 20 lbs. Two such batteries could supply more than sufficient power for the rotary inverter and actuators. Battery weight is estimated to be:

W = 2 x 20 = 40 lbs

Rotary inverter (100 watt class) during this time period are estimated to have weighed 15 lbs. The weight of the four servo actuator assemblies to control the jet vanes is estimated to be 80 lbs.

The MPS weight summary is shown in table VII.

TABLE 7. ESTIMATED MAIN POWER SUPPLY WEIGHT BREAKDOWN (U)

ITEM		WEIGHT (LBS)
Batteries		40
Rotary inverter		15
Frequency regulator		10
Miscellaneous		5
	TOTAL	70

1 9. [redacted] Trajectory (U)

1 a. [redacted] Center of Pressure (U)

Figure 19 shows the center of pressure vs Mach number for the SCUD missile. The center of pressure is considered as that point along the axis of the missile where the total lift force is acting.

1 [redacted] The missile has two major components contributing to the lift of the vehicle near the zero angle of attack. These components are the nose cone (with its attendant carry-over on the body) and the fins.

1 [redacted] The lift of the nose cylinder at supersonic speeds was estimated by interpolating curves in reference 1, **Appendix V.** These curves show good correlation with experimental data for this application. For subsonic and transonic speeds, a slender-body theory was used for the nose contribution. The carry-over of lift from nose to cylinder was estimated by extrapolating experimental data of reference 2, **Appendix V.**

1 [redacted] The supersonic lift of the fins and the fin centers of pressure were determined by linear theory and the design charts and methods of reference 3, **Appendix V.** Lift of the fin at Mach 6 was determined by the expression derived in reference 4, **Appendix V.** The subsonic fin conditions were determined from wind-tunnel data presented in reference 5, **Appendix V.** These data were for a fin with the same planform, but with an NACA 63A series, 4%-thick airfoil instead of the 4%-thick, single-wedge fin of the vehicle. This discrepancy is of small effect, however, since the fin planform is much more important than fin profile in this case.

1 [redacted] The cabling tunnel was ignored in the aerodynamic analysis. Its contribution to the total lift is very small and, because of its length, it would have little effect upon the center of pressure. It may cause some turbulent flow over the fins, but this would be minor as its height is small, the area of the fins near the body is in turbulent flow, and the cabling tunnel is interdigitated about 5 degrees with respect to the fins.

1 [redacted] The methods used in determining the center of pressure of the total vehicle give an accuracy of ±5% of the body length.

1 b. [redacted] Drag Coefficient (U)

Figure 20 shows the zero lift drag coefficient versus Mach number curve used for the SCUD missile.

1 c. [redacted] Range Optimization (U)

1 (1) [redacted] Method of Analysis (U)

The trajectory analysis was based on the following equations. The rate of change of missile velocity is given as:

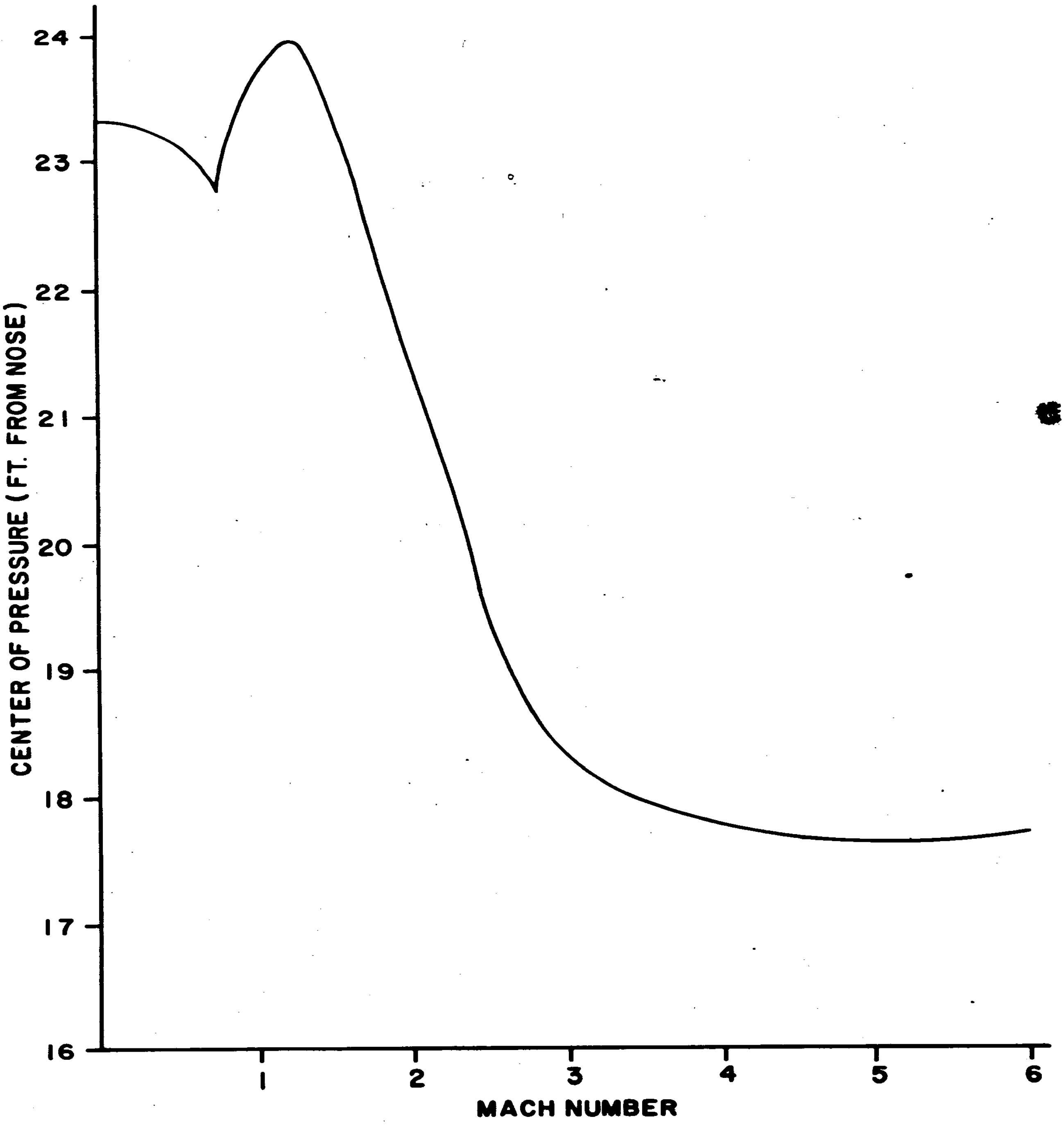

Figure 19. (SECRET) Center of Pressure vs Mach Number Curve for SCUD Missile (C)

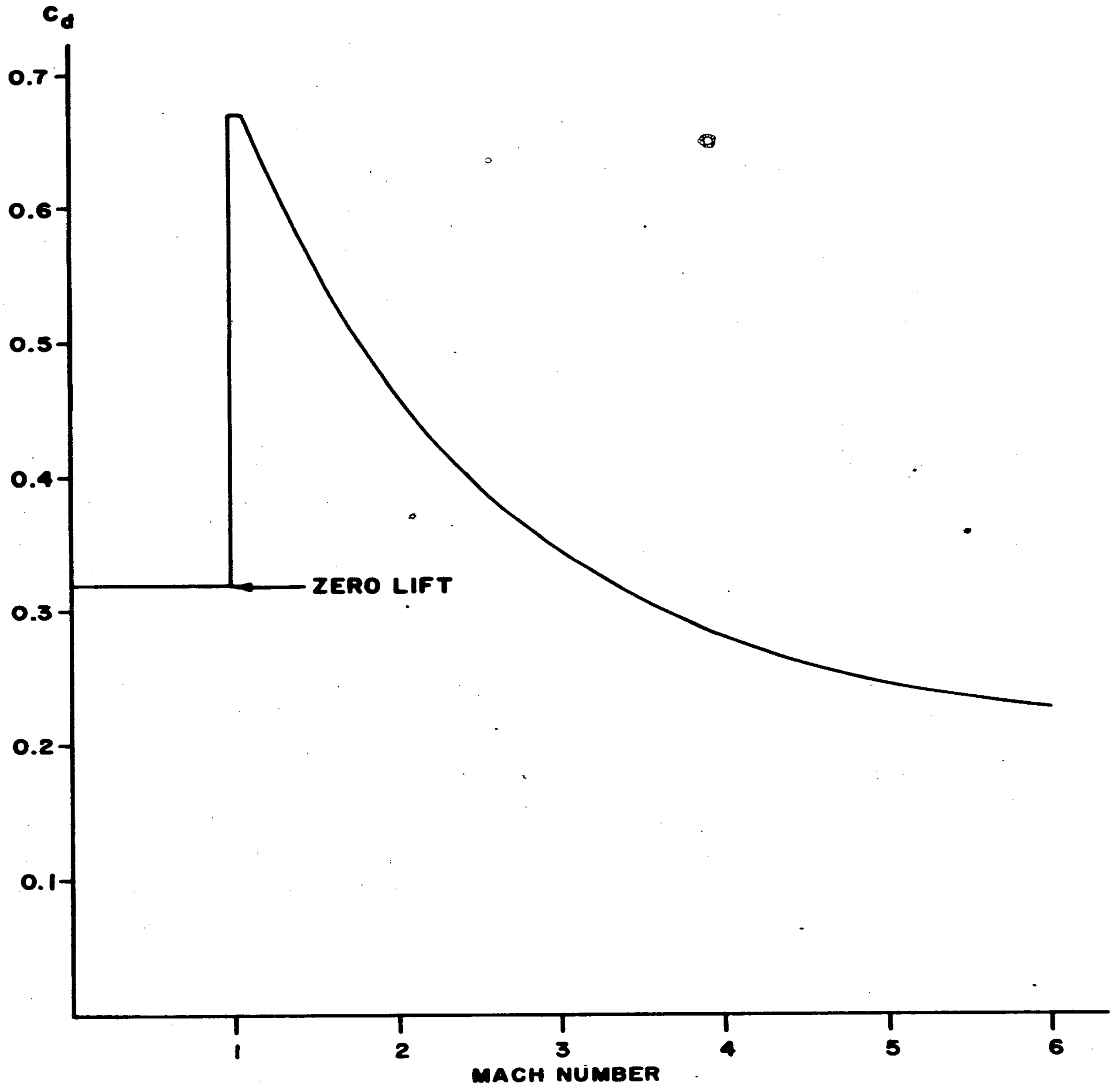

Figure 20. (SECRET) Drag Coefficient vs Mach Number Curve for SCUD Missile (C)

$$\dot{V} = \frac{T\,(\cos\beta)-D}{m} - g\sin\theta$$

where:

$\dot{V}$ = rate of change of velocity

$g = g_o\,(r_o/r)^2$

g_o = acceleration of gravity at sea level

r_o = radius of earth

$r = r_o$ + altitude

θ = Angle between missile velocity vector and local horizontal.

T = Thrust (sea level) + $(P_o-P_a)\,A_e$

P_o = Sea-level pressure

P_a = Pressure at altitude

A_e = Engine exhaust exit area

β = Angle between thrust vector and missile velocity vector.

$D = \frac{1}{2}\,V^2\,C_d\,A$

ρ = Atmospheric mass density at altitude

m = Missile mass

V = Velocity

C_d = Drag Coefficient

A = Cross-section area of missile

The rate of change of θ is:

$$\theta = \frac{V}{r} - \frac{g}{V}\cos\theta + \frac{\dot{X}}{r} + \frac{T\,(\sin\beta)}{m\,(V)}$$

where:

$$\dot{X} = \frac{r_o}{r}\,V\cos\theta$$

[redacted] The program allows the missile to proceed vertically for 6 seconds at which time θ is changed at the rate of 0.875 degrees/second

(56°/64 sec). The thrust misalignment remains constant for 10-20 seconds to cause the missile to start to pitch over. Then θ is reduced to zero and the missile undergoes zero angle of attack until cutoff (92 seconds). The value of β was chosen to produce a pitch program that permits maximum range.

(2) [redacted] Results of Analysis (U)

A detailed trajectory analysis utilizing warhead weights of 1550 and 2500 was conducted to provide performance parameters shown in figures **21 and 22.** Since the range of this vehicle would be affected only slightly by the rotation of the earth, non-rotating earth programs were used for trajectory analysis.

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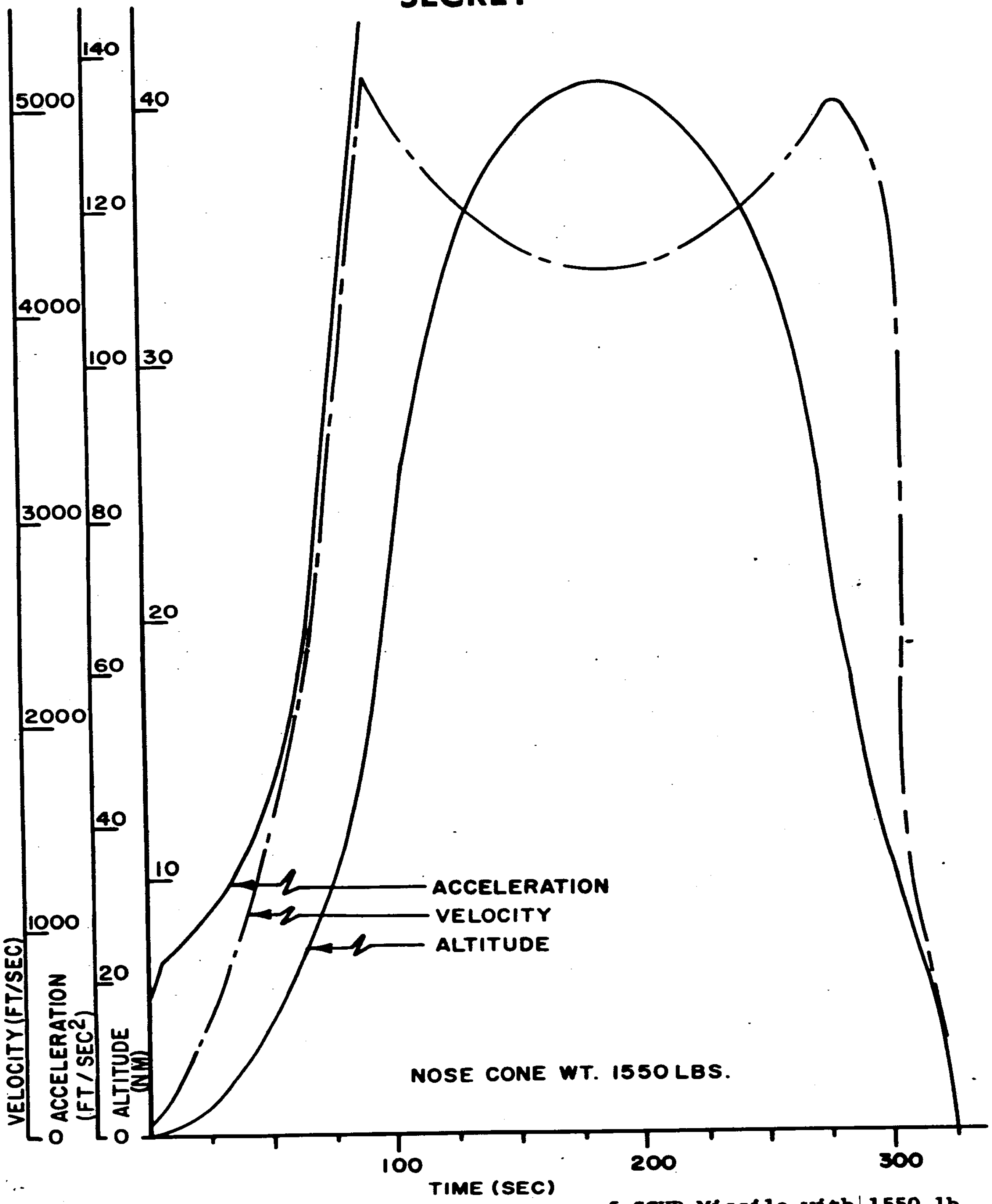

Figure 21. (SECRET) Performance Parameters of SCUD Missile with 1550 lb Warhead (C)

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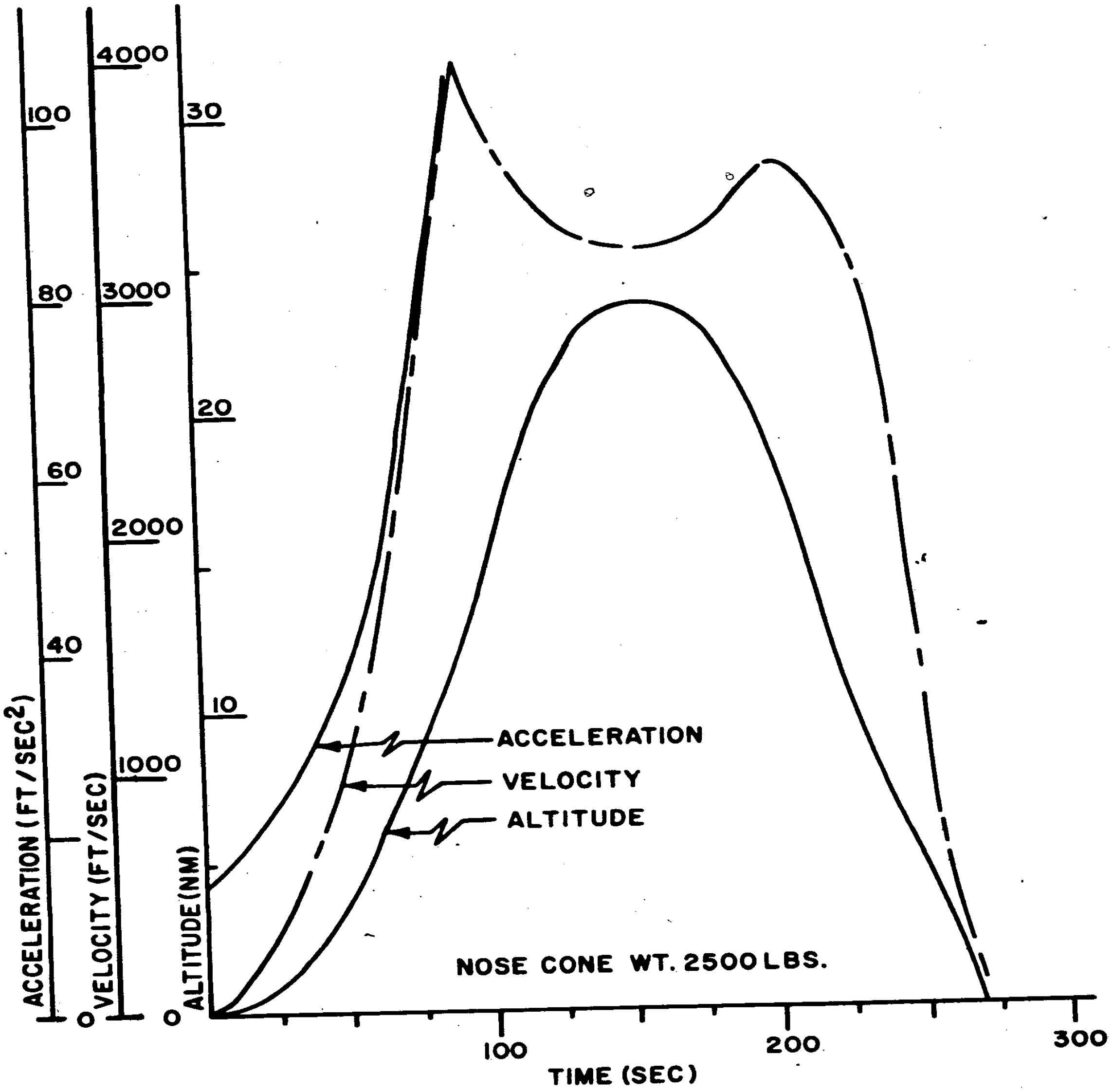


Figure 22. (SECRET) Performance Parameters of SCUD Missile with 2500 lb Warhead (C)

APPENDIX II HEAT TRANSFER ANALYSIS (U)

A. Introduction (U)

The purpose of this analysis is to obtain heat transfer data needed to perform the stress analysis of the SCUD missile. Specifically, maximum skin temperatures vs thickness at various sections along the missile are desired. Temperatures along the nose cone and cylindrical section of the missile were obtained directly by the use of an IBM 704 computer. The computer printouts were also utilized to estimate the heating which occurs at the tip of the nose cone and the skin temperature of the fins.

The basis for this analysis is the missile configuration (**Figure 3**) and the trajectory (**Figure 21**). It was assumed that the missile skin was AISI 347 stainless steel with physical properties as shown in table 8.

TABLE 8. MISSILE SKIN MATERIAL PROPERTIES (U)

ITEM	UNITS	VALUE
Specific heat	Btu/lb °F	0.13
Thermal conductivity	Btu/hr ft °F	10.2
Surface emissivity	--	0.30
Density	Lb/ft^3	494

B. Discussion (U)

1. Method of Analysis (U)

The basic equations of the IBM 704 computer program are as follows:

The heat transferred from the missile skin by radiation is:

$$q_r = e \sigma (T_w)^4$$

where:

q_r = Heat transferred by radiation, Btu/ft^2 hr

e = Vehicle surface emissivity

σ = Stefan-Boltzmann constant, 0.173×10^{-8} $Btu/ft^2\ hr^{o}R^4$

T_w = Wall temperature, °R

The heat transferred to the skin by convection is:

$$q_c = h (T_r - T_w)$$

where:

q_c = Heat transferred by convection, Btu/ft^2 hr

h = Heat transfer coefficient, Btu/ft^2 hr ^{o}R

T_r = Recovery temperature, ^{o}R

The heat transfer coefficient, h, is:

$$h = 0.332 \frac{k^*}{x} (Pr^*)^{1/3} (Re^*)^{0.5} \quad \text{(for laminar flow)}$$

and

$$h = 0.0296 \frac{k^*}{x} (Pr^*)^{1/3} (Re^*)^{0.8} \quad \text{(for turbulent flow)}$$

where:

k* = Thermal conductivity at T*, Btu/hr ft ^{o}R

T* = Reference temperature, ^{o}R

x = Distance from leading edge, ft

Pr* = Prandtl number at T*

Re= Reynolds number at T*

The recovery temperature is:

$$T_t = T_{oo} + \frac{R V_{oo}{}^2}{2 g J C_p}$$

where:

T_o = Ambient temperature, ^{o}R

R = Recovery factor

V_{oo} = Free stream velocity, ft/sec

g = Acceleration of gravity, ft/sec^2

J = Mechanical equivalent of heat, ft-lb/Btu

C_p = Specific heat of air, Btu/lb ^{o}R

The reference temperature at which fluid properties are evaluated is:

$$T^* = T_{oo} + 0.5\ (T_w = -T_{oo}) + 0.22\ (T_r - T_{oo})$$

X1 2. [redacted] <u>Results of Analysis</u> (U)

Tables 9, 10, and 11 show maximum skin temperatures as a function of skin thickness for various locations on the nose cone, missile body, and fins, respectively.

X1 [redacted] Temperatures on the nose cone and missile body were obtained from the computer printouts, while fin temperatures were estimated by hand calculations based upon the computer printouts. Figure 23 shows a typical skin temperature time history, in this case for an .081 inch wall and 8.2 feet from the forward end of the missile.

X1 [redacted] It is seen that the skin temperature at this location does not exceed 200°F during take-off, but that it rises very rapidly upon re-entry to a value of about 820°F and then decreases to about 770°F upon impact.

1 **TABLE 10.** [redacted] MISSILE BODY SKIN TEMPERATURE (U)

DISTANCE FROM TIP OF MISSILE (FT)	SKIN THICKNESS (IN)	MAXIMUM TEMPERATURE (°F)
8.2	0.081	820
	0.100	750
	0.125	675
13.2	0.060	855
	0.070	800
	0.090	725
18.2	0.060	835
	0.070	775
	0.090	700
23.2	0.060	810
	0.070	760
	0.090	690
28.2	0.060	920
	0.070	750
	0.090	670
33.2	0.030	1020
	0.050	850
	0.070	745

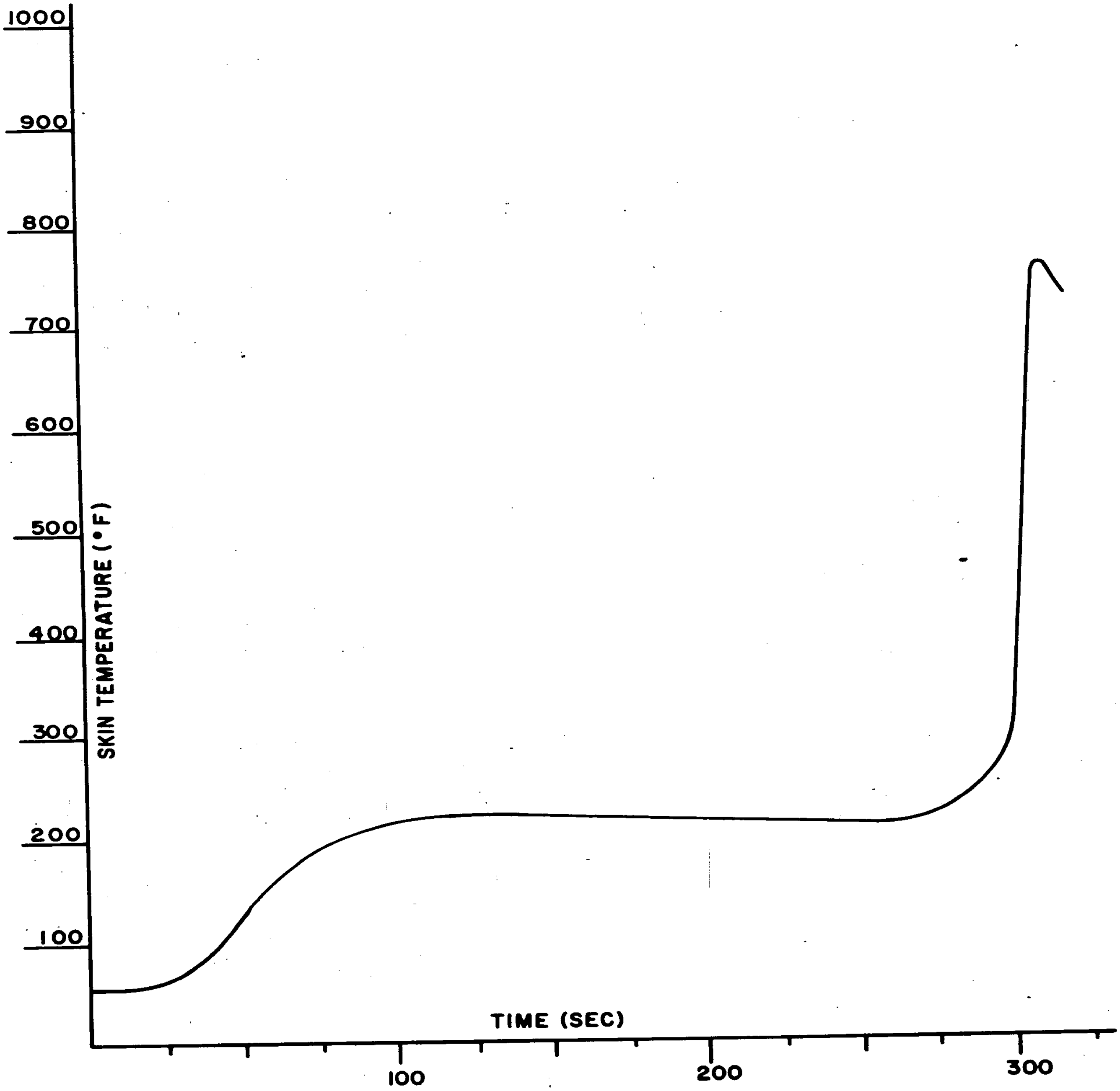


Figure 23. (SECRET) Skin Temperature vs Time History for SCUD Missile (C)

TABLE 11. [redacted] FIN SKIN TEMPERATURE (U)

DISTANCE FROM LEADING EDGE (FT)	SKIN THICKNESS (IN)	MAXIMUM TEMPERATURE (°F)
0.30	0.050	963
	0.100	581
0.50	0.050	1280
	0.100	738
1.00	0.050	1590
	0.100	894

[redacted] The most forward station for machine calculations was at a 1-foot distance from the tip of the nose cone. The heating rate at this point was extrapolated to obtain the heat transfer rates from the 1-foot distance to the tip of the nose cone by the method of reference 6, **Appendix V.** This heating rate is maximum at the leading edge and decreases with increasing distance from the leading edge. The ability of a solid cone to absorb heat per unit surface area, however, increases with the distance from the leading edge. At the tip of the cone, the metal has a small heat capacity, and the temperature approaches the melting point. Further aft, the metal has adequate heat capacity to absorb all of the transferred heat and remain well below its melting point. At a distance of 0.1 foot from the tip of the nose cone, the metal reaches a maximum temperature of about 1000°F. Thus, a solid tip about 0.1 foot long has adequate capacity to absorb the heat transferred during re-entry and maintain structural integrity.

[redacted] Because of the rounded leading edge of the fin, the temperature does not [redacted]h the high values of the nose cone tip. The temperature 0.3 feet from the leading edge of the fin can be considered about equal to the temperature of the leading edge **(table 11).**

APPENDIX III [redacted] AIRFRAME STRESS ANALYSIS (U)

[redacted] This analysis provides the estimated airframe weight of the SCUD missile. It takes into consideration loads imparted to the vehicle by the carrier during transportation and loads occurring during erection and flight of the missile. Tankage and transition sections are considered to be of full-monocoque welded construction, while the aft skirt and fins are of semi-monocoque construction.

[redacted] The airframe is assumed to be constructed of a material similar to 321 or 347 austenitic stainless steel. Paragraph 9, **Appendix I**, assumes that the propellant tanks are heat treated. No heat treatment is needed to improve physical properties after welding for the thinner sections encountered in the SCUD airframe.

[redacted] The SCUD configuration is shown in figure 3, and the overall weight breakdown is shown in table 2. **Table 12 shows the missile component weight** distribution, and table **13 shows the resulting weight breakdown of the air-frame** components.

[redacted] Tank pressures used as the basis for this analysis were 500 psia for the oxidizer tank and 500 psia for the fuel tank. The acceleration of the missile (g's) was obtained from the trajectory (Figure 21). The missile skin temperature as a function of thickness was obtained from tables 9, 10, 11.

TABLE 12. [redacted] ESTIMATED VEHICLE WEIGHT DISTRIBUTION (U)

	INITIAL WEIGHT (LBS)	BURNOUT WEIGHT (LBS)
PROPULSION COMPARTMENT		
Fins	168	168
Jet vanes	90	90
Jet vane actuators	80	80
Trim motors	30	30
Engine	580	580
Inverter/batteries (MPS)	80	80
Autopilot amplifier	30	30
Nitrogen pressurization system	12	12
Ignition pressurization system	30	30
Engine support frame	30	30
Aft transition	30	30
Aft support ring	9	9
Aft cylinder structure	122	122
Misc & power distribution	73	73
TOTAL	1,364	1,364
FUEL COMPARTMENT		
Tankage	164	164
Fuel (kerosene)	1,750	122
TOTAL	1,914	286

TABLE 12. ESTIMATED VEHICLE WEIGHT DISTRIBUTION (CONT'D) (U)

	INITIAL WEIGHT (LBS)	BURNOUT WEIGHT (LBS)
INTERTANK TRANSITION		
Intertank transition	66	66
Autopilot	60	60
Fuel pressurization system	54	54
TOTAL	180	180
OXIDIZER COMPARTMENT		
Tankage	294	294
Oxidizer (nitric acid)	6200	100
TOTAL	6494	394
FORWARD TRANSITION		
Oxidizer pressurization system	86	86
Ballast	63	63
Forward cylinder structure	43	43
Forward support ring	9	9
Warhead support structure	25	25
TOTAL	226	226
NOSE CONE		
Warhead (HE/nuclear)	1175	2125
Structure (shell)	375	375
TOTAL	1550	2500

LIFTOFF WEIGHT . . . . 11,728/12,678 lbs
BURNOUT WEIGHT . . . . 4000/4950 lbs

TABLE 13. ESTIMATED AIRFRAME WEIGHT BREAKDOWN (U)

ITEM	WEIGHT
Warhead support	25 lbs
Forward support ring	9 lbs
Forward transition	43 lbs
Oxidizer tank	294 lbs
Intertank transition	66 lbs
Fuel tank	164 lbs
Aft transition	30 lbs
Aft support ring	9 lbs
Tail section structure	122 lbs
Fins	168 lbs
Miscellaneous	73 lbs
TOTAL	1003 lbs

1 [redacted] The weights shown in table **13 for support members, aft cylindrical** structure, and fins were estimated using previous experience with similar structures constructed of steel.

1 [redacted] The nose cone must withstand the aerodynamic heating and pressure differential across the skin created during re-entry of the vehicle. For a skin thickness of 0.080 in., the maximum skin temperature is 940°F and the maximum pressure differential is 7.5 psia. This figure is based upon the assumption that the static pressure within the cone is equal to the local ambient pressure. This assumption has essentially been substantiated through experience gained with the Aerobee-sounding rocket.

The compressive stress (f_c) in the cone is:

$$f_c = \frac{pr}{t \cos \alpha} = \frac{7.5 \times 16.8}{0.080 \times 0.981} = 1610 \text{ psi}$$

where:

p = Pressure, psi

r = Radius, in

t = Thickness, in

α = Cone half angle, degrees

Conservatively, by assuming a cylinder 72 inches long and 33.6 inches in diameter, the critical buckling stress is computed as follows:

$$Z_L = \frac{L^2 \ (1-\mu^2)\ 1/2}{rt}$$

where:

Z = General length range parameter

L = Length, in

μ = Poisson's ratio

$$Z_L = \frac{(72)^2 \ (0.954)}{16.8 \times 0.080 \text{ in}} = 3680 \text{ psi}$$

The ratio of radius to thickness is:

$r/t = 16.8/0.080 = 210$

From a curve of K_c (buckling coefficient) vs Z_L for r/t equals 210,

$K_c = 70$

The critical buckling stress, F_{cr}, is calculated from:

$$F_{cr} = \frac{K_c \pi^2 E}{12 (1-\mu^2)} \left(\frac{t}{L}\right)^2$$

where:

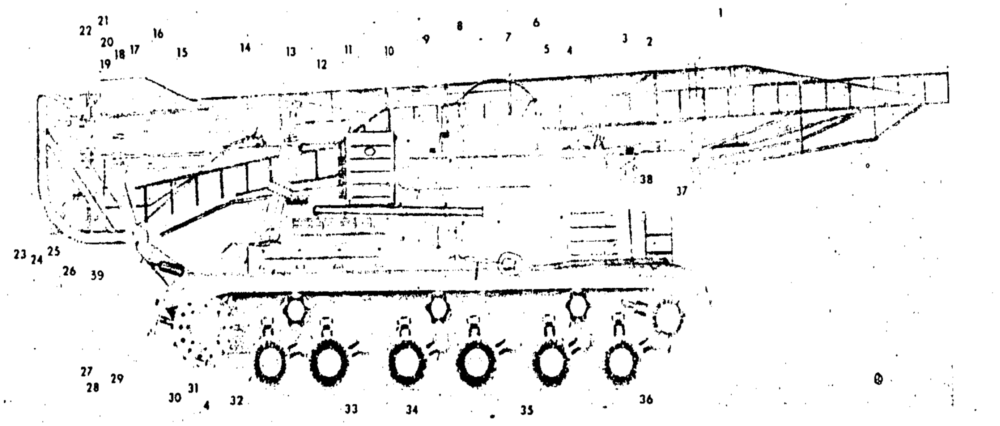
E = Modulus of elasticity (23×10^6 psi at 940 ° F)

$$F_{cr} = 70 (3.14)^2 \ (23 \times 10^6) \ \left(\frac{0.080}{72}\right)^2 = 1800 \text{ psi}$$

The margin of safety, M.S. = $\frac{\text{Maximum allowable stress}}{\text{Actual stress}}$

$$\text{M.S.} = \frac{F_{cr}}{f_c} = 1.12$$

The actual margin of safety is higher because a cone is more resistant to buckling than a cylinder; therefore, the skin thickness of the nose cone is sufficient.



NOMENCLATURE

1. Forward Retaining Strap
2. Antenna Mount
3. Hatch, Right Side
4. Equipment Storage Box
5. Access Door
6. Erector Clamps
7. Pressurized Cold Gas Bottle
8. Power Winch
9. Exhaust Ports
10. Fuel Tank (Transporter)
11. Hydraulic Jack (erector)
12. Jacking Plate
13. Alignment Fixture
14. Clamp (locking arm)
15. Idler Pulley
16. Firing Table Locking Arm
17. Azimuth Table
18. Support Foot (missile)
19. Spacer (azimuth table)
20. Pulley
21. Leveling Jacks (azimuth table)
22. Ground Jack
23. Blast Deflector Plate
24. Triangular Leveling Frame
25. Azimuth Table Races
26. Missile Tie Down Clamp
27. Pivot Support Arm
28. Fire Extinguisher
29. Support Jacks
30. Hydraulic Bleed Line
31. Drive Sprocket
32. Road Wheel
33. Shock Absorber
34. Torsion Bar Crank Arm
35. Track Return Roller
36. Idler Sprocket
37. Windows
38. Carriage Lock
39. Pivot Bearings

Figure 24. (CONFIDENTIAL) SCUD Missile on Carrier (C)

APPENDIX IV (S-NOFORN) TRANSPORTER-ERECTOR-LAUNCHER VEHICLE ANALYSIS (U)

A. [redacted] General (U)

[redacted] This appendix contains a detailed description of the carrier vehicle and launching equipment used with the SCUD missile system. This analysis is based upon the 1960 and 1961 Moscow parade photographs of the vehicle and missile, and is supported by other intelligence data.

B. [redacted] Basic Vehicle (U)

[redacted] The basic chassis used for this vehicle is the same as that used for the Joseph Stalin tank and also for the JSU-122 assault gun.

C. [redacted] Erector-Launcher Assembly

1. [redacted] Operation (U)

[redacted] The mechanical operation of the erector-launcher assemblies depends on use of the two hydraulic pistons for erection, and the winch cable and pulley arrangement for return of the firing table to the transporting position. The missile is supported on the transporter-erector carriage by a retaining strap assembly near the nose cone, and by alignment fixtures at the aft skirt section. The carriage is held on a 3-point support, the rear pivot points, and a lock forward on the hutment.

[redacted] The operation necessary to erect the missile and complete the mission is as follows (refer to **Figure 24** for items in parentheses below):

a. [redacted] Position erection clamps (6) around missile and lock in place on lowering jacks.

b. [redacted] Release carriage lock (38).

c. Activate lifting piston (11) -- rotating missile, carriage and firing table assembly about pivot point (39).

d. [redacted] Disengage and store carriage locking arms (16).

e. Level azimuth table (17).

f. Position missile in cross level for alignment with firing table (17), using alignment fixture (13).

g. [redacted] Release retaining strap (1).

h. Raise support feet (18) to contact lugs on missile fins.

i. Transfer missile to firing table with the erecting clamp (6) assembly.

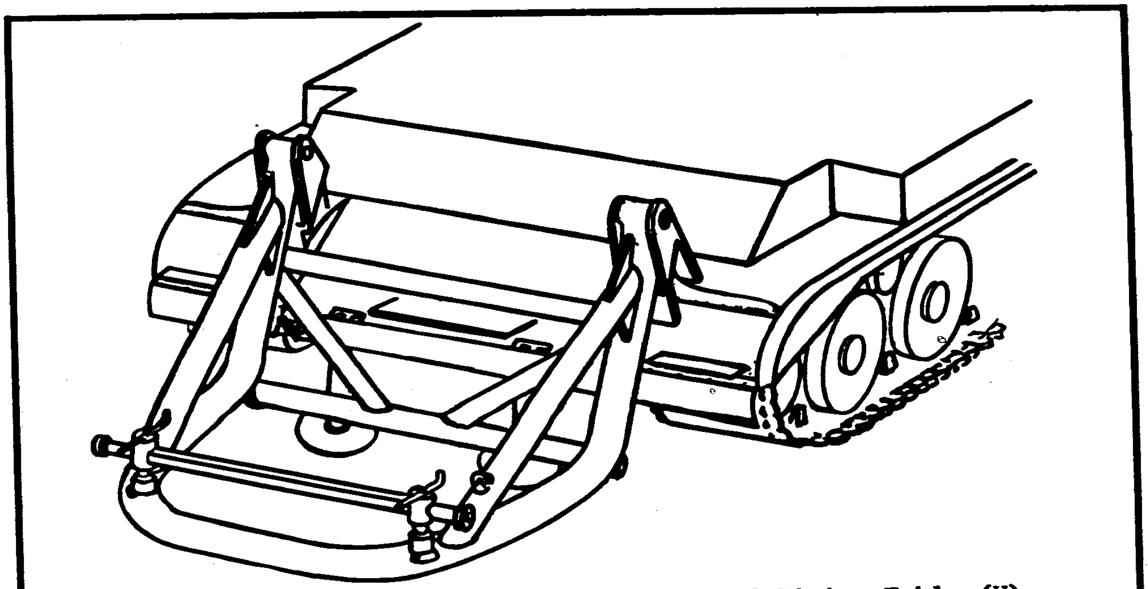
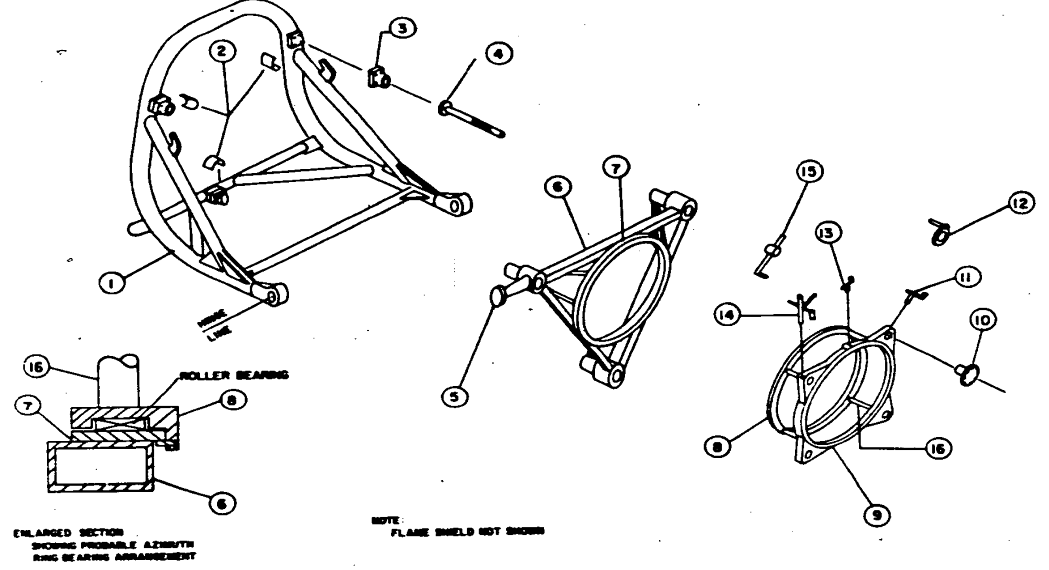


Figure 25. (CONFIDENTIAL) Artist's Concept of Firing Table (U)



1. HORSESHOE WELDED FRAME
2. FLAME SHIELD (FOR ADJUSTMENT SCREW THRUST BEARING)
3. THRUST BEARING HOUSING
4. LEVELING SCREW ADJUST AND BEARING ASSEMBLY
5. FRAME RETURN PULLY
6. TRIANGULAR LEVELING FRAME
7. INNER AZIMUTH RING
8. OUTER AZIMUTH RING
9. TRANSFER RING
10. SUPPORT FOOT
11. SUPPORT FOOT LOCK
12. CABLE TIE DOWN RING
13. CABLE TIE DOWN RING LOCK
14. MISSILE TIE DOWN CLAMP
15. LEVELING SCREW HANDLE
16. RING SPACER

Figure 26. (CONFIDENTIAL) Exploded View of Firing Table Assembly (U)

j. [redacted] Disassemble erecting clamps and stow.

k. Fine level missile.

l. Lower carriage to horizontal.

m. After launching, the baseplate assembly is winched into the transporting position.

[redacted] Althrough the lowering jacks are not visible in the photographs, the presence of the two erecting clamp assemblies on the transporter indicates that the jacks are probably on the inside of the carriage beams. In addition, this is the only method available in the system to position the missile on the launch table. It cannot definitely be determined whether the alignment fixtures are used in the role indicated above, however. It is possible that the table may not be leveled until after the load of the missile is placed on it. It is possible to lower and adjust the firing table assembly separate from the carriage using the winch. Since the load of the missile is held on the carriage, however, the firing table can as easily be lowered and adjusted at the time of missile erection (see **Figure 25** for artist's **concept of firing table).**

2. [redacted] <u>Firing Table Assembly</u> (U)

The horseshoe-shaped pipe frame is the basic structural member (**Figure 26**). To this, a triangular, welded member is attached by adjustable collars. Two of these are screw adjustments for cross leveling while the third collar provides leveling in the fore/aft direction, a 3-point support system. The next major component is a set of two circular rings separated by spacers. It is believed that the first ring contains the azimuth rotating mechanism while the second ring with the four support feet is probably only a load transfer plate. Azimuth adjustment is verified by examination of photographs. The blast deflector, hold-down clamp, and miscellaneous support pieces complete the baseplate assembly.

[redacted] Both the baseplate assembly and the launching carriage are supported and hinged at the same point at the rear of the vehicle. Mechanical stops prevent the angle between baseplate and launching carriage from becoming less than 180 degrees.

3. [redacted] <u>Transport Carriage</u> (U)

The transport carriage is made up of two major structural members; the side pieces. The supporting structure includes those members necessary to tie the major structural members rigidly together and the tubular steel framework forward of the retaining strap. A ladder built on the carriage beams is provided for servicing the missile when in the vertical position.

[redacted] The transport carriage is supported by the aft carriage supports, the hydraulic lifting arms and, when in the horizontal position, the hutment of the vehicle. Just forward of the hutment the launching carriage release provides a position lock, holding the launching carriage to the vehicle.

1 4. [redacted] Hydraulic Lifting Mechanism (U)

The hydraulic system which provides erecting service to the system is composed of two large extensible hydraulic pistons, a reservoir, a pump, and associated fill and bleed lines. The extension pistons permit erection to the vertical position and are well within design limits for this operation. Hydraulic exit orifices are controlled so that these same lifting pistons slow the descent of the launching carriage when it is lowered into the carrying position. The power for the hydraulic system is controlled by the driver who activates the auxiliary engine.

1 5. [redacted] Miscellaneous Launching Equipment (U)

1 a. [redacted] Winch (U)

The winch is located on the top of the hutment. This item is used to manipulate the baseplate assembly from the carrying position and return. There is a bar lock for securing the baseplate on the right side of the vehicle in the carrying position. Power for the winch is taken from either the main engine generator or the auxiliary engine generator.

1 b. [redacted] Cylindrical Tanks (U)

The purpose of the cylindrical tanks along either side of the hutment is not specifically indicated. Most probable uses, however, based on the needs of the missile are for storage of cold gas for use during pre-launching checkout and for pressurization. Inert cold gas is necessary for tests during the checkout period. If these external tanks carry nitrogen at an assumed pressure of 2940 psi, the size of the tanks is such that pressurization and checkout requirements are met and exceeded by a small amount (possibly an allowance for leakage due to field operation).

1 c. [redacted] Remote Checkout Gear (U)

Due to the nature of the missile, the vehicle, and the launching equipment, it is deemed unsafe to fire the missile while the crew is on the vehicle. Thus, remote equipment, both for radio operation and last minute checkout and firing, is essential. The opening on the right side of the hutment, covered by a hinged access plate, could be used to house this remote gear. It is believed that this remote equipment is used beginning approximately 5 minutes prior to launching time for final go-no-go circuit checks and for initiating tank pressurization.

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APPENDIX VI [redacted] GLOSSARY OF TERMS AND SYMBOLS (U)

Collimator	A component of an instrument set that is designed to measure horizontal and vertical angles, and also is used as the aiming point.
DVO	Far Eastern Military District
GRAU	Chief Missile Artillery Directorate
GSFG	Group of Soviet Forces in Germany
KP	Command Post
PAMS Station	Mobile Meteorological Artillery Station
Panoramic Sight	A component of an instrument set used to aim the missile at the target.
PRTB	First letter of the four Russian words meaning Mobile Repair Technical Base.
Quartz generator	Frequency control device
RV	Missile troops
SGF	Southern Group Forces
Siting Area	Launch position area
SP	Siting position or launch point
S/S	Supply depot
Technical Site	Forward area missile storage and checkout area
Turk VO	Turkestan Military District
Waiting Area	Forward holding area occupied temporarily by units prior to moving forward to siting area.
Zak Vo	Transcaucasian Military District
8A61	Another Soviet designation for the SCUD missile

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