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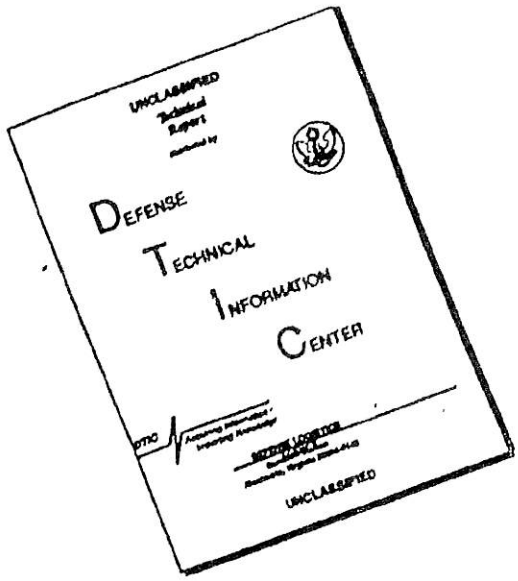

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NUCLEAR RAMJET PROPULSION SYSTEM
APPLIED RESEARCH AND ADVANCED TECHNOLOGY
(PROJECT PLUTO)

VOLUME V
PROPULSION SYSTEM TEST PLANNING AND GROUND TEST FACILITY STUDIES

TECHNICAL DOCUMENTARY REPORT ASD-TDR-63-277, Volume V

15 February 1963

Directorate of Aeromechanics
Propulsion Laboratory
Aeronautical Systems Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

Project No 655A, Tasks Nos. 1 and 5

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FOREWORD

This report was prepared by The Marquardt Corporation, Van Nuys, California, on Air Force Contract AF 33(657)-8123, under Tasks Nos. 1 and 5 of Project No. 655A, "Nuclear Ramjet Propulsion Systems Research and Technology." The work was administered under the direction of the Propulsion Laboratory (Directorate of Aeromechanics), Aeronautical Systems Division. R. F. Latham was Project Engineer for the Laboratory.

The studies presented here were performed during the contract period 1 January to 31 December 1962. The Marquardt Corporation activities were under the direction of A. O. Mooneyham, Senior Project Engineer. Chief contributors were J. G. Bendot, Aerothermodynamics; R. D. Grossman, Design and Development; and R. K. Nuno, Controls.

This report is the final technical summary report and concludes the work on Contract AF 33(657)-8123. The contractor's report number is Marquardt Report 6004. The volumes of this report are as follows:

Volume I:	Summary
Volume II:	Propulsion System Performance and Aerothermodynamics
Volume III.	Propulsion System Controls
Volume IV:	Propulsion System Design and Structural Analysis
Volume V:	Propulsion System Test Planning and Ground Test Facility Studies
Volume VI:	Structural Materials Investigations

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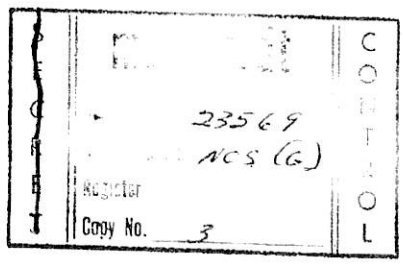

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ABSTRACT

Test planning studies in this report present the present concept of test programs, their scope, test objectives, probable testing schedule, estimated number of test weeks and test runs, existing facilities which can be utilized, and test conditions. The schedule and test plans presented are based upon the program outlined in the Air Force Development/Plan for Pluto (AF Report 655A(62A SRS 1614) dated 28 June 1962.)

Flight engine ground test facility criteria are updated to reflect the latest facility studies and test planning. The site selection core drilling program and underground air storage experiment are described.

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1.0 INTRODUCTION

Experience accumulated by The Marquardt Corporation and other powerplant companies on many propulsion system development programs has firmly established the requirement for test facility and test program planning and analysis prior to and during a development program. This advanced planning has become increasingly more important with the advent of larger, faster, more expensive, and more sophisticated propulsion systems.

A concept of the Pluto propulsion system and flight vehicle configuration is shown in Figure 1. The propulsion system consists of a supersonic inlet, subsonic diffuser, nuclear reactor, exhaust nozzle, and associated inlet, bypass, and reactor controls. The test program as outlined takes each of these components through the appropriate steps of model testing, component tests, subsystem tests, and integrated system tests. The test planning results evolved and presented herein concern only the propulsion system and represent a first iteration. Subsequent propulsion system test planning studies are required to revise the development plan to incorporate advancements in technology and program requirements. Further test planning studies are required to provide a thoroughly coordinated plan with the AEC reactor contractor and the vehicle contractor.

It is noteworthy to point out the evolution of test planning philosophy associated with the Pluto program. During the early conception of the program it was envisioned that system testing would constitute the bulk of the development. This would involve many units in a long series of tests to develop simultaneously both components and systems. As more knowledge of the system and its components was gained, it became apparent that a more logical and more economical development would manifest itself as an extensive component development program followed by a few judiciously selected systems tests.

The nuclear ramjet propulsion system requires a specially designed facility to accommodate both the large quantities of air required for simulated flight testing and the nuclear radiation from the reactor. The test facility, and in particular the air supply, may be considered a long lead item and its requirements and preliminary design must be established to allow definitive development program planning to proceed.

Test facility studies have been conducted to assure incorporation of the most recent test requirements into the facility criteria. Facility studies have also been directed toward establishing feasibility of economical design concepts such as the storage of large quantities of air in underground chambers.

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2.0 SUMMARY

The test planning studies assume a development plan proceeding from initial model and component test programs up through PFRT (Preliminary Flight Rating Tests). In addition, preliminary system tests are presented for formulation of military specifications governing Acceptance Test and Qualification Test procedures for the nuclear ramjet powerplant.

The proposed nuclear ramjet development program schedule is shown in Figure 2. The program schedule shows the estimated time span for propulsion system development and facility construction. The schedule and test plans presented in this report are based upon and are in accordance with the program outlined in the Air Force Development Plan for Pluto (AF Report 655A(62A SRS 1614) dated 28 June 1962).

The FEGTF (Flight Engine Ground Test Facility) studies were conducted to incorporate current testing philosophies into the facility design and to update the facility criteria accordingly. The criteria updating reflects changes in test time, air storage system recovery time, engine design changes, and test planning. Design studies have included the concept of an "open" test point and cost comparison of facilities designed to accommodate various maximum engine sizes and test run duration.

The concept of economical air storage in underground chambers was investigated further through a site selection core drilling program, design of an underground air storage chamber, and the underground air storage experiment. The core drilling program included the drilling, core recovery, and logging of nine holes that ranged in depth from 262 to 1000 feet. Two sites which appear suitable for underground air storage were located within the area proposed for the FEGTF.

Design of an underground air storage chamber was completed based on the assumption that the surrounding rock mass would behave as an elastic, semi-infinite thick walled cylinder and a minimum in situ modulus of elasticity of 1.5×10^6 psi. The design included necessary structural and mechanical calculations, design drawings, specifications, and cost estimate. For a chamber capacity of 7 million pounds useable air stored under 3,600 psig, the cost was estimated at $9 176,047.

An experimental program was conducted for the purpose of obtaining data on the performance of a high pressure metal lined underground air storage chamber located in the 401 Area of the Nevada Test Site.

During the experiment, a pressure of 2560 psi was obtained. At this point the metal liner ruptured and the experiment had to be terminated. An inspection of the test chamber revealed that a sudden displacement of the rock mass to one side of the chamber occurred, thereby allowing the metal liner to rupture.

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For economical reasons the pilot chamber was located at the relatively shallow depth of 190 feet. The rock in this area exhibited more than adequate quality in laboratory testing. However, during excavation a rather high degree of fracturing and gappage was found to exist. It is expected, based upon the inspection of cores from the site selection core drilling program, that a significantly lower degree of fracturing and tightly sealed gappage occurs at the full chamber depth of 500 to 800 feet.

The data obtained from the experiment have confirmed the design approach and have established a theoretical model describing the behavior of pressurized rock.

A quantitative correlation between the characteristics of pilot location rock and full chamber location rock must be made to allow a full evaluation of the experimental data relative to liner design.

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3.0 PROPULSION SYSTEM TEST PLANNING

3.1 Model Test Programs

Initial design optimization of certain Pluto components and subsystems may be accomplished more economically utilizing scale models. Components in this category and for which model test programs were defined include the supersonic inlet, the subsonic diffuser, the exhaust nozzle, and the exhaust system afterbody. A model test program is also defined to provide design criteria for the full scale free jet test nozzles.

3.1.1 Supersonic Inlet

Two inlet design configurations are currently under investigation for use on the Pluto propulsion system: the axisymmetric inlet being investigated at TMC; and the double scoop inlet being investigated by CVC. The test program for the axisymmetric inlet is presented in this report (Table I) and covers the period of October 1962 to July 1965. Three scaled models will be used for the test program. These are:

1. 1/11 scale model for aerodynamic parametric studies, performance predictions and drag measurement
2. 1/3 scale model for control parameter studies and inlet dynamics; and
3. 0.15 scale model for inlet bleed, control parameter and performance studies.

During CY 1962, CVC conducted a development program on the double scoop inlet design similar to that on the axisymmetric design. Following the NASA Ames test scheduled for December 1962 on the 0.15 scale axisymmetric model, the Air Force will select a design from the two inlets. The selected inlet design will then be developed. The indicated test program scope shown in Table I is applicable for either inlet design. The test program outlined consists of 87 test days yielding approximately 600 test data runs over a calendar period of 33 months. The test conditions include a Mach number range of 2.4 to 3.6 with angle of attack and yaw range of 0° to 5°.

3.1.2 Subsonic Diffuser

The nuclear ramjet missile design includes a submerged installation of the propulsion system. The controlling influence on design of the subsonic diffuser emanates from vehicle integration and structural considerations. Development of the subsonic diffuser must therefore be accomplished in conjunction with the vehicle. Internal aerodynamic development of the diffuser will be accomplished concurrently with the supersonic inlet.

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In the aerodynamic evaluation program, the subsonic diffuser utilizing structural lines supplied by CVC, will be tested with the 1/11, 1/3 and 0.15 scale inlet models. The number of test runs, number of test days, and test conditions will correspond to that shown for the inlet model program and will coincide with the program shown in Table I for the period 1963 through mid-1965. The development information to be obtained is as follows:

1. Pressure recovery characteristics
2. Inlet and exit pressure profiles
3. Drag data
4. Inlet-diffuser coupling effects
5. Separation at pitch and yaw operation, and
6. General duct dynamics

3.1.3 Exhaust Nozzle

Initial development tests of the exhaust nozzle were accomplished during 1961. From these tests a design concept was selected which exhibited superior performance characteristics and a favorable trade-off between weight, material of construction and cooling. The development of the convergent-divergent ejector type exhaust nozzle will proceed through a combination of scaled model testing and full scale component testing. The full scale component test program is described in Section 5.1.2 of this report. A summary of the scaled model test program is shown in Table II.

The model test program will utilize both full scale test sectors and scaled models during the four test periods consisting of 55 test days and yielding approximately 254 test data runs. Development information to be obtained will include (1) heat transfer design data and demonstrate feasibility of ejector cooling concept, (2) investigate structural design integrity, and (3) determine the nozzle performance characteristic.

Temperature, pressure and air flow ratios of the secondary and primary air streams will be varied to bracket the characteristics of any configuration which may be selected upstream in the secondary flow channel.

Test facility surveys indicate that existing test facilities at MJL-VN or NASA are suitable for the test program. Special test equipment required includes a booster air heater of the vitiated type.

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3.1.4 Exhaust System Afterbody Optimization

The current system design requires that the cooling air used for airframe, air conditioning, shielding, and auxiliary environment control be discharged overboard through the annular space between the exhaust nozzle and airframe shroud. As shown in Figure 3, there will be four air streams impinging within this area: primary air stream, secondary air stream, airframe and auxiliary cooling, and vehicle external air stream. Flow interference problems may develop during off-design operation affecting auxiliary flow requirements, nozzle performance, and drag.

Wind tunnel tests of 1/12 scale models will be accomplished in two series of tests as shown in Table III. Test objectives will include optimization of the annular gap configuration between the exhaust nozzle and airframe for the initial PS-1 design and the final flight design. Annulus temperature, pressure, and boattail drag will be determined.

Existing wind tunnel facilities, either commerical or government, with simulation capability for the "on the deck" flight condition are available. Special test equipment in the form of air heater capacity may be required.

3.1.5 Free Jet Nozzle Spillage Ratio and Starting Technique Tests

The model tests (Table III) to be conducted will provide design criteria for the flight engine ground test facility. The effects of blockage of current proposed engine inlet designs on startup and operation of free jet nozzles will be determined. Engine inlet loads will be obtained during flow transition from subsonic to supersonic. The test program will include evaluation of the selected Pluto/Slam inlet configuration using 1/11 scale models with several free jet nozzle systems having broad spillage ratios.

Existing Air Force facilities can be utilized for the test program. Special test equipment needs include the free jet nozzles and shrouds.

3.2 Component Test Programs

Test programs are defined for development of the following components which make up the Pluto propulsion system: exhaust nozzle, reactor side support, inlet-diffuser, reactor axial supports, controls, and the airframe auxiliary cooling system.

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The component development test plans presented in the next four tables include documentation of the components at the most severe operational conditions expected in programmed flight to establish a high degree of component reliability. Additionally, test conditions will be imposed during the tests which will simulate several eventualities which may occur during the flight program. The eventualities include the following: inlet-diffuser buzz, extreme g maneuver, operation at off-design conditions, extreme climatic conditions, handling and transport accidents, and reactor over-temperature. A description of each component development test area is presented below.

3.2.1 Exhaust Nozzle

The convergent-divergent ejector type exhaust nozzle design which evolved from the scale model program has been selected for full scale development test. The uncoated nozzle configuration must satisfy the following requirements: (1) high performance ($C_d > 0.98$), (2) withstand 2600°R gas temperature and 325 psia pressure for an extended period of time, (3) withstand high g loads, and (4) have remote coupling/uncoupling capability for reactor removal/installation.

The component development test areas of the exhaust nozzle include the primary duct wall and liner, the airframe cooling system, the liner seal, the duct attach mechanism (including the remote disconnect feature) and the instrumentation required for determination of propulsion performance. Proof tests of hardware required for PS-1, PS-2, and PFRT system test programs are also defined. The test program is shown in Table IV. The development test program is shown in Table IV. The development test program outlined in the table consists of 30 test weeks over a time span of approximately 27 months with completion during the first quarter of 1966.

Test facility surveys indicate the Tory IIC facility has the required flow capabilities. Special test equipment required includes an air heater booster (2600°R temperature and 2000 pps capability) and an air distribution manifold upstream from the test item.

3.2.2 Reactor Side Support

The reactor side support system provides radial restraint of the reactor core during thermal cycling of the reactor, and during vehicle maneuvers maintains proper alignment of the reactor with the exhaust duct.

The development test program as defined proceeds in a step pattern involving individual spring component tests, full length sector model tests, and full scale slice tests. The component tests will consist of load-deflection and structural evaluation of several candidate spring designs under elevated temperature conditions of 1200°F. The full length sector model will be used to determine pressure drop and heat transfer characteristics at design mass flow (120 pps total) and temperature (1200°F). Approximately 12 weeks of tests yielding approximately 80 test data runs are required for the sector tests as shown in Table V.

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Side support system dynamic behavior will be determined by vibration and shock tests of a full diameter slice. The proposed tests will be conducted at ambient conditions and with various spring preloads. Test conditions will include random and sinusoidal vibration inputs up to 7 g's and cyclic differential pressure loading to simulate effects of buzz condition on the core matrix and side support system. The core matrix will be of steatite tubes representing actual fuel element geometry. Three test periods involving a total of 12 test weeks, are required as indicated in Table V.

Test facility surveys indicate several existing commercial and Air Force facilities having the required capabilities are available for the side support system tests. Special test equipment required includes an air booster heater (1200°F) and cyclic differential pressure simulation.

3.2.3 Inlet-Diffuser

The development test program for the inlet-diffuser is divided into 5 phases which includes the air bleed system, the bypass doors, variable geometry inlet, remote coupling, and proof tests of hardware for PS-1, PS-2 and PFRT system demonstration programs. The test programs are summarized in Tables V and VI. A brief description of the tests follows:

1. Bleed system - Eight test weeks yielding 20 test data runs at free jet flow conditions of Mach 2.5, 2.7 and 3.0 are required to optimize bleed slot position and performance documentation. National test facilities (OAL-Texas and Tory IIC-Nevada) are available for the subject tests. Special test equipment required includes free jet nozzles and shrouds.

2. Bypass door - Approximately 9 weeks of direct-connect test are indicated yielding about 25 data runs to evaluate door size and flow characteristics, door functional operation under load, and structural integrity. National facilities indicated under Item 1 above can be utilized for the tests. Special test equipment required includes a direct-connect air nozzle and booster air heater.

3. Variable geometry inlet - Development tests of the cowl and translating spike are required to determine inlet recovery characteristics at predetermined spike positions; to obtain control parameter data; and to verify structural integrity of components during inlet start, unstart and restart conditions. Approximately 10 free jet flow test weeks in the Tory IIC facility are required which is estimated to yield 27 data runs.

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4. Remote coupling - These series of tests involve functional and structural evaluation of a remote coupling device for the inlet which is required for subsequent propulsion system ground documentation tests. Static tests at expected operating pressures to prove the structural integrity are required.

5. System proof tests.- Three test periods in the Tory IIC facility are required for documentation of structural integrity of hardware required for the PS-1, PS-2 and PFRT test demonstration programs.

3.2.4 Reactor Axial Supports

Development tests of the reactor axial supports will be accomplished by a reactor contractor selected by the AEC, therefore, only structural proof tests of hardware for the PS-1, PS-2, and PFRT propulsion system programs are defined (Table VI). The axial supports consist of the forward grid front support, the core tie rods, and the downstream base plates. Existing Air Force and National facilities are available for test use; however, a booster air heater (2550°R temperature capability)and load simulation equipment is required as special test equipment.

3.2.5 Propulsion System Controls

The functions of inflight propulsion system controls include precise modulation of engine thrust and engine aerodynamics to fit a programmed mission course. The controls must compensate for any variations from programmed thrust, altitude, Mach number, angle of attack, and angle of yaw. The control components while being subjected to elevated temperatures and a nuclear environment must perform their function for extended periods of time, possibly for 10-hour flight missions.

The major components which make up the control system include the following:

1. Mechanical-pneumatic actuators and servo valves to operate the reactor control rods, the bypass doors, and the contraction ratio controller.

2. Inflight control electronic circuits and associated sensors which supply the intelligence to control the nuclear reactor during flight.

3. Ground control system consisting of sensors and electronic computing and control equipment to start the nuclear reactor and bring it to a power level ready for launching.

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The proposed controls test program schedule is shown in Table VII. The development test program consists of bench development testing and environmental test of the components. The development test mileposts include component development test phase completion by mid 1964, completion of flight prototype hardware tests by the end of 1965 and documentation of flight type hardware prior to pre-PFRT. A detailed description of the component development test phases is included in Reference 1.

3.2.6 Airframe and Auxiliary Cooling System

The airframe and auxiliary cooling system perform a variety of functions within the propulsion system and the flight vehicle. These functions are as follows:

1. Provides the air requirements for the pneumatic actuator systems of the variable geometry inlet, bypass doors, and reactor control rods

2. Provides the air requirements for the air conditioning system located in the vehicle, and

3. Supplies cooling air for the warhead shielding, the airframe attach structure, and the exhaust nozzle shroud and convergent-divergent sections

The air is scooped within the propulsion system diffuser and is exhausted to the atmosphere at the aft end of the exhaust nozzle.

The development problems associated with the airframe and auxiliary cooling system include sizing of air inlet scoops and the exhaust passage to meet the pressure and mass flow requirements of the functions listed above. Additionally, exhaust system afterbody geometry has a significant effect on propulsion system drag and will require a sophisticated development program. Initial development and concept selection will be performed with a scale model as indicated in the model section of this report. Full scale development tests can best be accomplished as part of the diffuser and exhaust nozzle component programs.

3.3 Subsystem Test Programs

The purpose of subsystem testing is to demonstrate the compatability of two or more developed components and to document subsystem performance and structural characteristics of the combined components. The subsystems of the PLUTO propulsion system are identified as follows:

1. Inlet, diffuser, bypass doors, and actuator systems for variable geometry and bypass doors

2. Reactor side support system, control rod assembly, and exhaust nozzle

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3. Nuclear reactor, control rod assembly, control rod actuator system, and exhaust nozzle

A summary of the planned test programs is presented in Table VIII. A brief description of each subsystem program follows.

3.3.1 Inlet, Diffuser, Bypass and Actuator Systems

The subsystem test program involves documentation of the variable geometry inlet, the diffuser, and the bypass doors with the actuator systems which position the variable geometry inlet and the bypass doors. The main purpose of these tests will be to verify the function and response of the integrated components during conditions of inlet start, unstart and restart. Additional test objectives will include documentation of inlet performance, verification of selected locations of control sensors, and the documentation of subsystem structural characteristics. Backpressure simulation of the reactor and exhaust nozzle performance will be obtained using a pressure drop device and plug arrangement.

Three test periods each of 6 weeks duration are required yielding approximately 60 test data runs. The first two test periods will be devoted to documentation of initial component development designs and the latter test period will culminate the development program with documentation of the final PFRT/flight design.

The test objectives, test conditions, and the required special test equipment are shown in Table VIII. The indicated test conditions were established based on the facility capabilities of MJL-VN and OAL-Texas. These facilities have short run time capabilities; however, they were selected for these test series because of anticipated scheduling problems in the Tory IIC facility. If the testing can be accomplished in the Tory IIC facility, then lower altitudes than indicated can be documented.

The special test equipment which is required includes the backpressure simulator, the Mach 2.5, 3.0, and 3.6 free jet nozzles and shrouds, and the test item support stand.

3.3.2 Reactor Side Support System

Proof tests of the full scale (length and diameter) reactor side support system (and associated components) are required to demonstrate system dynamics and structural integrity under normal programmed flight conditions of boost, gust, maneuver, and stares ejection loading.

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During the vibration tests, lateral acceleration at the fore and aft reactor stations will be varied in and out of phase to simulate engine structure whip. The side support structure and reactor core should be subjected to the elevated temperature environment (if practicable) expected in flight during the subject tests, and for time periods equalling that in flight. The proof tests will include vibration of the test item through the g load range of 1 to 9 and a frequency range of 1 to 500 cps.

The test item will include the reactor core, the pressure vessel, reactor side and axial supports, the exhaust nozzle and the control rods (mounted in simulated diffuser section). The reactor core will be simulated using steatite tubes.

Commercial test facilities are available for the vibration tests; however, capabilities are limited. To meet the above test requirements, shaker assemblies will have to be added to existing ganged shaker systems. In addition, the vibration test facilities investigated lack the required temperature environmental capability.

3.3.3 Reactor, Reactor Control Rod Actuators and Exhaust Nozzle

This subsystem test program will involve demonstration tests of the reactor, exhaust nozzle, and the inflight reactor control system. The overall purpose of the test program will be to demonstrate reactor control by the inflight control system. The demonstration will include control system modulation of reactor power level from the condition of launch to cruise power while maintaining the reactivity below "prompt" critical and reactor temperature at 2500°F. Additional test objectives will include documentation of reactor performance using control system overrides and structural and functional evaluation of the flight type actuator systems. The detail test objectives and test conditions are listed in Table VIII.

Two test program periods each of 6 weeks duration are required for the subject tests. The latter test period which is shown scheduled just prior to pre-PFRT will culminate the reactor development program.

3.4 Integrated System Test Planning

The PLUTO propulsion system test demonstration program was established by the Air Force in mid-1962 and is presented in the Air Force Development Plan for PLUTO (Reference 2). The integrated system test programs which have been scheduled include the following:

PS-1. To be accomplished 20 months after initiation of the full scale program

PS-2. To start 9 months after PS-1

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PS-3. (Pre-PFRT) To start 18 months after PS-2

PS-4. (PFRT) To start 24 months after PS-2

A brief description of each system test program and the planning studies which were accomplished during CY 1962 is presented below.

3.4.1 PS-1 Program Plan

The purpose of the PS-1 test program is to demonstrate successful operation of a ramjet engine consisting of a supersonic inlet, an S-shaped subsonic diffuser, a Tory IIC type reactor, and an exhaust nozzle. Test hardware will be flight type but not flight weight. Testing will be accomplished in the Tory IIC facility and test conditions will be restricted to those available with current capabilities.

The detail test program objectives, test installations, and special test equipment needs are contained in Reference 1. The proposed test run plan is shown in Table IX. A detail test run plan will be formulated jointly by the participating Air Force contractors and the AEC reactor contractor prior to the test demonstration.

3.4.2 PS-2 and PS-3 Program Plans

Detail test program planning for PS-2 and PS-3 has not been accomplished to date. In general, the test conditions and test run plan for PS-2 will be identical to PS-1. It is assumed at this time that, following the Tory IIC reactor demonstration tests, an AEC reactor contractor will be selected and assigned the task of designing and fabricating a flight prototype reactor. PS-2 will then serve as the test demonstration of an integrated system of flight weight design utilizing this reactor. The test program will be conducted in the Tory IIC facility.

The PS-3 program objective will be the documentation of integrated system endurance with flight prototype hardware. Test conditions will duplicate typical flight conditions and expected flight operating times. The new Air Force test facility will be used for the program. Successful completion of the PS-3 program will demonstrate the system is ready for formal PFRT.

3.4.3 PS-4 (PFRT) Program Plan

The proposed test program plan is in general conformance with the philosophy and intent of tests outlined in MIL-E-8223A Preliminary Flight Rating Test for Ramjet Engines with deviations and additions to accommodate unique and special features associated with a nuclear ramjet power plant. The PFRT will be conducted in two parts: (1) full scale propulsion system testing, and (2) component/subsystem testing. The PFRT program summary is presented in Table X.

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Propulsion system tests will include boost simulation, high altitude performance and dynamics, boost takeover, letdown, low altitude performance and dynamics, and low altitude durability. Subsystem PFRT will include documentation of performance and endurance characteristics of the inlet, reactor, controls, reactor lateral support, and exhaust nozzle.

3.5 Proposed Procedures for Acceptance and Qualification Test of the Nuclear Ramjet

3.5.1 Acceptance Tests

Acceptance test procedures will, in general, follow those described in MIL-E-8222A (ASG) Acceptance Test for Ramjet Engines. The major deviation from the military specification is the elimination of the thrust demonstration run. The radiation level subsequent to a hot reactor run would prohibit post test inspection and use of the engine for flight. The proposed tests will include calibration of non-nuclear components separately and calibration of the engine system using a pressure drop simulator in place of the nuclear reactor.

3.5.2 Qualification Tests

The qualification test program philosophy presented in Reference 1 is in general conformance with the military specification MIL-E-8221A (ASG) Qualification Test for Ramjet Engines. The test program described in the reference takes into account factors peculiar to nuclear power plants. These include nuclear power plant trajectory times, the limitation on nuclear component cycling, radiation hazards, and the post test inspection limitation. Because of the above factors propulsion system tests are subdivided into nuclear and non-nuclear test phases. The major deviation from the military specification is in regard to demonstration of propulsion system endurance. In the proposed plan, system endurance will be documented in flight.

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4.0 PROPULSION SYSTEM GROUND TEST FACILITY STUDIES

4.1 Facility Criteria Studies

As part of the 1962 contract, FEGTF studies were conducted and the criteria were updated accordingly. This updating reflected changes in run time, air storage system recovery time, PLUTO engine design changes, and engine test planning revisions. The following discussions of the facility revised criteria studies are excerpted from Reference 3.

4.1.1 Facility and Test Requirements

At the beginning of the contract year, an evaluation of the testing requirements for the facility was made, and ground rules were established which provided that the facility shall

1. Provide an independent Air Force test point while sharing the Tory II Maintenance and Disassembly Building and making maximum use of exiting Tory II services

2. Utilize underground air storage and vitiated air heating (finding results of the UAS Experiment and Core Drilling Program)

3. Be capable of handling test engines to a maximum of 63 inches in diameter

4. Provide the following maximum operating conditions for the 63-inch diameter engine

Mach Number	Day	Altitude	Mass Flow	Duration
3.0	ANA Cold	1000 ft	2585 pps	90 minutes
3.0	ANA Hot	1000 ft	2300 pps	90 minutes
3.1	ANA Cold	Sea Level	3240 pps	60 minutes

5. Be capable of handling a maximum equivalent of 1 full power 90-minute run every fifteen days

6. Be capable of free jet testing an axisymmetric inlet configuration on engines of maximum diameter

7. Have an open test point with provisions for remote inspection of the test item but no provision for remote maintenance or service shall be established.

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4.1.2 Air Supply System

Updating of the design criteria covering the test air supply system was accomplished during the 1962 contract year to reflect revisions of the required test air flows. The test air flow requirements resulted from revisions to engine operating conditions such as Mach number, day, altitude, mass flow, test duration, and other related criteria. The basic areas of the air supply system affected were: compressors, low pressure blowers, air storage system, piping and valving, and the heater.

4.1.2.1 Air Compressor System

Study of the testing requirements of the PLUTO propulsion system, (that is, testing frequency and duration) changed the test air compressor system performance criteria. The basic requirements for the high pressure compressor system were redefined as follows:

Component or Function	Requirement
Air Discharge, Average Capacity	8.43 lbs/sec
Air Discharge Pressure	3800 psig
Air Discharge Temperature	100°F
Ambient Air Intake Pressure	12.5 psia
Ambient Air Intake Temperature	85°F
Compressor Type	Reciprocating piston, multi-stage
Compressor Drive	Diesel engine integral drive
Compressor Horsepower (approx.)	3960 hp total
Compressor Units, Quantity	3 min to 4 max
Compressor Control	Manual start and setpoint with automatic hold on setpoint

The compressors shall be designed to operate against a continuous 3800 psig discharge backpressure. This backpressure shall be controlled downstream from the aftercooling system.

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In accordance with previous economic studies of alternate compressor units, a diesel engine drive system was selected for the compressors, and new requirements for the required fuel storage system were defined. Pumping and piping requirements for the engine fuel system were determined and included in the revised criteria. Figure 4 shows the general arrangement of the compressors, piping, and compressor building.

4.1.2.2 Low Pressure Blower System

For an "open" test point concept, the requirements for low pressure test air would be revised as follows. The bunker, access tunnel, and head house require filtered air ventilation for personnel. Also, the test item requires approximately 50 pps of cooling air for extended periods after each test run. This cooling air must be supplied by a low pressure blower system, rather than from the high pressure test air storage system, in order that reliable reactor after-cooling can be assured. Thus, the high pressure storage system can be recharged for a subsequent engine test, and serve as backup to the low pressure blower system in an emergency.

The low pressure blower system criteria specifies primary supply blowers for the head house. These primary blowers will supply filtered air ventilation (at positive pressure) for the head house, tunnel, and test point bunker. They will also provide intake to the secondary blowers located in the bunker and used for engine cool-down. Figure 5 shows the test bunker and arrangement ofthe equipment including the blower system.

4.1.2.3 Air Storage System

Design investigations for underground test air storage have been conducted at The Marquardt Corporation. The general feasibility and economic desirability of this type system has been established to the point that detail design, construction specifications, and cost estimates were prepared for a full scale duration during the current contract year. This work solved many design and analytical problems subject to final design revisions based on experiment and core drilling results. This part of the program is summarized more explicitly in Section 4.5 of this report.

4.1.2.4 High Pressure Test Air Piping and Valving

Extensive investigation of piping systems for economical delivery of high pressure test air at distances of 2000 ft and greater, have been performed by TMC. During the design of the Tory II test air system it was determined that, for storage purposes, standard oil well casing provided the most economical system. For the FDETF, the required volumes of stored air are far too great for an economically feasible aboveground, high pressure, compressed air storage system. However, the high air flow rate required by the test item suggested that the piping system utilize a number of these standard high pressure oilwell casings rather than a single large air pipe. Economic study confirmed this and the design criteria have been changed to multiple pipes for air delivery to the test point. The bunker (Figure 5) shows a suggested array of 13 pipes, of 10 3/4-inch OD terminating in a plenum chamber

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at the test point bunker. The number of pipes were determined from preliminary studies of pressure drop during flow and required total pressure at the test item. However, the criteria does not restrict the final design architect engineer to this number of pipes, only the type and size.

Pressure control valve types were selected, and specified in the design criteria, utilizing a multiple valve system in preference to a single large pressure control valve. A large valve, capable of controlling the air flow control required for the FEGTF, presents difficulties in flow sensitivity and response, whereas the use of several smaller valves, sequentially controlled, eliminates these problems. The design criteria were changed to include the multi-valve pressure control concept.

4.1.2.5 Test Air Heater System

Continuous high heat impact to the test air is necessary for the long run times planned for the FEGTF. An efficient, reliable, test air heater system of the type shown in Figure 6. Details of the development work done on this type of heater have been reported to the Air Force in References 4 and 5.

The design criteria were modified to include a vitiated air heating system with the following basic requirements:

Test air contamination by rust or corrosion	None
Fuel	Propane
Total startup time to "on line" condition	8 min max.
Maximum air flow	6800 pps
Heater exit air pressure	600 psia
Inlet air temperature	1100°F
Maximum permissible pressure drop	35 psi
Duration	Continuous

4.1.3 Test Point

The "open" test point and bunker requirements, as described in the criteria, are shown graphically in Figure 5. The test bunker, test air ducting, and test item orientation will be such that the test item exhaust will discharge to the northeast with a test item centerline azimuth of N 58° E.

Nuclear radiation from the test item imposes restrictions on building and other component spacing. Study of ground and equipment activating and personnel damage has shown that the "open" test point must be a minimum distance of 1900 feet from the head house, air storage system or other equipment where exterior work must be performed. In addition, the

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following features have been determined as necessary for the test point design, and have been included in the design criteria report:

1. The test point shall utilize the general topography in such a way that the test item will be below the natural grade as much as neutronics and topography permit (See Figure 5).

2. A concrete shielding wall shall be located between the test item and the bunker to protect bunker equipment from radiation.

3. Shielding shall attenuate nuclear radiation in order to prevent exceeding the following:

   a. During Test.- Control building, compressor building and other support facilities shall be left at distances greater than 4000 ft from the test point based upon limitations of personnel whole-body gamma dosage to 2.5 mr/hr.

   b. 24 Hours After Test.- Designated working areas, protected by shadow shield, shall permit personnel occupancy with whole-body gamma radiation limited to 1.0 mr/hr.

4.1.4 Instrumentation and Controls

The criteria covering instrumentation and controls requirements for the Flight Engine Ground Test Facility were updated during the contract year based on changes in test air heater concept, pressure control system and test air compressor requirements. This revision effort is summarized on the following instrumentation and control drawings.

Title	Drawing No.
Instrumentation and Controls - Schematic Temperature Control System (T_{t_o}) - Test Air Supply System	730262
Instrumentation and Controls - Schematic Pressure Control System (P_{t_o}) - Test Air Supply System	730263
Instrumentation and Controls - Schematic Raw Water System - Test Air Supply System	730265
Instrumentation and Controls - Schematic Vitiated Air Heater - Fuel Supply System Test Air Supply System	730267
Control Building - Plan and Elevations	730322

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4.2 Preliminary Design Studies

The studies conducted during the contract year were influenced greatly by the change in test philosophy for the Pluto flight engine. A closed cell type of test point was originally considered for the FEGTF based on the requirement for a high utilization factor engine test facility. Recent engine test planning assumes that most of the component testing, inlet and reactor controls synthesis, and flow stability and instability determinations, will be conducted at the Tory IIC facility. Furthermore, short run engine tests will be conducted at Tory IIC to develop a good confidence factor prior to the PFRT. As a consequence of this change in test philosophy and planning, the primary purpose of the FEGTF now is for durability test demonstration and performance of the PFRT.

A PFRT-type testing program normally consists of a relatively few runs of long duration with a resulting low annual accumulated run time. With this consideration dominating the testing philosophy, an "open" test point has been selected for the FEGTF, rather than the "closed" cell concept previously specified. The open test point, with its bunker, access tunnel and head house, is a testing system with inherent test item size flexibility. The closed cell concept, with its borated water shielding around the test item, and support equipment outside the shield area, is better suited for a heavy engine development workload where recovery from normal nuclear activation is critical to maintenance of engine development schedules.

The FEGTF arrangement studies have been made for test point, control and air storage system areas. For reasons previously described, these studies have been predicated on the concepts of (1) an open test point, (2) two underground air storage chambers, (3) a railroad car-mounted test engine, and (4) vitiated air heating.

4.2.1 Cost Estimates

Test facility costing activities were initiated primarily as a result of changes in testing philosophy, changes in size of the test engine, and variation in anticipated run times, test frequency, and support equipment and facilities. Cost estimates for 7 of the various alternate test facility concepts are presented in Table XI.

In addition to the cost estimating performed for the alternate concepts of the FEGTF estimates were made of costs for modifying the existing Tory IIC facility to meet the developmental testing requirements of the flight engine. Three air flow rates were considered: 1960, 2200, and 2500 pps. Also, run times of 15, 45, 90, and 180 minutes were included in the evaluations of costs for the three air flow rates. Tables XII, XIII, and XIV show in chart form the estimated costs of modifying the Tory IIC facility (as defined during February 1962) to comply with these various testing requirements. Figures 7, 8, and 9 show curves of these modification costs.

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It was concluded, from the analysis of the problem of Tory IIC facility modification, that the necessary air storage expansion could be most logically accomplished by additions to the above-ground oil-well casing system currently utilized. Figure 10 shows a schematic view of the Tory IIC air storage casing expansion.

4.3 UAS Site Selection Core Drilling - Phase I

During 1961 exploratory core drilling work was performed to locate a site suitable for an experimental underground air storage chamber, and to provide preliminary data that would aid in additional UAS site selection investigation planned for 1962. The 1962 core drilling program, Phase I, had a singular purpose: to select two sites suitable for full scale underground air storage chambers at locations that would permit an economically feasible aboveground air distribution system to the FEGTF. This site selection could be subject to minor movement as a result of the Phase II core drilling programs that will provide documentation of the rock walls for rock properties, fracture, and gappage. This latter phase must be conducted prior to construction of the underground air storage chambers. The work performed during the 1962 contract year (Phase I) was completed, and the results submitted in detail in Reference 6. The data presented in this report are excerpted from that reference.

4.3.1 Initial Core Hole Locations

When the site was established for the experimental underground air storage chamber in 1961, it was concluded that the rock in that area probably was suitable for construction of one of the full scale chambers, based upon its inherent qualities. Consequently, the area was selected as one to be explored as part of the 1962 Phase I core drilling program. Because of the cost of the high pressure aboveground air supply piping system necessary for the FEGTF, it was highly desirable to locate the second full scale underground air storage chamber as close to the first as practicable. Overburden involvement, however, prevents the second chamber from being closer than about 500 feet from the first chamber. In addition, the location of a site for the second chamber was further complicated by apparent faults in the area and by a lack of geological information due to the sparsity of rock outcrops.

These considerations dictated the decision to establish the first chamber area in the vicinity of hole TMC-1 and the second area approximately 700 feet SE of TMC-1. TMC-10 was the first point of exploration in this second area. Figure 11 shows the two areas explored during the Phase I Core Drilling Program, together with charted data of holes bored and total depths of each hole.

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4.3.2 Geological Description

The holes bored in this exploration are charted on the topographical map shown in Figure 12.

The easterly trending main access road to the TMC-1 and TMC-10 sites is approximately in the center of an easterly trending dike located south of TMC-1. All of the major northeast to northwest trending faults in the area that cut the dike probably offset it -- thus geologic mapping along the dike can detect positions of most or all of the major faults. This mapping has shown that two possible faults approach the TMC-1 area -- both of these trend about N 20 to 40°W; one cuts the easterly trending road near the TMC-1 access road and the other possible fault parallels the first and is about 600 feet east of it (about 100 feet east of TMC-12').

To the north of TMC-1, no convenient reference plane such as a dike exists, and major faults are more difficult to recognize from surface evidence. To establish the presence or absence of faults in this area and their locations, if present, could require a very costly drilling program. Therefore this area to the north of TMC-1 was avoided during this drilling program.

If the second chamber site were to be located 600 feet or so to the east or west of TMC-1, a major fault might be located between the two chambers (extensions of the faults that cut the main access road). Fault zones tend to be high in clay content and normally contain intensely broken rock. Such a zone of weak rock is undesirable in the vicinity of a chamber site.

Because of the various considerations involved, the area located about 700 feet south southeast of TMC-1 was considered to be the most promising to investigate.

An east trending igneous dike about 150 feet wide cuts this area. The dike rock is younger than much or all of the bedrock in the area. Some of the earth movements that have caused much of the rock fracturing in the area may have taken place before the dike was emplaced. If this was the case, then it was possible that the dike rock would prove, in general, less fractured than the surrounding older rock. Hole TMC-10, the first hole to be drilled at the hole 10 site, is located near the north edge of the dike outcrop and about equidistant between the two aforementioned north northwest trending faults.

4.3.3 Core Drilling and Logging

4.3.3.1 Core Drilling

The core holes were drilled using two skid-mounted drilling rigs. Three mud tanks were used for each of the drilling rigs: a working tank of 150 gallons, and two reserve tanks with a total capacity of 1500 gallons. Drilling circulation was performed with a double acting mud

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pump that circulated approximately 700 gallons per hour. The drilling was performed with "N" drill rods and an "M" series NX core barrel.

During the initial drilling of core holes TMC 7', 8, 11', 12', and 13, circulation water loss was a problem because of some higher permeability zones encountered during the drilling. In the zones where lost circulation was most prevalent, cementing was used to reduce the water loss, and in those cases where cementing was not effective, casing was set through the zone. Below 210 feet the water loss problem was not severe. Caving was encountered in three of the holes: TMC 6, 12' and 15' and in these holes it was necessary to case completely through the caved zones in order to complete the core drilling.

The wear on the drilling bits was moderate and in most cases over 100 ft of coring was accomplished with each drilling bit before the diamonds required resetting.

The vertical deviation of the core holes was less than 2° from vertical in each case, determined by the use of acid tubes run to a depth of 500 feet in each of the holes.

4.3.3.2 Core Logging

The cores recovered from the core holes were in general of sufficient lengths to permit good sample testing. Documentation of the data during core examination was made on a special form developed for the Phase I drilling program for purposes of standardization. Extreme detail included in the core logging was necessary to gather sufficient data on the rock units for correlation with rock units in adjacent holes and also to gather suitable data for use in the detail design of the full scale UAS chambers. During the core examinations, emphasis was placed on observations of (1) the fracture intensity and dip, (2) the materials in the fracture openings, and (3) rock alteration.

4.3.4 Core Test Results

Complete stress-strain curves in both axial and peripheral directions were generated for selected rock samples. These curves, with identifying core holes and core hole depths, calculated modulus of elasticity, calculated Poisson's ratio, and ultimate compressive stress are presented in the core drilling report (Reference 6). A summary of these results is presented in Table XV.

4.4 Underground Air Storage Experiment

4.4.1 Objectives

The Underground Air Storage Experiment was performed for the purpose of obtaining data on the performance of a high pressure metal lined underground air storage chamber and the surrounding rock. This experiment was located in the 401 Area of the Nevada Test Site. The information

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thus derived will be used in determining the feasibility of utilizing a similar, but larger, air storage chamber to satisfy the air supply requirements for ground testing of the PLUTO nuclear ramjet propulsion system. Included in the experiment detail report are the geophysical studies made of the 401 Area, design of an underground air storage pilot chamber, its instrumentation, techniques of construction, experimental data reduction and analysis, and the results and conclusions derived therefrom. New and unique rock liner theoretical analyses are presented and performance of the rock under pressures to 2500 psi are quantitatively defined.

4.4.2 Pilot Chamber Design

The underground air storage experimental chamber was designed and installed during 1962 to simulate as nearly as possible the rock loading conditions that will exist with the full scale chamber at the maximum operating pressure of 3600 psig. The rock loadings result from vertical forces tending to lift the top from the chamber, and from radial forces (acting perpendicular to the liner) that tend to compress the concrete and rock. A complete description of the experiment including objectives, results and conclusions will be found in Reference 7, "Underground Air Storage Experiment". The following are excerpts from Reference 7:

The storage chamber cavity requires a means for prevention of air leakage into the surrounding rock structure, and this was accomplished by fitting the chamber with a thin liner of steel. Because of this possibility that inadvertent leakage from the liner could create an external backpressure that would collapse the liner during blowdown, a leakage air vent system was designed to relieve any pressure buildup to aboveground atmosphere. Figures 13 and 14 show a simplified schematic of the experimental chamber (liner leak vent piping is not shown, but anchor leak vent tubes are).

To measure the effect of air pressure forces on the liner and surrounding rock structure, an instrumentation system composed of strain, pressure, and temperature gages was utilized. These gages were installed on the liner surfaces and embedded in the surrounding rock structure. An extensive data recording system was installed for use in subsequent analysis of the measured data.

4.4.2.1 Anchor System

To resist the vertical forces developed during pressurization of the chamber, a tapered plug-type anchor was designed of high strength concrete with a system of alloy steel load transfer rods included. This anchor uniquely distributes the vertical forces equally into the chamber rock walls and overburden structure. The anchor also serves as an effective replacement for the rock excavated during construction of the chamber. The total upward thrust of 11,309,000 lbs to be resisted by the concrete anchor, results from the 4000 psi maximum chamber pressure acting on a 5-foot diameter.

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The steel load transfer rods serve two purposes. Rod preload develops compressive stresses in the concrete that must be balanced out before the concrete can become loaded in shear, and secondly the rod system results in transfer of the vertical loads from the chamber by tension in the rods and thence to the walls of the anchor cavity.

4.4.2.2 Chamber

The experimental chamber was designed to approximate the full scale chamber in general configuration and components. Both the full scale chamber and the pilot chamber have a transition section extending through the concrete anchor, a conical section, a cylindrical section, and a lower hemispherical end. The pressure section which is below the concrete anchor is of thin steel material acting as a chamber seal. The steel used in the experiment liner required a high yield point, the purpose being to allow considerable stretch within its elastic limit. The material used for this liner was U.S. Steel T-1 which satisfied these above requirements for a high yield strength.

The liner design provided for a thin shell in order that the surrounding rock would resist the major portion of the pressure loads. No reinforcing steel was used in the concrete surrounding the chamber liner inasmuch as one of the prime purposes of the experiment was to determine the action of the rock and concrete during chamber pressurization. The presence of reinforcing steel would affect the transfer of the pressure loads into the concrete and surrounding rock.

The nozzle section extending through the concrete anchor was designed to withstand full chamber pressure without transfer of radial loads into the surrounding concrete and rock structure.

4.4.2.3 Vent System

The effect of air leakage from the chamber liner could be serious if no provision were made for its relief. Voids in the rock surrounding the chamber could conceivably become charged with high pressure air, during pressurization of the chamber and subsequent storage. Upon blowdown of the chamber during test, the high pressure air in the rock voids would provide an unbalanced pressure on the chamber liner exterior and collapse it. Furthermore, air leakage from the liner might also distribute itself across the bottom surface of the anchor and create an excessive vertical load.

The vent system was designed to eliminate these possible high backpressures. Embedded in the concrete surrounding the chamber liner, a manifold and feeder system was installed to gather leakage air. Twelve vent pipes were installed in the concrete anchor extending from its bottom surface to the atmosphere above the anchor mass. The liner vent manifold system was connected to a flow meter at the control building to measure flows resulting from the minor fractures or pin holes in the chamber

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liner. The twelve 1 1/2-inch diameter pipes in the anchor mass were designed to relieve a pressure buildup on the bottom surface of the anchor resulting from a major rupture of the liner.

4.4.2.4 Instrumentation

The pressure chamber below the anchor was instrumented to measure changes in liner diameter and circumference when pressurized. By knowing the change in diameter of the chamber, the deflection or change in displacement of the external rock adjacent to the concrete can be determined. Comparing these changes with the strain data from the gages cast in holes bored radially in the rock, the behavior of the rock can be determined to a depth equal to the depth of the instrument holes.

4.4.3 Chamber Liner Fabrication

The liner detail design and chamber liner specifications were completed during December, 1961 and a fabrication contract was awarded in early 1962. Fabrication of the liner was completed on May 24, 1962. Figure 15 shows the completed liner prior to installation of the instrumentation system.

4.4.4 Instrumentation

The data acquisition system designed for the Underground Air Storage Chamber Experiment was composed of three major divisions: (1) the chamber liner instrumentation, (2) concrete and rock instrumentation, and (3) leak system instrumentation.

4.4.4.1 Chamber Liner Instrumentation

Strain data from the chamber liner were of utmost importance and BLH foil type strain gages were used both for active data acquisition and temperature compensation. A predetermined, carefully calculated pattern was established for the location of the gages at 6 different levels in the chamber liner and arranged circumferentially to give an evenly distributed overall strain picture. Figure 16 shows typical locations for liner gages.

An extensometer system was utilized for axial and diametral growth measurements of the liner. The system consisted basically of telescoping rods which transmitted their relative displacements through linear potentiometers.

The measurement of temperatures within the chamber liner was required of the experiment, and two sets of gages were provided for this purpose. These temperature gages were the strap-on type, with each set so installed that one gage of each set measured air temperature and the other gage measured adjacent metal temperature.

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Transmission of the strain and temperature gage signals from the high pressure chamber area to the external atmospheric pressure area was accomplished by specially developed Conax fittings. These fittings, after installation, were pressure tested to 6000 psig for evidence of leakage.

4.4.4.2 Concrete and Rock Instrumentation

To measure the strains and temperatures within the concrete mass surrounding the chamber liner, strain gages were encapsulated in Hydrostone and embedded in the concrete mass. Strain and temperature data from the surrounding rock structure were gathered through a system of instrumentation probes inserted in radial core holes. Five core holes were drilled radially from the liner chamber excavation and two core holes drilled radially from the anchor chamber excavation. The instrumentation probes were grouted into the core holes with a water resistant grouting material called Hydromite.

A total of 64 gages were used in the concrete and rock measuring system. Because the strain gages were not of the self-compensating type, it was necessary to provide dummy gages for temperature compensation. The designed system provided for 6 dummy gages to be located in brass tubes isolating them from pressure and strain effects.

4.4.4.3 Anchor Instrumentation

Three rods in the anchor rod system were selected as representative for strain data acquisition. On each of the three rods a full bridge, temperature compensating, strain gage was mounted. Two resistive strap-on gages were embedded in the anchor concrete adjacent to the rods for temperature information.

4.4.4.4 Lift Indicators

To measure any appreciable physical lift of the chamber liner of the surrounding chamber overburden, a system of draft gage indicators were used. The indicators were located in the control room and connected by tubing to liquid containers mounted on steel rods extending downward in one case to the chamber transition section, and in the other case to the concrete collar at the top of the chamber access shaft. The draft gages were designed to register liquid level changes in the respective liquid containers.

4.4.4.5 Leak System Instrumentation

In order to measure chamber liner leakage, a flow measuring system was designed. Leakage air was gathered by leak pick-up pipes, manifolded together by a common pipe that ran to the flow measuring system located adjacent to the control room. The flow measuring system included an orifice plate and a system of differential pressure measuring transducers and temperature probes. To check out the leak vent system, it

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was necessary to design a pressure supply and flow measuring system to simulate liner leakage; consequently, a piping, flow measuring, and valving system was provided to permit introduction of high pressure compressor air into the concrete structure surrounding the liner so that the leak vent system could be checked for functional reliability.

4.4.5 Test Site Construction

4.4.5.1 Construction Program

The construction phase of the experiment extended roughly from 2 April 1962 to 30 September 1962, and consisted of the following major items:

1. Excavation and grouting
2. Rock instrumentation installation
3. Chamber liner assembly installation
4. Concrete placement
5. Piping installation
6. Recording equipment installation

The chamber access shaft was excavated at an approximate diameter at 6 feet to the top of the anchor cavity at the 158 feet level. At this level, the excavation widened to provide room for the anchor, and then continued downward to the bottom level of 196 feet. Wire mesh, planking, and rock bolts were utilized to retain the rock loosened by blasting and by previous earth movements and contractions.

At the excavation depth of 158 feet, hardened ground water was encountered, and pumps and grouting were required to control the water from that level to the bottom of the excavation. As the excavation depth increased, the water seepage into the chamber cavity tended to increase, and pressure grouting was utilized to fill the rock gappage and minimize the water flow.

The instrumentation for determination of rock involvement depths, rock strains and temperatures followed the excavation for the chamber. Core holes were drilled radially from the chamber and anchor cavities, and the instrumentation probes were installed and grouted with Hydromite.

Upon completion of the core hole instrumentation installation and electrical connections, the chamber liner assembly was lowered into the cavity and supported on temporary supports at the top of the transition section. The 2-foot thick space between the chamber liner assembly and the rock walls was then filled with high strength concrete. The concrete

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pours were mainly consecutive and cold joints were kept to a minimum. When the bottom of the anchor chamber level was reached, the concrete pour was continuous to the top of the chamber. The anchor rods had been previously installed in the anchor chamber. When the concrete had reached its twenty-eigth day value of 6000 psi minimum, the anchor rods were tensioned in accordance with a preset pattern to maximum loads of 53 tons each.

The air pressure piping and vent system piping were installed at the completion of anchor rod tensioning, the air compressor system was installed and checked out, and the air flow meters were installed and checked out. At the same time, recording equipment for recording strain gage readings, pressures, temperatures, anchor lift, etc. were installed in the control building. The instrumentation and data recording system were checked out and the pilot chamber experiment was basically ready for the test program.

4.4.5.2 Geology Determination and Water Survey

As part of the Underground Air Storage Experiment, the following activities were included:

1. An investigation of the fractures in the chamber rock walls
2. Lithologic logging of core holes drilled radially from the excavation
3. Stress strain curves of rock cores obtained from the core holes
4. A survey of ground water in the excavation area. These activities are reported in detail in References 8 and 9

4.4.5.3 Instrumentation Hole Core Tests

Cores removed from the instrumentation holes for the strain gage probe assemblies, were tested at a laboratory to determine stress strain curves, modulus of elasticity, Poisson's ratio, and ultimate stress of the unconfined rock samples. The complete curves, and related data, are included in Reference 7. Table XVI presents a summary of these data.

4.4.6 Test Plan

The detailed test procedure was developed and modified through the early part of the experiment design and finalized prior to start of the test program. The test objectives are as follows:

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1. Determine the zone of involvement
2. Determine the rock performance (in strain) within that zone
3. Determine which rock-liner theory most closely fits this rock performance
4. Calculate the minimum effective E from experiment data and the above selected theory
5. Compare this E to the minimum core unconfined E in this area
6. Determine the variation of effective E with rock pressure
7. Assess liner performance range; i.e., elastic or plastic
8. Measure anchor lift vs. chamber pressure
9. Measure chamber overburden lift vs. chamber pressure
10. Determine leak vent system collection capability with simulated leak pressure, measuring any leak flows through vent system
11. Assess concrete and rock creep characteristics under static loading
12. Measure performance of anchor rods
13. Determine effects of cycling upon rock and liner

4.4.7 Test Results

4.4.7.1 Zone of Involvement

The zone of involvement has been determined from radial strain vs. distance log-log plots. In the rock around the cylindrical portion of the pilot chamber, based on 1 percent of the at-the-liner strain, the zone of involvement was determined to be 8 chamber radii. For the sphere, this zone is 3.6 chamber radii.

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4.4.7.2 Rock Performance

The performance of the rock surrounding the pilot chamber has been shown to conform very closely to the theoretical model of the semi-infinite elastic thick walled cylinder (in the rock surrounding the cylindrical portion of the chamber), and an elastic thick walled sphere (in the rock adjacent to the hemispherical portion of the chamber). The variation of strain with chamber pressure has been established. The changes in slope of the log-log plots of radial strain vs. distance indicate that at about 1000 psi some phenomenon occurred in which the rock became more compact or rigid with pressure. Because of the general agreement in these data, it is postulated that the rock must have displaced (that is, moved without corresponding changes in strain) with increases in pressure. This displacement while significant at pressures to 1000 psi became insignificant when a pressure of 1500 psi was exceeded. The fact that these changes in slope occurred along the horizontal, or nearly horizontal, probes and did not occur along the vertical probe (probe E) leads to the conclusion that the nearly vertical fractures in the rock were the causitive factor, and these fractures closed at relatively low pressures.

The concrete appears to have broken in tension at relatively low chamber pressure and then, with increase in pressure, compacted to act more as a fluid than as a series of rock prisms. If this were not so, the slope of the pressure-strain lines should have decreased, not increased. To further check this conclusion, the chnage in radius was divided by the change in liner strain, to give an apparent liner radius. The results showed that at low pressure this radius was about 30 inches (which it should be) and the apparent radius increased with pressure to about 40 inches at a pressure of 2500 psi. Hence, the first 10 inches of the concrete must have subjected a more or less hydrostatic load to the surrounding concrete and rock.

The fact that the pressure-strain relationship at the hemispherical end had a slope of about -3, and the slope at the cylindrical section was about -2 leads to the conclusion that the effective E (modulus of elasticity) of the rock should be computed from the relationships for a thick wall pipe around a cylinder or sphere.

4.4.7.3 Effective Moduli

Local effective elastic moduli in compression have been computed from the experimental data utilizing the above rock liner theory. These moduli have been found to reflect the fracture gappage existing around the pilot chamber. Although 144 10-foot long holes were pressure grouted, an examination of cores recovered from the instrumentation bore holes indicated an average filling of fractured gappage of only approximately 25 percent within the zone of involvement of the chamber. The calculated local effective E's were compared with the unconfined laboratory tested E's for the action strain gages and the calculated effective E's were found to be roughly one-third that of the laboratory tested E's.

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4.4.7.4 Cycle and Endurance

Due to rupture of the liner at 2560 psi during the first pumpup, creep and cycling rock data could not be obtained.

4.4.7.5 Anchor

The anchor, as designed for the pilot chamber, performed satisfactorily during both the pumpup and the blowdown immediately following liner rupture. During this latter blowdown, the bottom of the anchor plug developed an estimated upward thrust of between 10 and 22 million pounds without evidence of appreciable vertical translation. Two cracks appeared in the anchor concrete (possibly owing to bending stress) but these did not appear to adversely affect anchor performance. Vent tubes in the anchor released the air pressure to the access shaft. Any minute anchor movements that possibly occurred during the experiment were below the sensitivity of the draft gage system employed for this monitoring.

4.4.7.6 Leak Vent System

Upon liner fracturing, the high pressure air escaped through the annulus between the chamber and the rock and on upward through the anchor plug vent tubes. The pressure sensors in the leak vent manifold system, radially monitoring close to the liner, registered no appreciable pressure. No flow of air was measurable through the leak vent manifold and pipe. Overall adequacy of the leak vent system design was indicated by the adequate venting of the high pressure air to atmosphere upon liner rupture.

4.4.7.7 Concrete

The use of 6,000 pounds of concrete, the mixing, water control, techniques of distributing, and timed stinging proved adequate in limiting shrink, since experimental data indicate that the radial shrinkage of the concrete was limited to no more than 0.007 inch.

4.4.7.8 Liner

The weldability and fabricability of the T-1 steel, selected for the pilot chamber has proven adequate. Its relatively high ratio of yield point to elastic modulus gave assurance of elastic performance over a greater range of strain than other field-weldable materials could provide. In addition, due to the very low strain rate resulting from the slow compressor pumpup inherent in UAS chamber operation, the T-1's creep characteristics were surprisingly good. It stretched, during the experiment, to an equivalent elastic stress of 156,000 psi, although its yield point is rated at 100,000 psi normally and its ultimate strength is 115,000 to 135,000 psi.

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4.4.7.9 Coded Upper Vessel (Transition Section)

The heavy walled upper vessel design performed satisfactorily. Instrumentation penetrations performed as designed. The T-1 steel head, welded in the field to the thick walled T-1 upper vessel, performed satisfactorily.

4.4.8 Conclusions

The Underground Air Storage Experiment has provided unique and detailed data on the high pressure performance of a pressurized chamber. It has confirmed the adequacy of the design of the anchor, air venting system, and upper vessel. It has identified the performance characteristics of the rock, quantized it in a theoretical and mathematical model, and has permitted prediction of the zone of involvement. The experiment has indicated adequacy in the design of the overburden depth to both anchor and pilot chamber and has confirmed the existence of a good margin of safety. From the radial strain-distance curves, the experiment indicates that the fracture gappage unique to the pilot chamber rock regime has had a significant effect upon the calculated effective rock moduli (E_R). If these moduli were used for the big chamber, the big chamber would be penalized, since its surrounding rock regime has significantly lower fracture frequency (2.2 fractures per foot vs. 0.9 fractures per foot) and fracture gappage is known to be tightly closed as compared to the 1/32- to 1/16-inch in the pilot chamber regime. In order to utilize these effective rock elastic moduli for full scale chamber design, a study should be made of quantitative analytical methods which can be used to correct these moduli for the effects of the pilot chamber's unique rock crackage. When this has been done, the resulting E's may then be compared with the unconfined laboratory E's for both the pilot and big chamber rock regimes. This comparison should result in a realistic effective modulus of elasticity for use in predicting the performance of the liner of the full scale chamber.

4.5 Underground Air Storage Chamber

Investigations and preliminary design effort have been conducted by The Marquardt Corporation in the underground storage of high pressure air. The 1962 contract requirements involved the detail design, analytical work, cost estimate, and specification preparation necessary for a high pressure underground air storage system.

The basic criteria to which the detail design was performed are as follows:

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Usable Air (2 chambers)	14,424,000 lbs
Air Storage Pressure	3,600 psig
Minimum Discharge Pressure	800 psig
Minimum Temperature of Discharge Air	0°F
Maximum Air Flow Rate (2 chambers)	5,000 pps
Chamber Volume (total 2 chambers)	1,236,000 cu ft
Chamber Liner	Steel
Vertical Thrust Anchor	Reinforced Concrete Conical Plug
Air Discharge System	Multiple Oil Well Casing
Chamber Overburden Factor of Safety	20
Chamber Separation Overburden Factor of Safety	18
Anchor Emergency Overburden Factor of Safety	10

4.5.1 Liner Design Assumptions:

In situ minimum rock E = 1.5 million psi

Poisson's ratio of rock = 0.2

Maximum Chamber Pressure = 3600 psi

Elastic modulus of liner = 30 million psi

Elastic rock performance

Liner to operate elastically (i.e., liner hoop stress, σ_H, must be less than yield point of T-1--100,000 psi minimum)

See Reference 7: Marquardt Report FE 272-7, pp. 92 through 94, paragraph 12.2.1 Elastic Analysis, equation (4).

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4.5.1.1 Additional Design Features

1. Leak vent and monitor system
2. Internal support and maintenance structure
3. Inspection cage
4. Surface skip frame and hoisting equipment
5. Blow down sized for maximum flow
6. Reparable via dental work and liner weld patching
7. Dewatering of rock around chamber - deep well pumps
8. Rock grouting program
9. Located in 401 Area, Nevada Test Site
10. References 10 and 11

4.5.1.2 Detail Design Drawings

A total of 66 drawings were made on the detail design of the underground air storage chamber. During April 1962, preliminary plans and specifications were submitted to the Air Force for approval prior to a final detail design effort. These plans were approved by the Air Force, and returned to TMC in June 1962 at which time detail design was started.

Of the total number of drawings generated for the chamber detail design, 3 provide a good general description of the chamber and appear as Figures 17, 18, and 19:

4.5.2 Underground Air Storage Analyses

4.5.2.1 Chamber Design Computations

Complete and detailed design calculations were performed covering the underground air storage chamber system. The major phases of the calculations program included: shape and size investigation, liner and liner support structure, concrete anchor plug, rock excavation and analysis, access shaft, piping, internal steel structure, hoist cage, tower, and the buildings. The program results were compiled and submitted to the Air Force in Reference 12. Rock-liner performance theories and their corresponding mathematical models, fully described and interpreted, are reported in Reference 7.

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4.5.2.2 Chamber Liner Material

During the detail design drawing phase of the Underground Air Storage chambers, a materials selection investigation was conducted. The investigation centered basically on aluminum, steel, manganese, and titanium alloys, with weldability versus yield strength of major importance. Table XVII lists some of the materials, their various properties in parent material and welded material, and a generated rating factor based on yield stress in welded material and modulus of elasticity. Figure 20 is a graph of stress vs. strain for 2 materials (T-1 and 6061 Al. Alloy) with a superimposed strain abscissa corresponding to a radial increase of 2 inches in a 63-foot diameter chamber. For liner operation within the elastic limit, T-1 steel is indicated, since a liner of this material would permit greater strain (inch per inch) before reaching its plastic region.

4.5.3 Cost Estimate

A complete cost estimate and breakdown was prepared during the latter stages of the detail design. The estimate was prepared on the basis of two alternate approaches. The first alternate was for a single chamber that would meet the requirements as defined in Section 4.5. The second alternate was for 2 chambers constructed simultaneously, and would satisfy a possible requirement for twice the running time of 45 minues or a total of 90 minutes.

The cost estimate was based on current material and labor costs, anticipated adders necessary for construction at the Nevada Test Site 401 Area, a nominal 6 percent contingency, and an estimated escalation of 4 percent for a 1 year period. The estimate was presented with the following main sections:

1. Summary Total Costs
2. Individual Cost Items
3. Shift Costs and Subcontractor Costs
4. General Plant Costs
5. General Expense and Overhead Costs

The total estimated construction costs for 1 and 2 chamber programs are $9,176,047 and $18,190,163, respectively.

The estimate was submitted to the Air Force during October 1962, Reference 13.

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4.5.4 UAS Chamber Specification

A construction specification was prepared covering the underground air storage chamber as designed. The specification was submitted in rough draft form during April 1962, approved by the Air Force, and finalized and resubmitted in final form during November 1962, (Reference 14).

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2. "Development Plan for Nuclear Ramjet Powered Supersonic Low Altitude Vehicle Technology (Pluto): System 655A," Air Force Systems Command, 26 June 1962, Report 62ASRS1614, ~~SECRET RESTRICTED DATA~~.

3. "Design Criteria Studies for Project Pluto Ground Test Facilities," The Marquardt Corporation, 15 February 1963, Marquardt Report 5970, ~~SECRET RESTRICTED DATA~~, Reg. 23,085.

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11. Tunnel Safety Orders, State of California Department of Industrial Relations, September 1954.

12. "Underground Air Storage Chamber Design Calculations," The Marquardt Corporation, October 1962, Marquardt Report 272-4.

13. "Underground Air Storage Chamber Cost Estimate," The Marquardt Corporation, October 1962, Marquardt Report FE-272-5.

14. "Specification for Underground Air Storage Chamber Pluto Flight Engine Ground Test Facility, 401 Area, Nevada Test Site," The Marquardt Corporation, November 1962, Marquardt Report 272-6.

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FIGURE 1. Pluto Propulsion System

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FIGURE 2. Pluto Nuclear Ramjet Development Program

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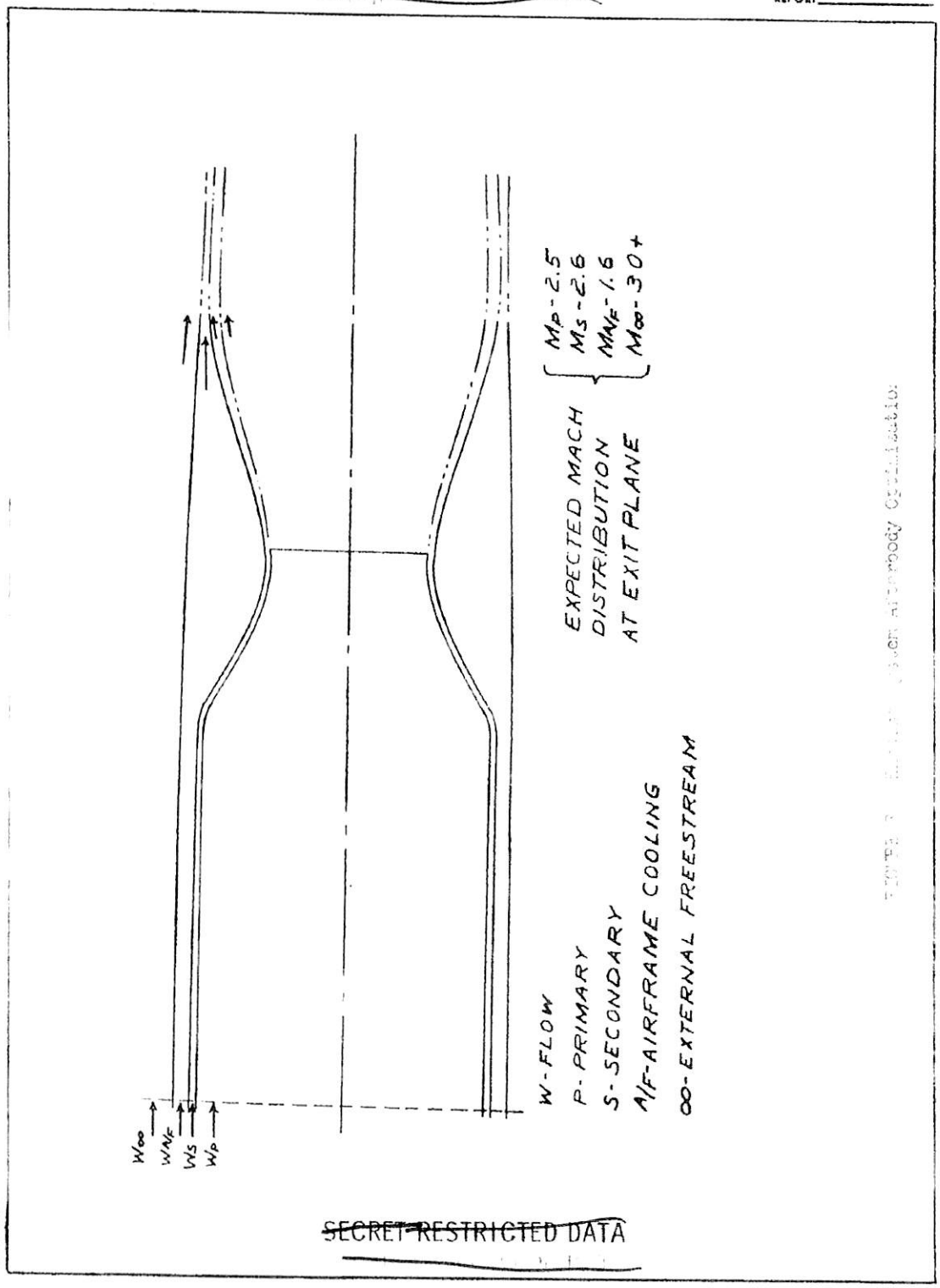

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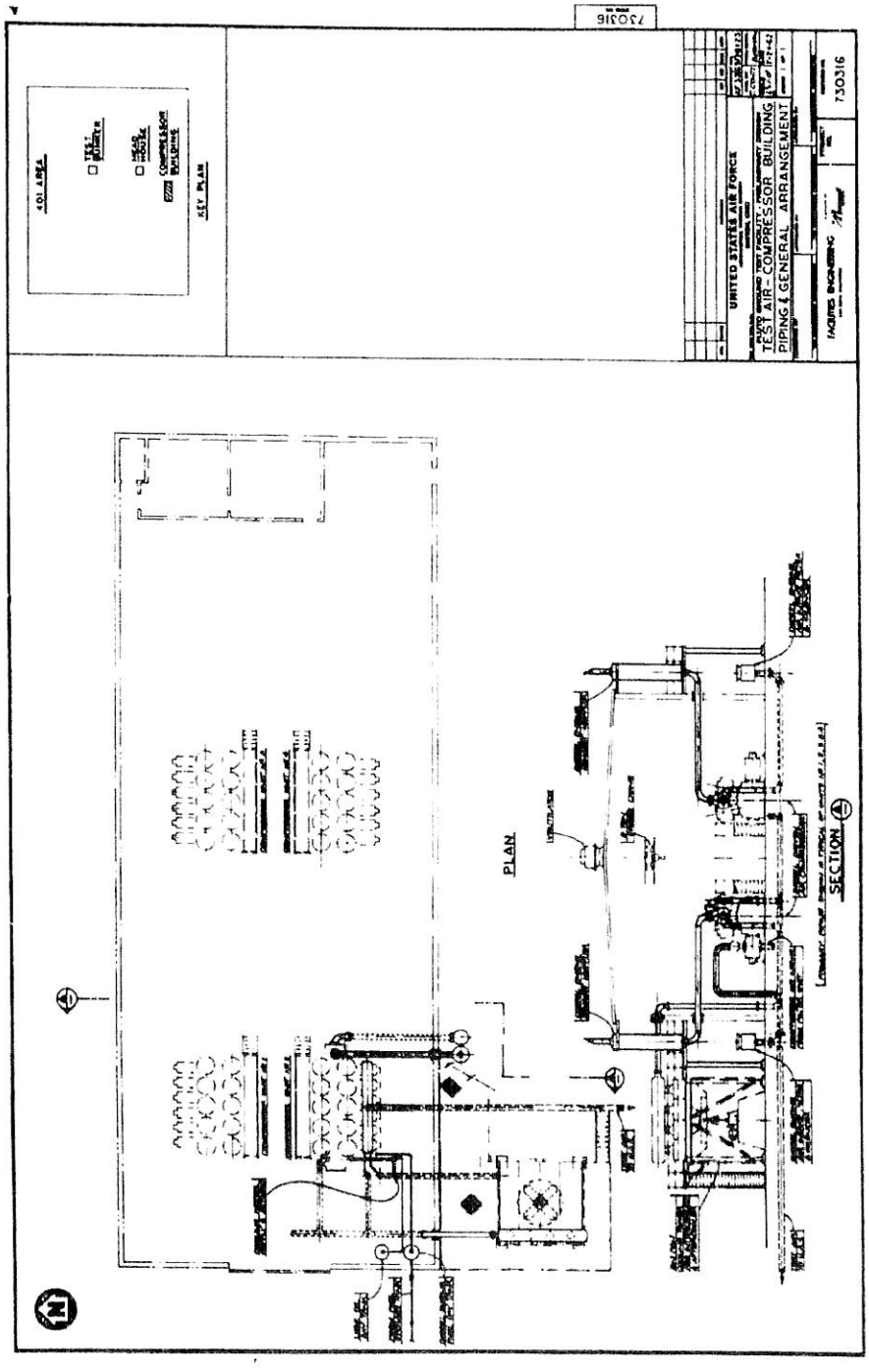

FIGURE 4. Test Air--Compressor Building--Piping and General Arrangement

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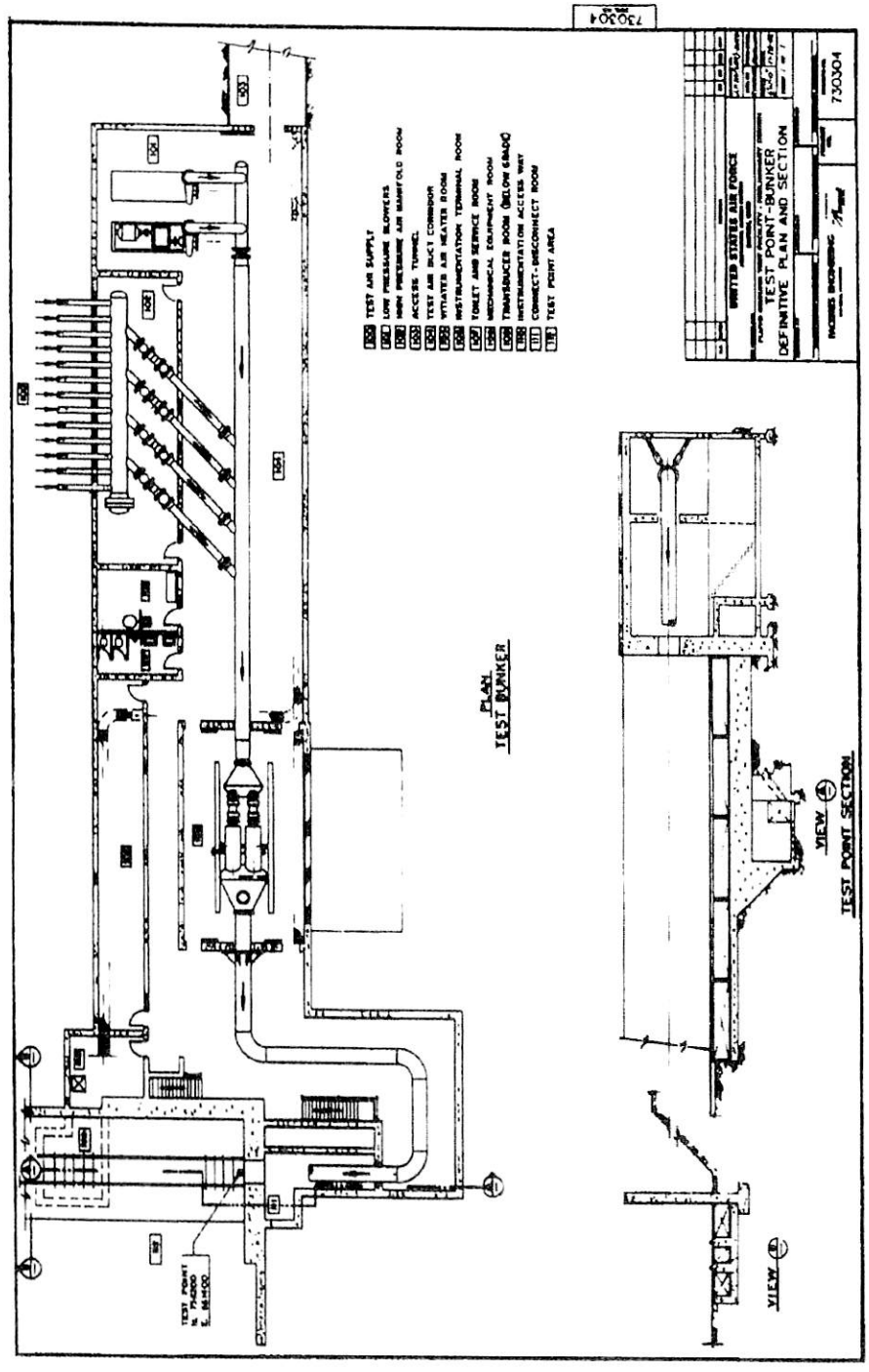

FIGURE 5. Test Point--Bunker--Definitive Plan and Section

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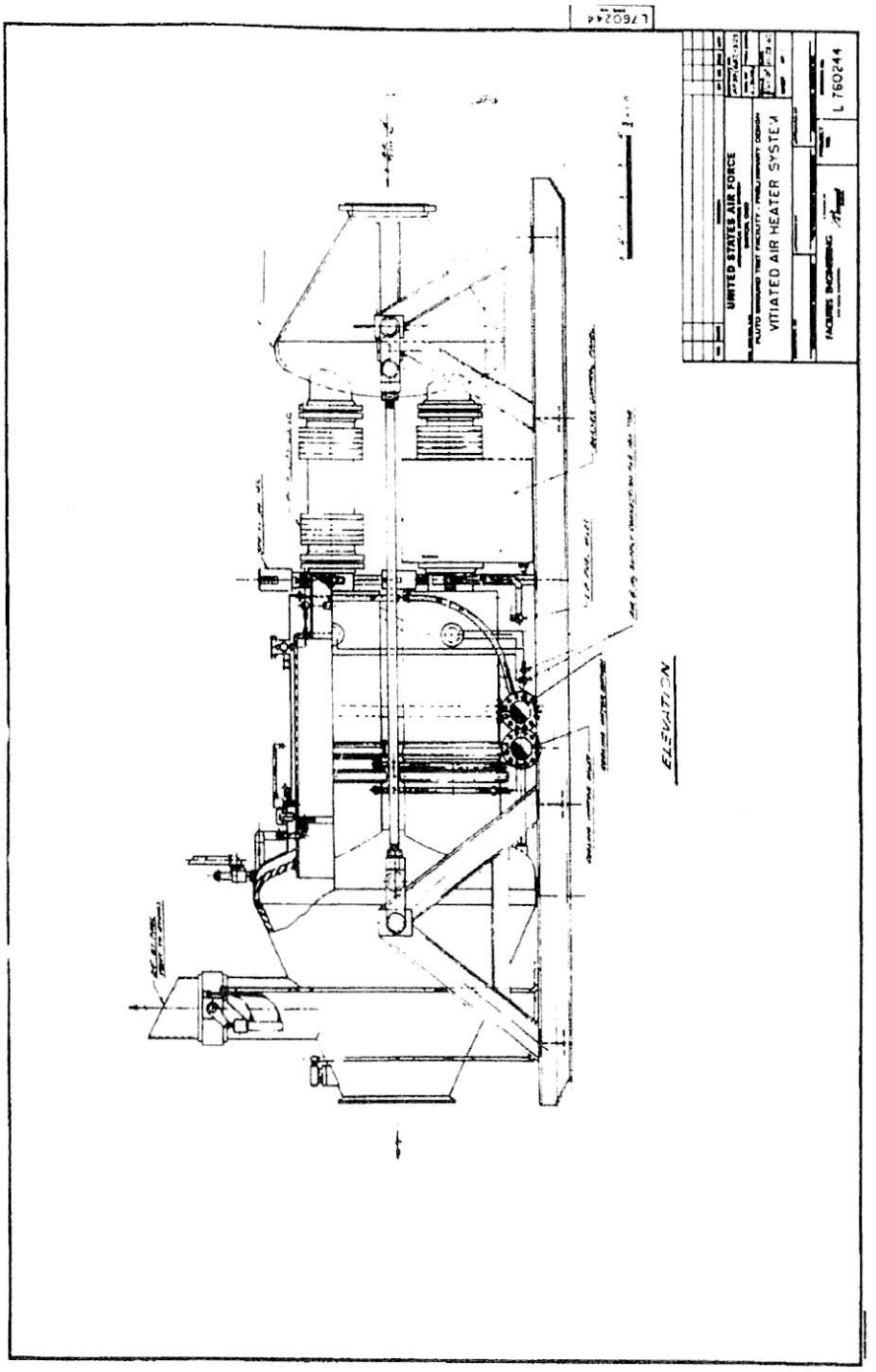

FIGURE 6. Vitiated Air Heater System

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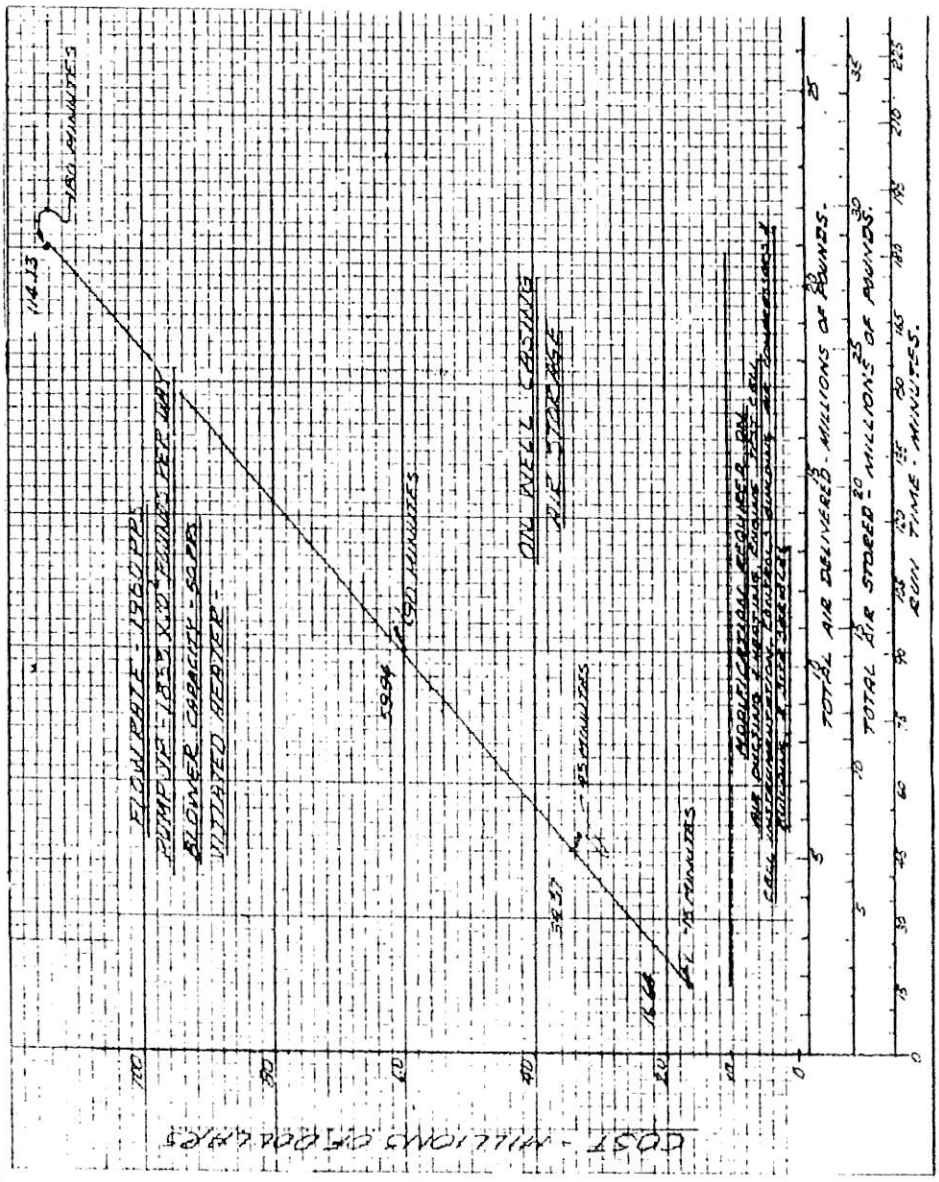

FIGURE 7. Estimated Power Plant Requirements for Typical Green Base

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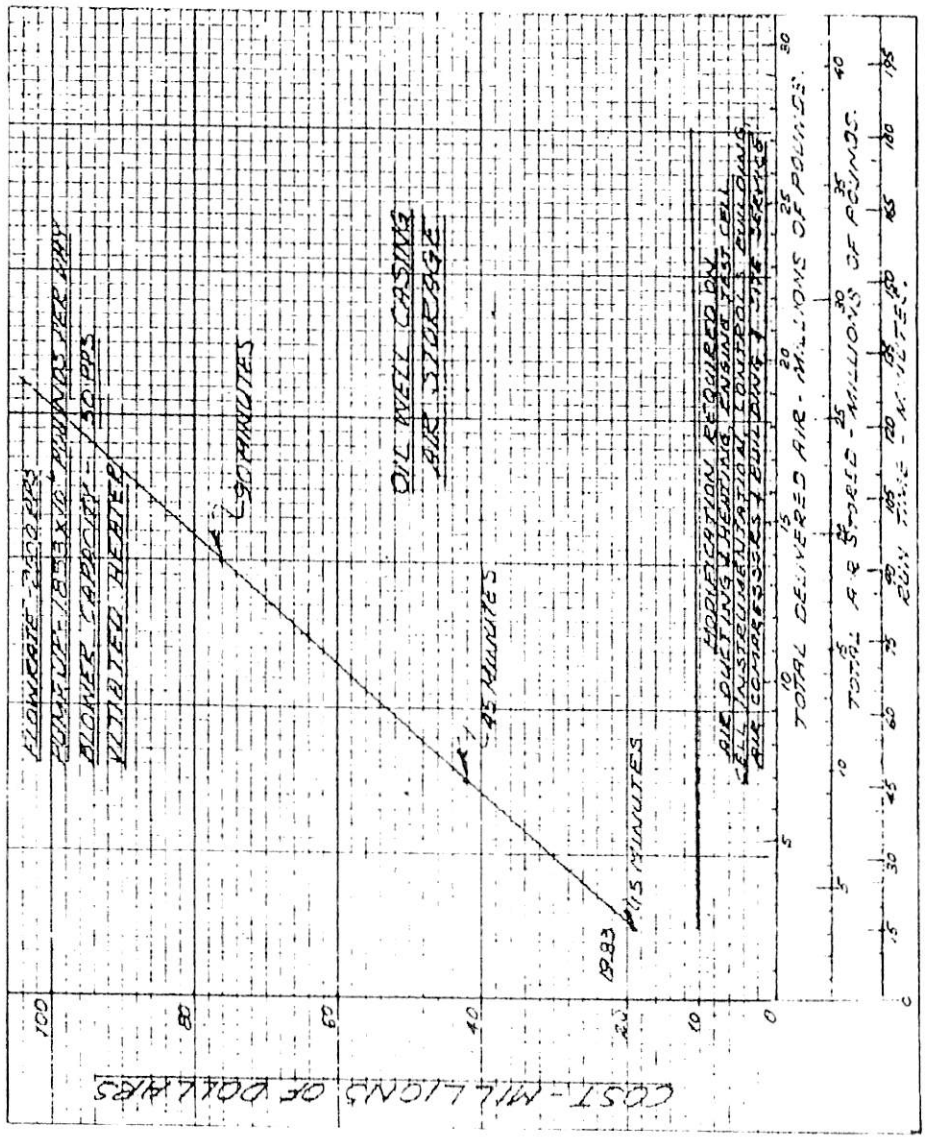

FIGURE 8. Estimated Costs To Modify LTC Modification of Flight Engine Ground Test Cells

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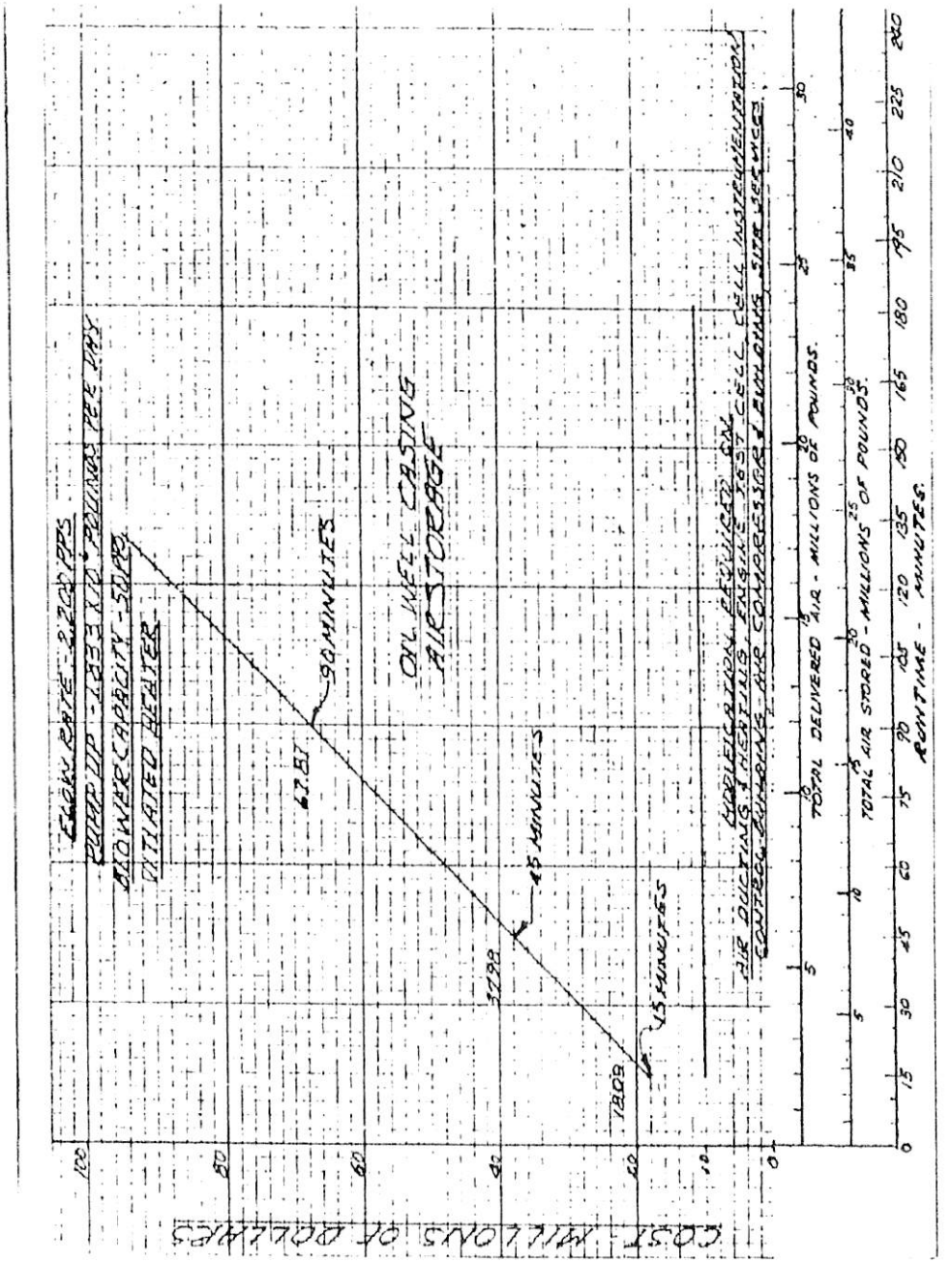

FIGURE 9. Estimated Costs - Tony IIC Modification of Flight Engine Ground Testing

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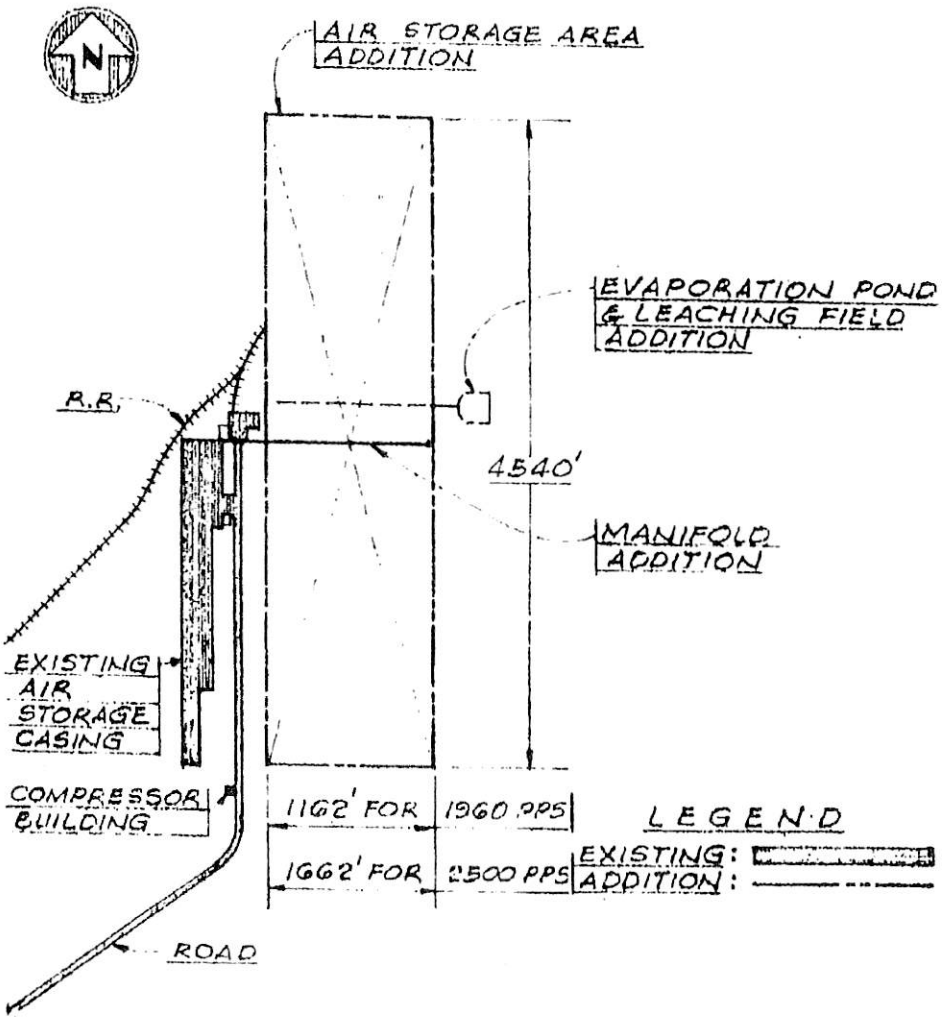

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CORE HOLE LOCATION
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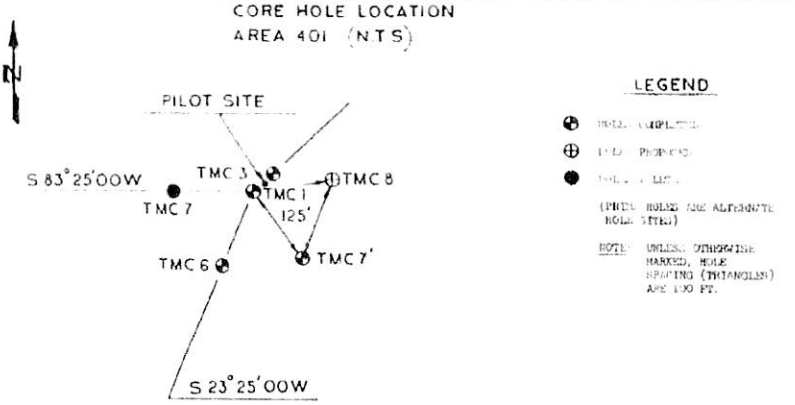
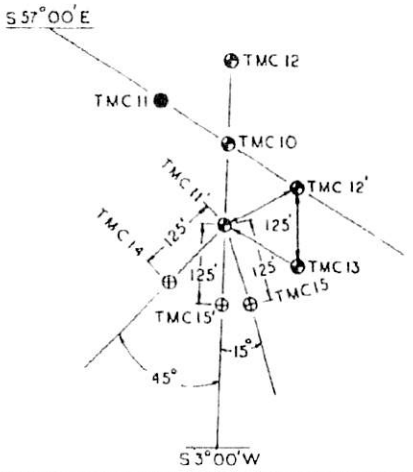
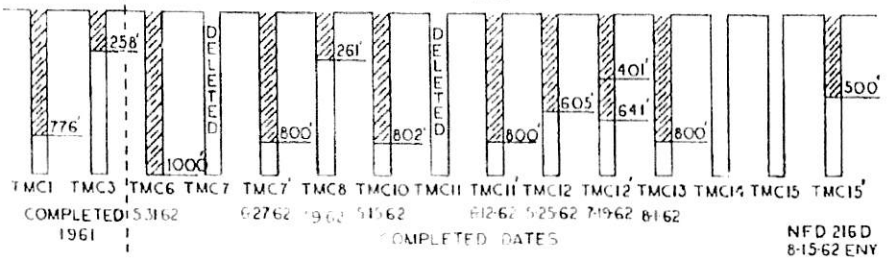




CORE HOLE DEPTH (DATA FROM CHAS. PRICE)



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UNDERGROUND AIR STORAGE CHAMBER SITE, 401 AREA, NEVADA TEST SITE

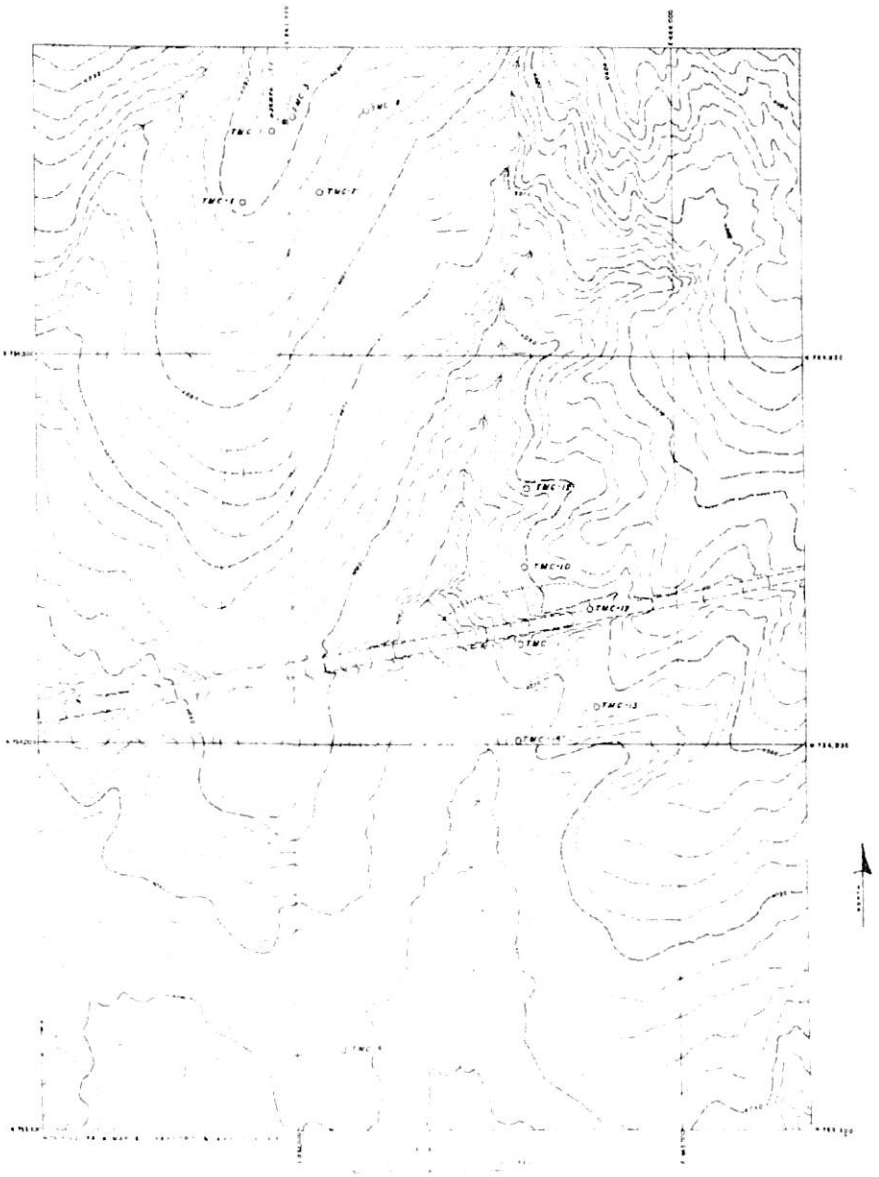

FIGURE 12. UAS Chamber Site, 401 Area, Nevada Test Site

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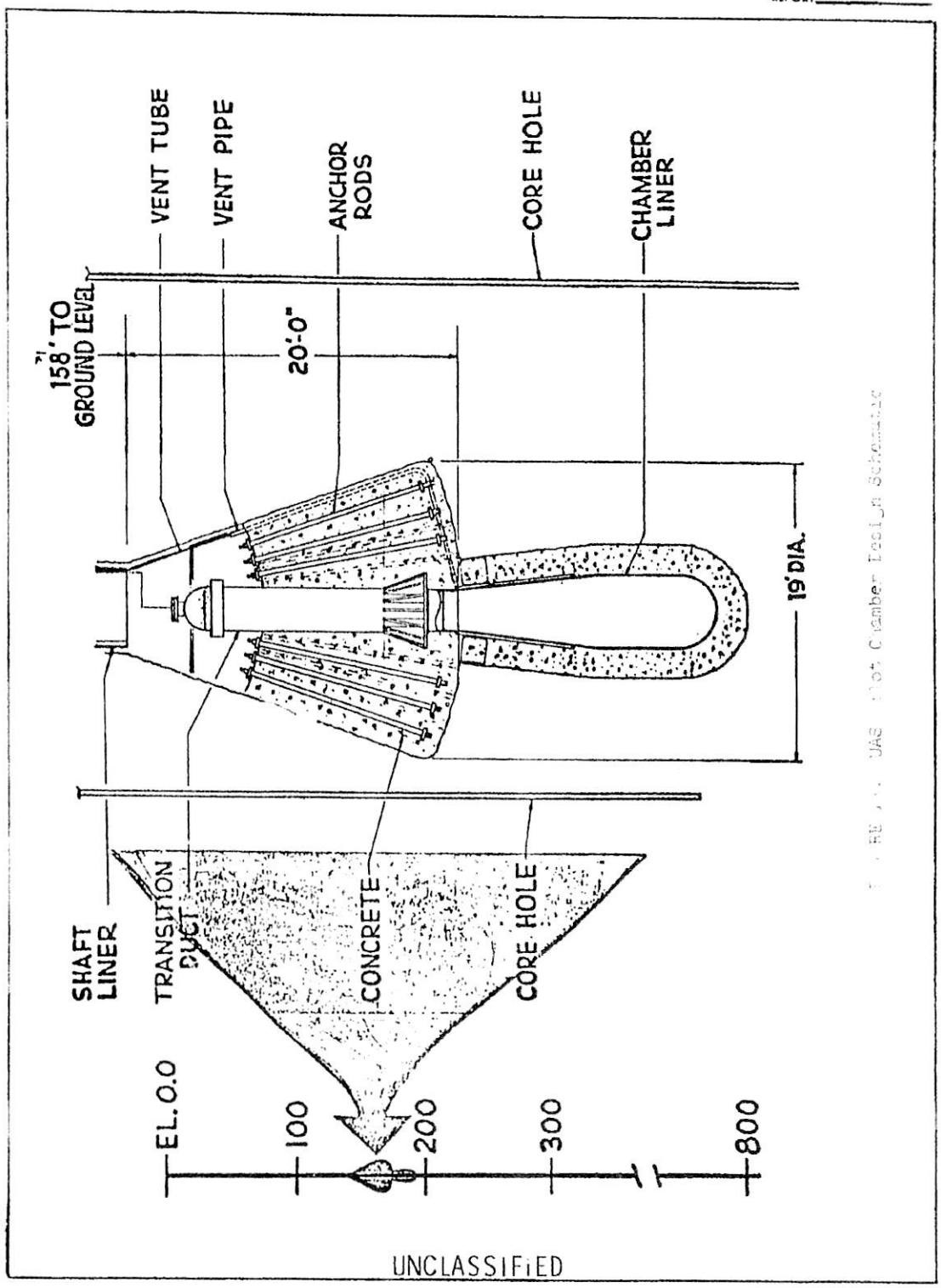

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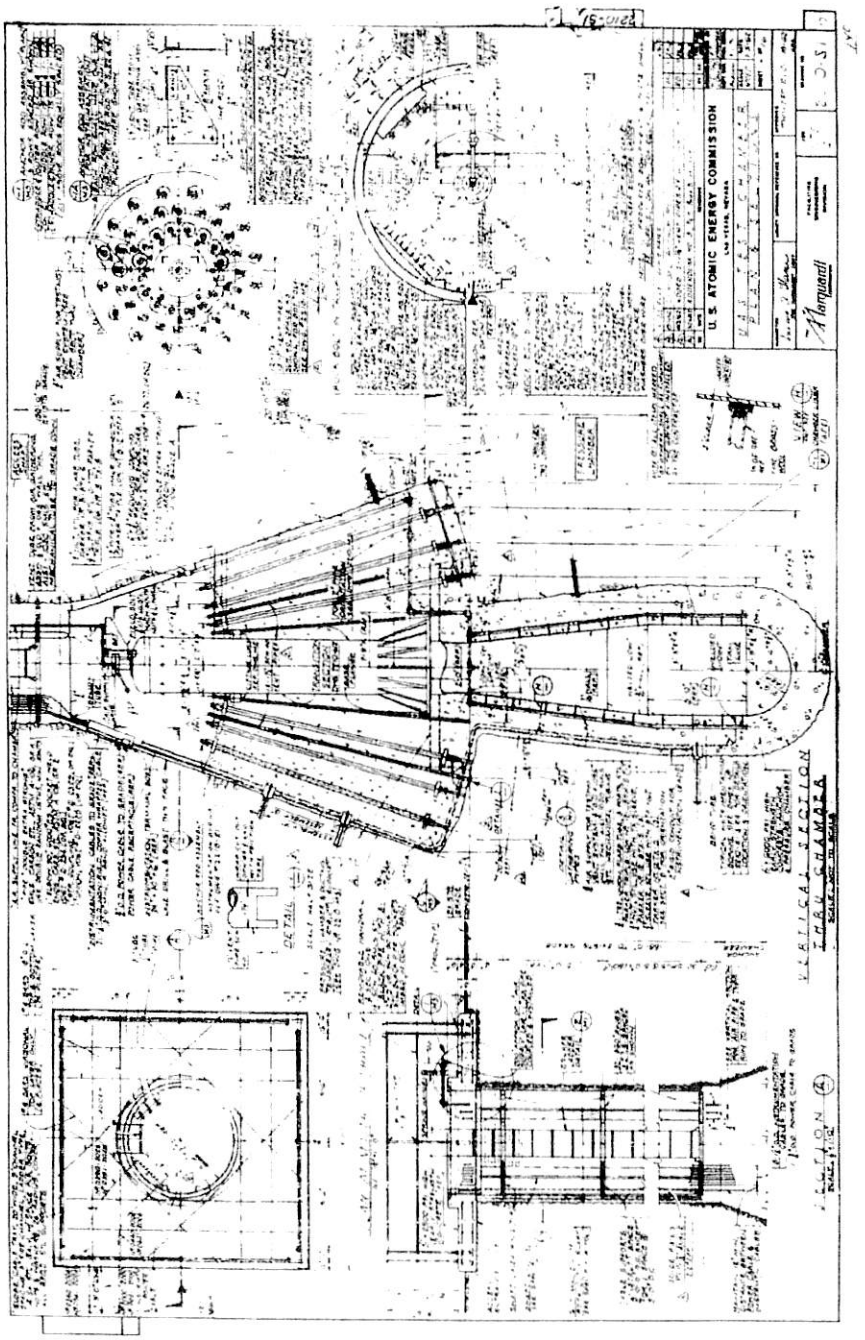

FIGURE 14. UAS Test Chamber Plan and Sections

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FIGURE 15. View of Pilot Chamber After Fabrication

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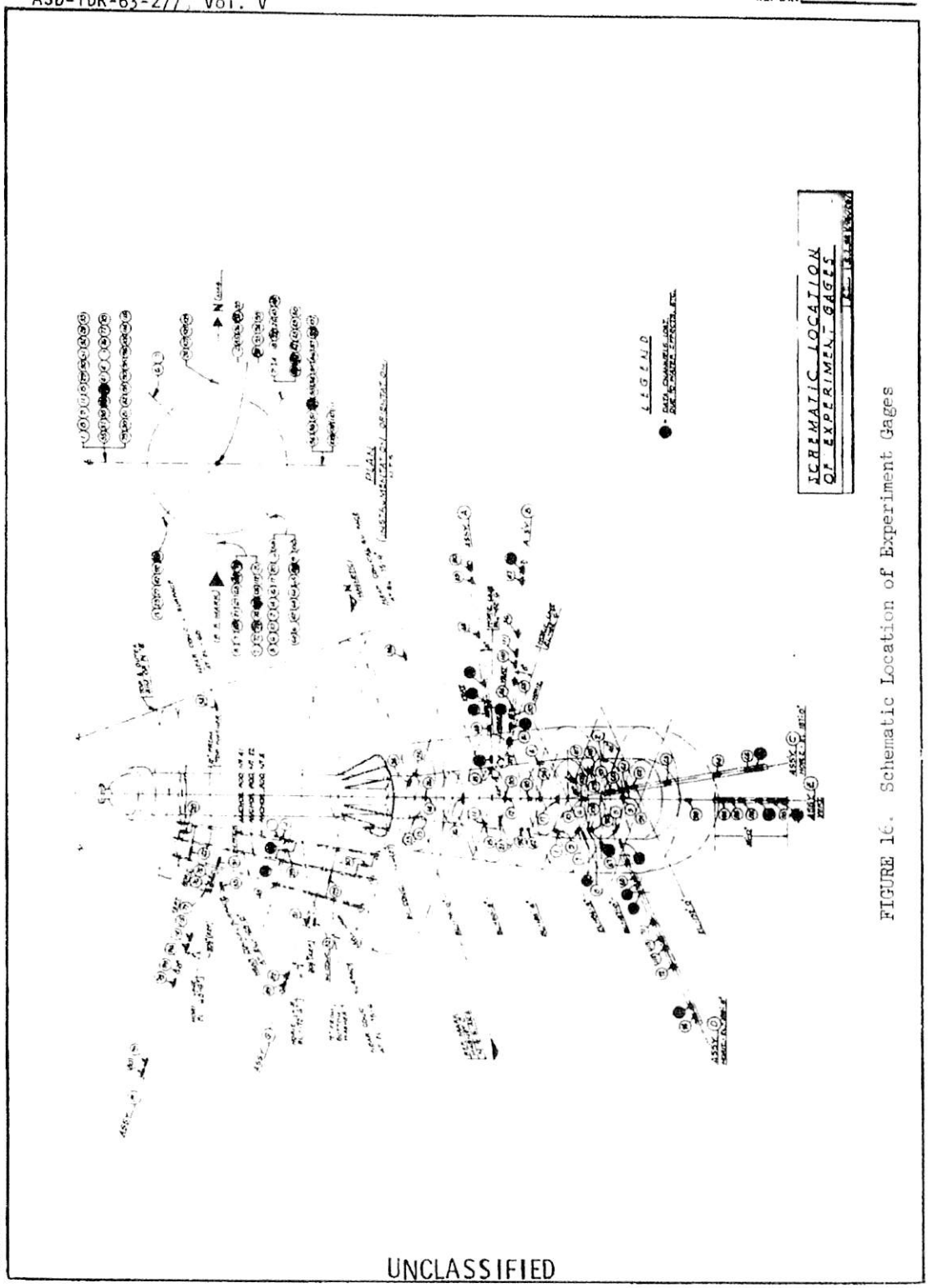

FIGURE 16. Schematic Location of Experiment Gages

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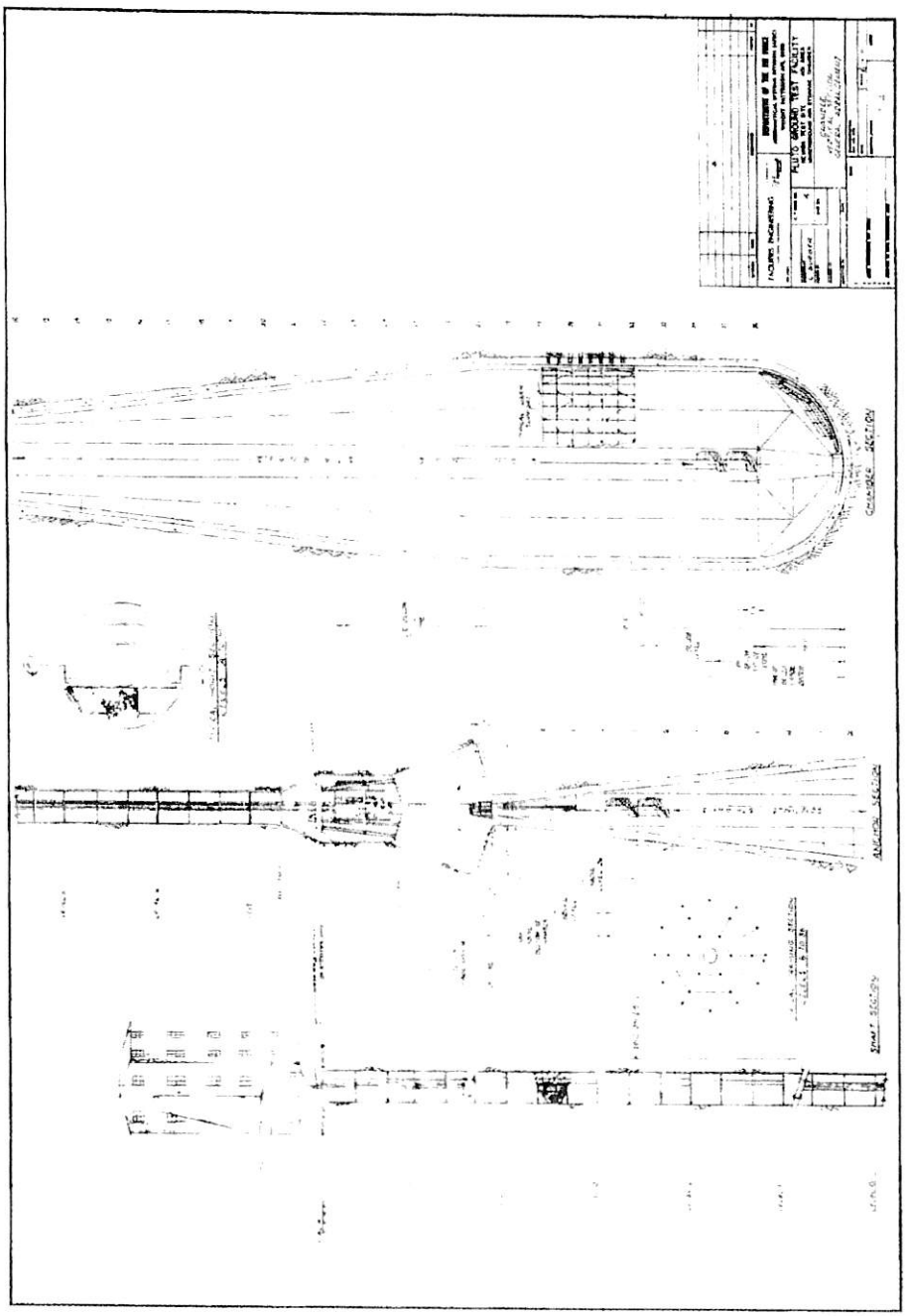

FIGURE 17. Chamber--Vertical Section--General Arrangement

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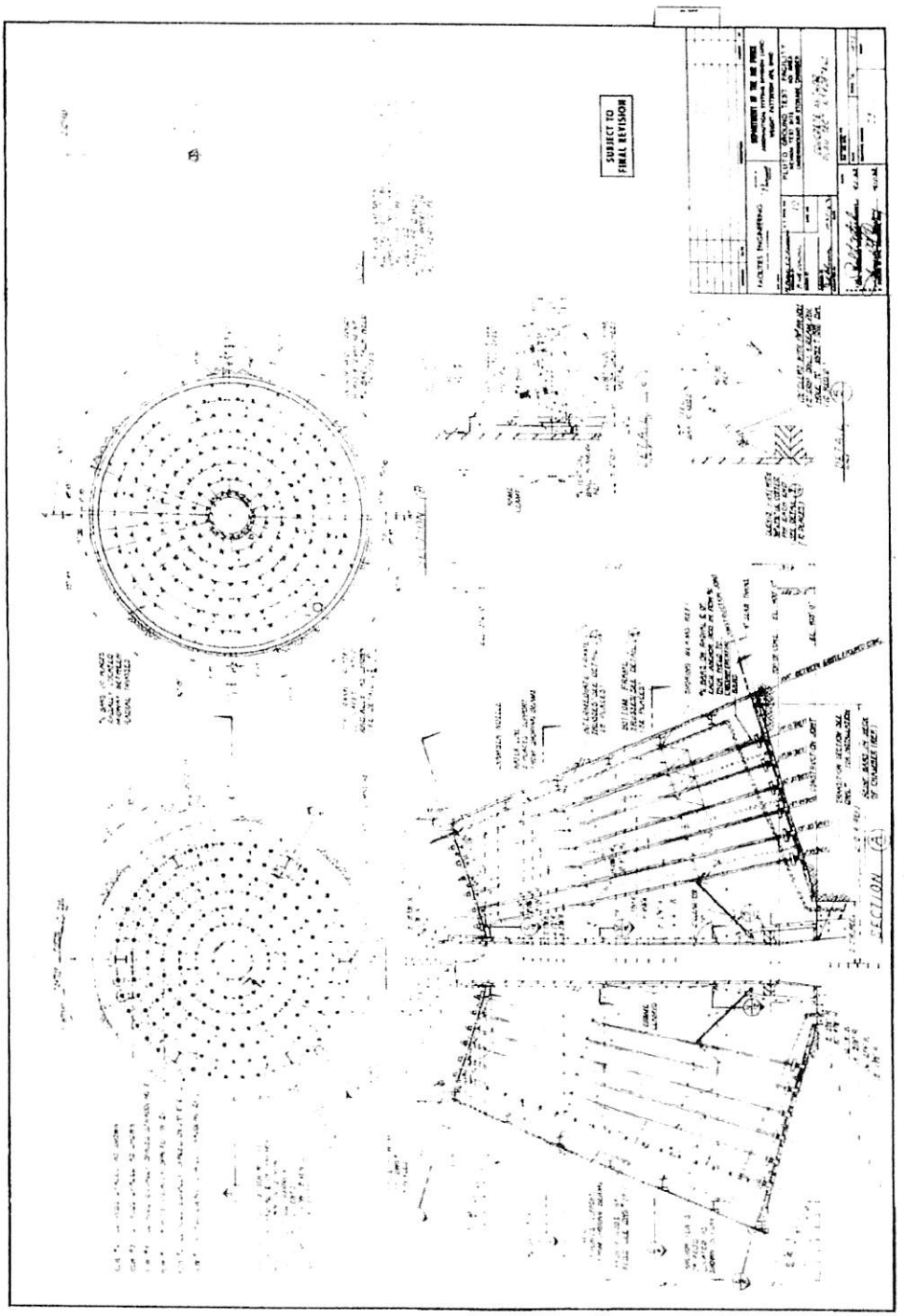

FIGURE 18. Concrete Anchor--Plan, Sections and Details

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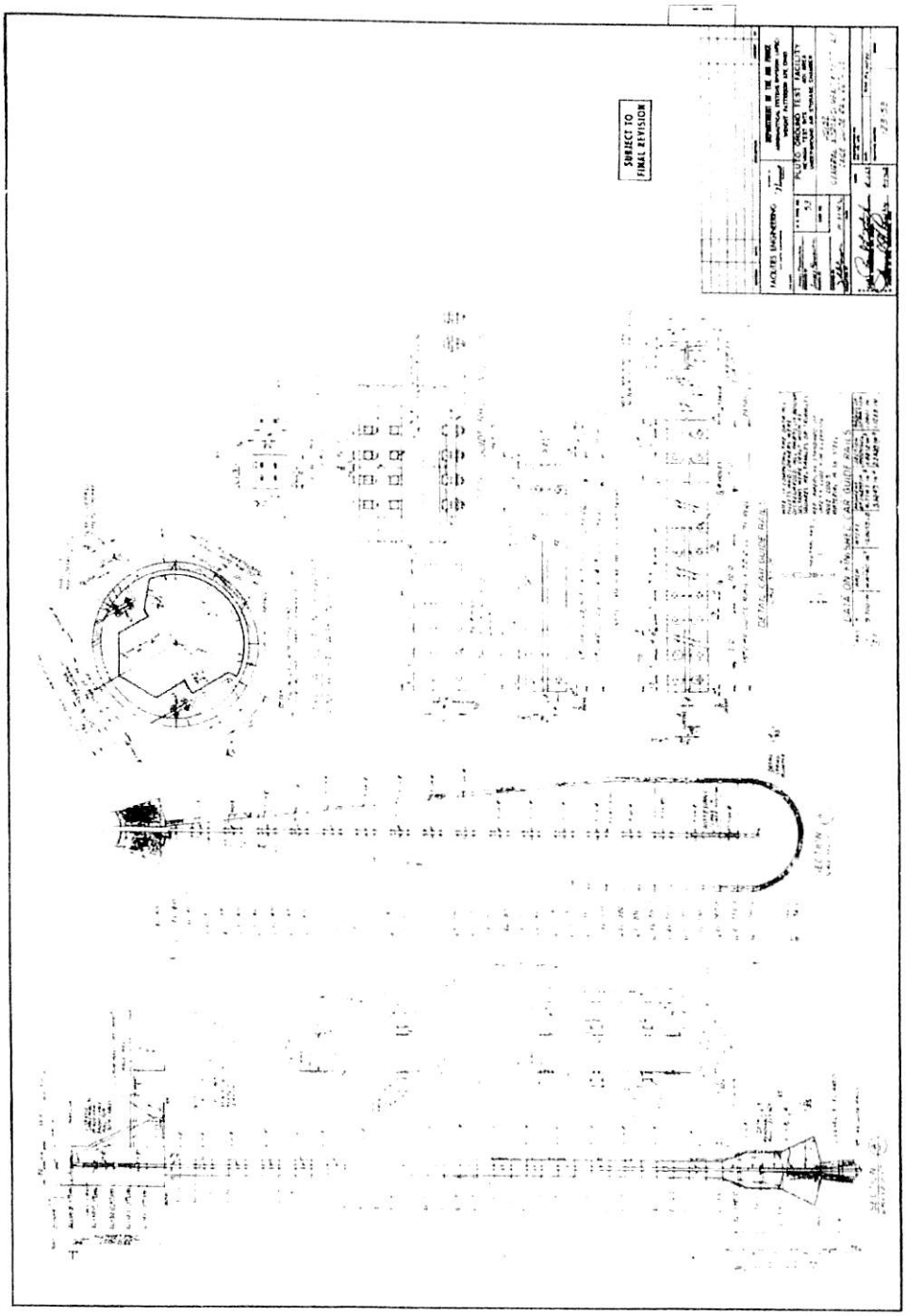

FIGURE 19. Hoist--General Arrangement and Sections Cage Guide, Rail Details

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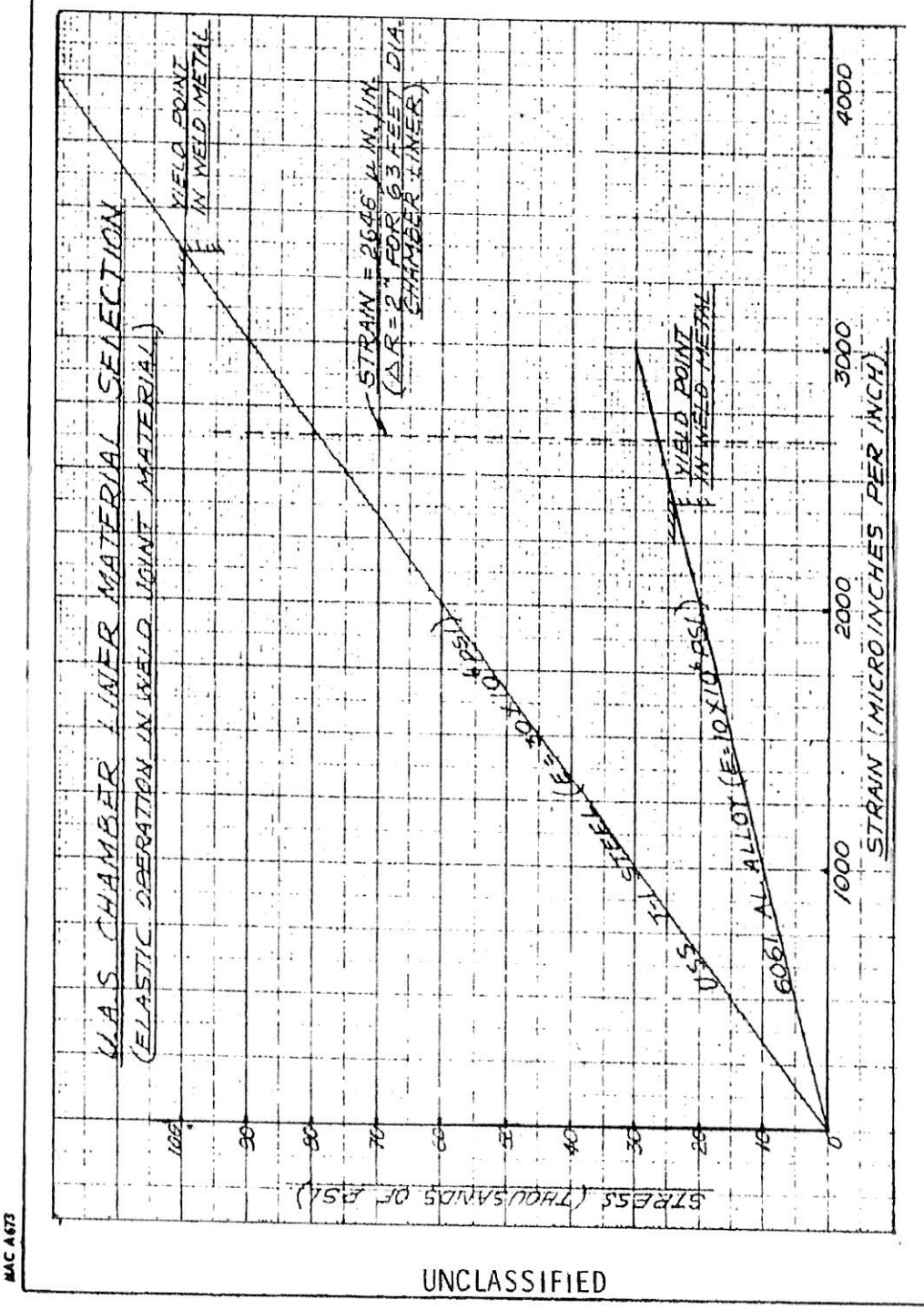

FIGURE 20. MAS Chamber Liner Material Selection

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TABLE I

INLET MODEL TEST PROGRAM SUMMARY

Model	Date	Time	Number of Runs	M_o	α_o	β_o	Test Objectives
1/11 Scale (Langley)	Oct. 1962	7 test days	20	2.4 to 3.6	0° to 5°	0° to 5°	(1) Obtain drag data (2) Flow field survey
1/3 Scale (Free jet) (MJL)	Oct. 1962	5 test days	8	3.0	0°	0°	(1) Evaluate reactor dynamic behavior (2) Inlet bleed study (3) Control parameter data (4) Inlet performance
0.15 Scale (Ames)	Dec. 1962	10 test days	90	2.4 to 3.6	0° to 5°	0° to 5°	(1) Inlet bleed study (2) Canard deflection effects (3) Inlet performance
1/11 Scale	June 1963 Sept. 1963	10 test days 10 test days	60 60	2.4 to 3.6	0° to 5°	0° to 5°	(1) Evaluate inlet spike and cowl geometries (2) Off design contraction ratios (3) Inlet performance
0.15 Scale (Tory IIC) (Ames)	Aug. 1963	10 test days	90	2.4 to 3.6	0° to 5°	0° to 5°	(1) Evaluate Tory IIC lines (2) Inlet boundary layer gutter height (3) Bypass door operations (4) Inlet performance
1/3 Scale (Free jet) (MJL)	June 1963	5 test days	10	2.70	0°	0°	(1) Obtain inlet control parameters (2) Duct dynamics (3) Inlet performance

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TABLE I (Continued)

Model	Date	Time	Number of Runs	M_o	α_o	β_o	Test Objectives
0.15 Scale (Ames)	Feb. 1964	10 test days	90	2.4 to 3.6	0° to 5°	0° to 5°	(1) Incorporate subsonic diffuser lines (2) Bypass door duct dynamics (3) Inlet controls (4) Inlet performance
1/3 Scale (Ames or AEDC)	Aug. 1964	10 test days	80	0.6 to 0.8 2.4 to 3.6	0° to 5°	0° to 5°	(1) Transonic inlet performance (2) Incorporate model configurations from previous tests (3) Inlet performance
1/3 Scale (Ames or AEDC)	Feb. 1965	10 test days	90	2.4 to 3.6	0° to 5°	0° to 5°	(1) Incorporates August test results (2) Final inlet test (3) Inlet performance
1/11 Scale Free jet nozzle optimization	Mar-May 1963	30 test days	160	3.0	--	--	(1) Define minimum spillage ratio (2) Define maximum altitude for free jet testing of PS-1

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TABLE II

EXHAUST NOZZLE MODEL TEST PROGRAM SUMMARY

Test	Date	Time	Number of Runs	Test Conditions	Test Objectives
Flow tests of several exit nozzle concepts with 1/12th scale models	Nov. 1961	15 days	94	PR = 2 - 30; W_s/W_p = 0 - 7%	Evaluate thrust coefficient, discharge coefficients, effects of secondary cooling on performance and to obtain nozzle drag data
Nozzle sector heat transfer test - full axial scale	July 1963 Dec. 1964	15 days 10 days	60 40	PR = 2 - 20; W_s/W_p = 2 - 8% Vary T_{t_s}, T_{t_p}	Document nozzle coupling and verify off-design heat transfer analysis - two dimensional unit
Scale, axisymmetric heat transfer, structural and performance	Nov. 1964	15 days	60	Same	Experimentally evaluate cooling, drag and structural integrity and exhaust system performance of optimized axisymmetric system

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TABLE III

MISCELLANEOUS MODEL TEST PROGRAM SUMMARY

	1963	1964	1965	1966
Exhaust System Afterbody Optimization	6	Initial Design	6 Modified Design	1. Evaluate nozzle drag influence 2. Document flow distribution
Free Jet Nozzle Spillage Tests	4	Selected PLUTO Inlet Design		1. Define optimum free jet nozzle (Aspect ratio). 2. Determine nozzle to inlet area ratio for starting at α = 7, θ = 3°. 3. Determine shroud gap. 4. Determine inlet-nozzle positioning. 5. Determine loads on inlet during flow transition

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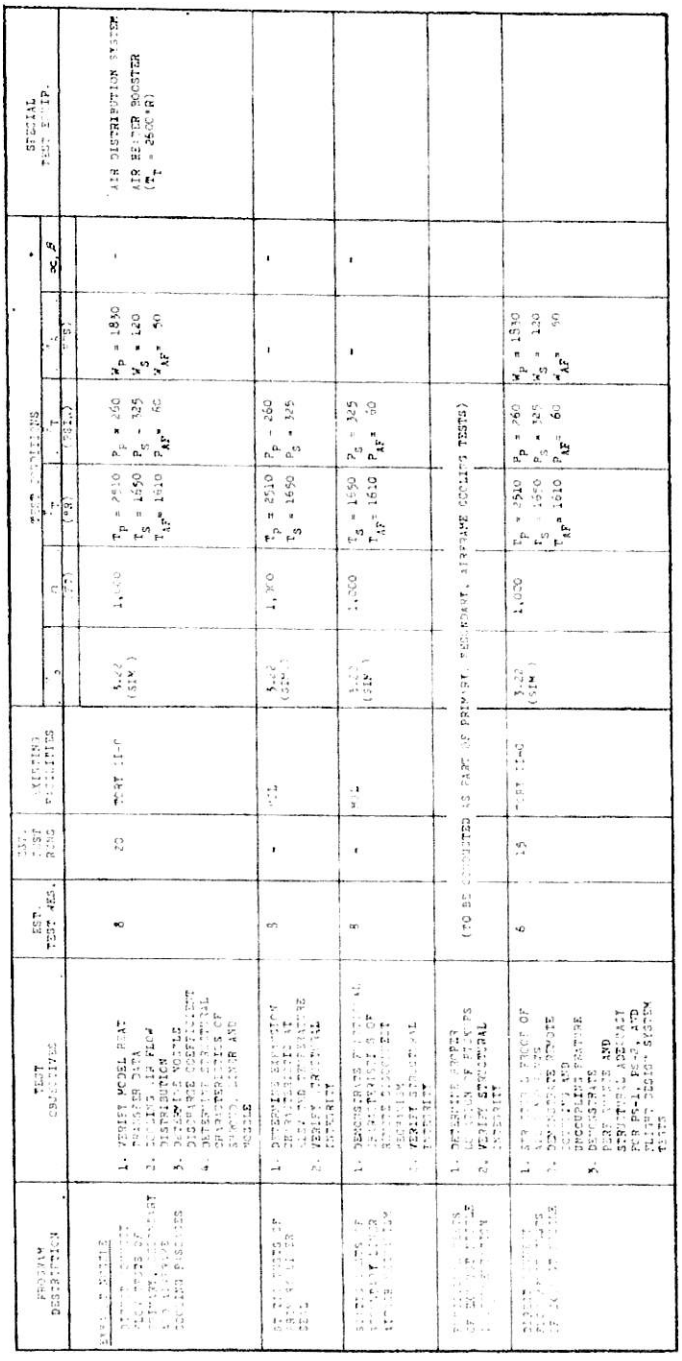

PROGRAM DESCRIPTION	TEST OBJECTIVES	EST TEST REQ.	EST TEST RUNS	REMARKS FACILITIES	DESIGN CONDITIONS						SPECIAL TEST EQUIP.
					W (PPS)	P (PSIA)	T (°R)	T (°F)	α_s	α_p	
[illegible]	1. VERIFY MODEL HEAT EXCHANGER DATA 2. [illegible] AT FLOW DISTRIBUTION 3. DETERMINE NOZZLE DISCHARGE COEFFICIENT 4. DETERMINE [illegible] OF [illegible] AND NOZZLE	8	20	HEAT EX-P	3.42 (GW)	1,450	T_P = 2510 T_S = 1690 T_{AF} = 1610	P_P = 260 P_S = 325 P_{AF} = 60	W_P = 1830 W_S = 120 W_{AF} = 90	-	AIR DISTRIBUTION SYSTEM AIR HEATER BOOSTER (T_T = 2600°R)
[illegible]	1. DETERMINE [illegible] 2. VERIFY [illegible]	8	-	[illegible]	3.42 (GW)	1,450	T_P = 2510 T_S = 1690	P_P = 260 P_S = 325	-	-	
[illegible]	1. DEMONSTRATE [illegible] 2. VERIFY [illegible]	8	-	[illegible]	3.42 (GW)	1,450	T_S = 1690 T_{AF} = 1610	P_S = 325 P_{AF} = 60	-	-	
[illegible]	1. DEMONSTRATE [illegible] 2. VERIFY STRUCTURAL [illegible]	(TO BE CONDUCTED AS PART OF PRIMARY AIRFRAME COOLING TESTS)									
[illegible]	1. SUPPORT PROOF OF [illegible] 2. DETERMINE [illegible] AND [illegible] 3. DEMONSTRATE AND [illegible] ASSEMBLY PER PS-II PROP. AND [illegible] SYSTEM	6	15	[illegible]	3.42 (GW)	1,450	T_P = 2510 T_S = 1690 T_{AF} = 1610	P_P = 260 P_S = 325 P_{AF} = 60	W_P = 1830 W_S = 120 W_{AF} = 90		

α_s, α_p INCLUDES X RADIATION FACTOR + 20% SAFETY MARGIN

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TABLE III (Continued)

PROGRAM DESCRIPTION	TEST DESCRIPTION	EST. TEST AREA	NOT TO EXCEED RATE	EXPOSING RADIATION	TEST CONDITIONS						SPECIAL TEST EQUIP.
					M	h (FT)	T_t (°R)	P_t (PSIA)	V (FPS)	α, β	
SUBSYSTEMS (CONT.) GUIDANCE (CONT.) STORED DATA	1. DETERMINE OPERATION OF STORED DATA UNIT AT LOADS SPECIFIED IN PARAGRAPHS 15 ELEVATED TEMPERATURE 2. DETERMINE OPERATION OF DATA UNIT UNDER SPECIFIED VIBRATION	-	-	MAG	-	-	1650	-	-	-	-
	1. DETERMINE PASSAGE OF [illegible] THROUGH [illegible] 2. OBTAIN READ TIME UNDER [illegible] 3. DETERMINE [illegible]	12	90	[illegible]	[illegible]	1.0-6	1660	505	< 120	-	SEE ACS BRIEFING FOR [illegible]
	1. DETERMINE [illegible] AT [illegible] 2. DETERMINE [illegible] UNDER [illegible]	12	50	(40 MI RADIAL)	FROM [illegible] TO 30 CPS "G" WITH PA [illegible] LIMIT ACCEL. CONTROLLED						
COMMUNICATIONS TELEMETRY RADIO	1. DETERMINE EQUIPMENT PERFORMANCE MODEL DATA 2. DETERMINE TRANSMISSION 3. OBTAIN ANTENNA PATTERN 4. DETERMINE [illegible]	8	40	CAL	3.5 2.7 5.0	14,000- 25,000 40,000- 55,000 22,000- 35,000	1050- 920 1100- 930 1250- 1100	140- 100 150- 50 260- 130	1,000- 700 900- 450 970- 550	-15 TO +5 -15 TO +5 -15 TO +5	M @ 2.7 FREE AIR RELEASE AND SPROUT
	1. DETERMINE BLEND AND [illegible] 2. VERIFY PHYSICAL [illegible] 3. DETERMINE [illegible] UNDER LOAD AND VIBRATION	9	25	CAL FOR 11-3	3.5- 5.2 5.0- 5.6	1,000- 36,000 5,000- 36,000	1500- 1000 1400- 1100	360- 90 360- 95	2,000- 500 1,650- 500	0 0	DIRECT [illegible]

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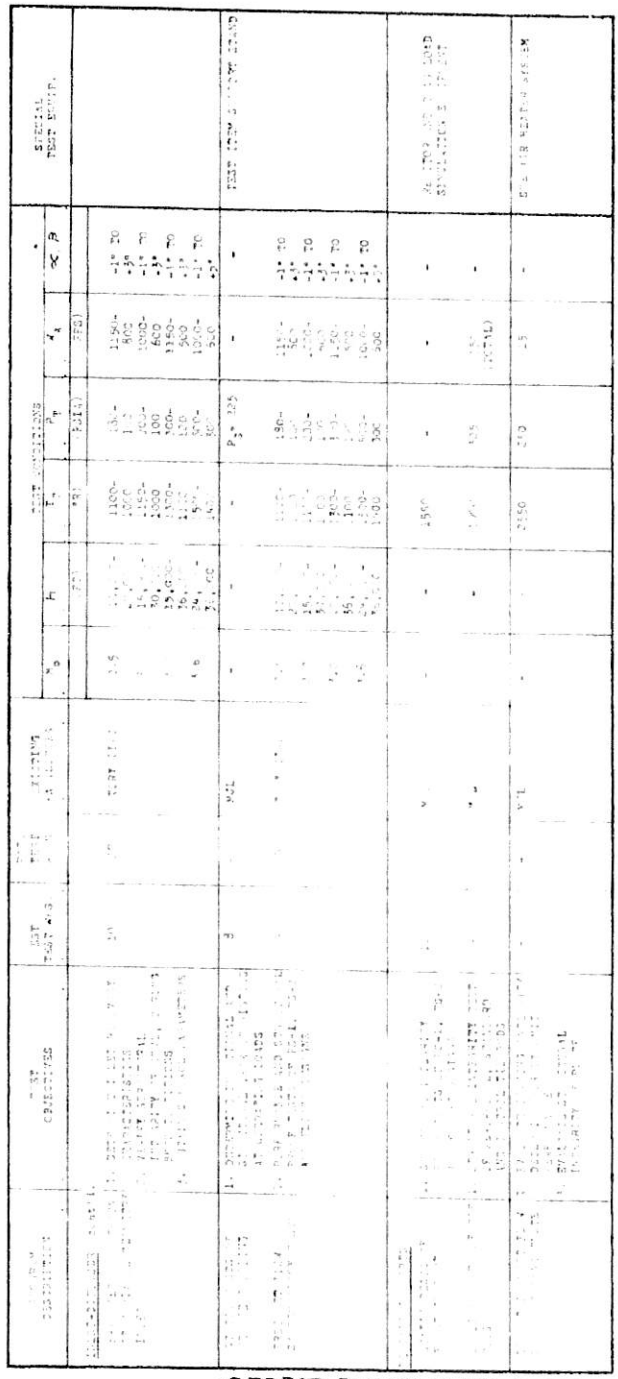

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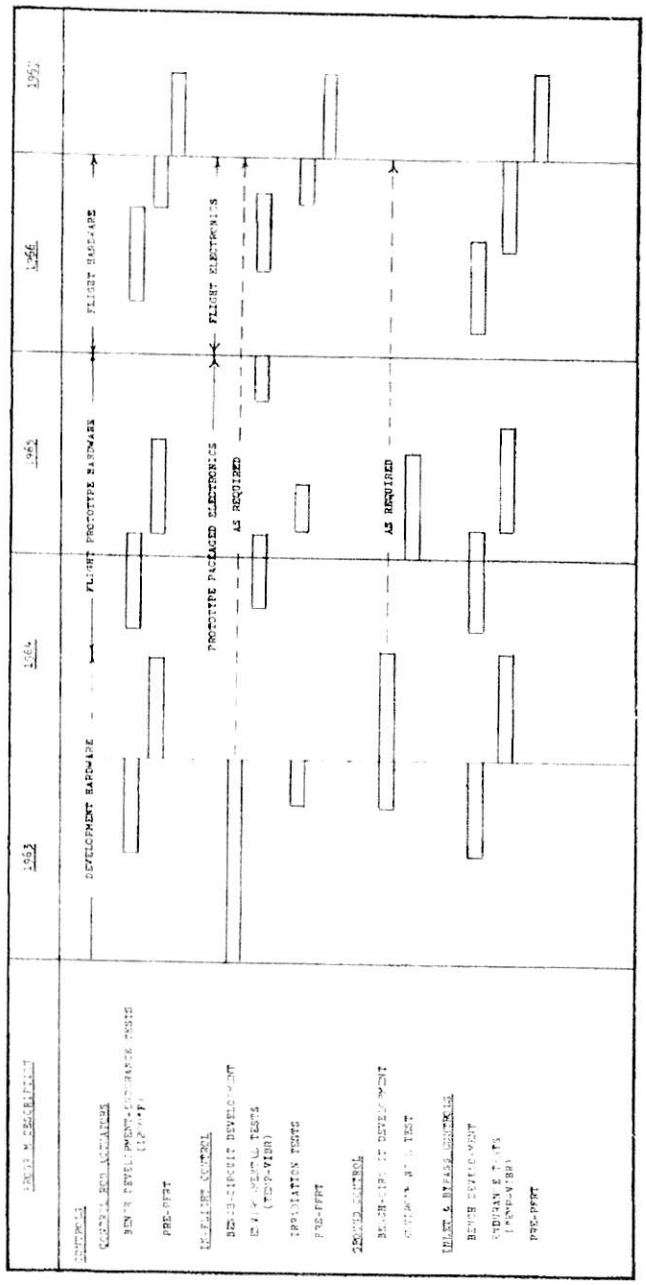

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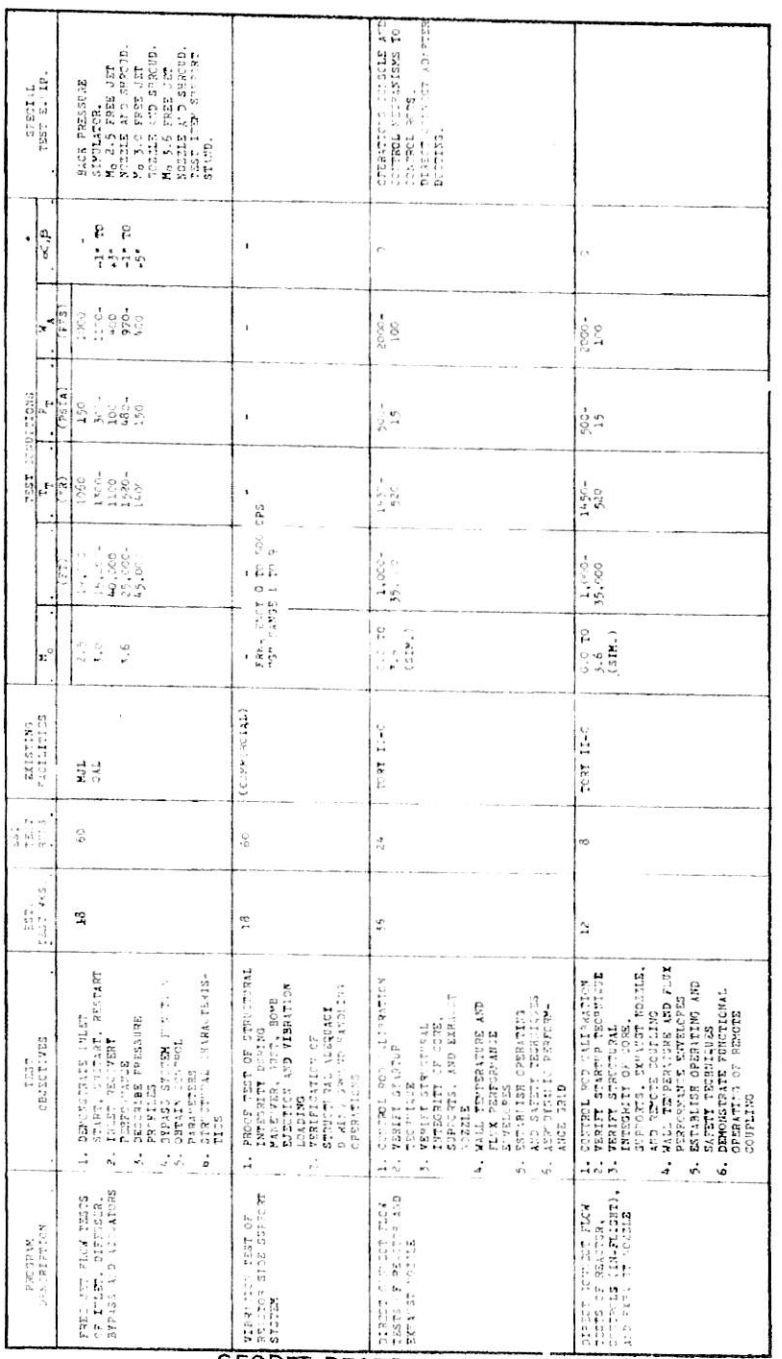

PROGRAM DESCRIPTION	TEST OBJECTIVES	EST. TEST TIME (HRS)	EST. TEST TIME (HRS)	EXISTING FACILITIES	TEST CONDITIONS M_0	P_T (PSIA)	T_T (°R)	P_T (PSIA)	V_A (FPS)	α, β	SPECIAL TEST EQ. REQ.
PRELIM. FLOW TESTS OF NOZZLE DIFFUSER. DEFINE LOADINGS	1. DEMONSTRATE INLET STARTING, UNSTART, RESTART 2. EFFECT OF VENT 3. DEFINE INLET PRESSURE RECOVERY 4. DEFINE PRESSURE DISTORTION 5. CONTROL SYSTEM PARAMETERS 6. DETERMINE STRUCTURAL LOADINGS	48	60	MAIL SAL	2.5 4.6 5.6	1,000 40,000 120,000- 45,000	1060 1400- 1130 1290- 1470	150 34 - 10 48- 150	2960 1170- 960 970- 960	- -1° TO +1° TO -1° TO -5°	BACK PRESSURE SIMULATORS No. 2.5 FREE JET. No. 4.6 FREE JET W/SHOCK STRUCTURE. No. 5.6 FREE JET W/SHOCK AND SHOCK INDUCED SEPARATION. MAY USE STEAM.
VERIFY REST OF PROGRAM OBJECTIVES	1. PROOF TEST OF STRUCTURAL INTEGRITY DURING MACH NO., ALT., BOMB EJECTION AND VIBRATION LOADING 2. VERIFICATION OF STRUCTURAL MARGINS 3. CHECK CONTROL SYSTEM OPERATIONS	18	60	(SAME AS ABOVE)	- SAME AS ABOVE FOR RANGE 1 TO 6	- - - FOR 0 TO 500 CPS	-	-	-	-	
DIRECT CONTROL FLAPS CHECK PERFORMANCE AND EVALUATE NOZZLE	1. CONTROL AUTHORITY 2. VERIFY GROUP RESPONSE 3. VERIFY STRUCTURAL INTEGRITY OF CORE, SUPPORTS, AND KEEL 4. WALL TEMPERATURE AND FLUX PERFORMANCE 5. SYSTEMS OPERATIONS 6. ASP TRANSIENT PERFORMANCE	45	24	SAME AS	0.8 TO 3.6 (SIM.)	1,000- 35,000	1457- 820	300- 15	2000- 100	0	OPERATIONS SIMULATE ATP CONTROL DEFLECTIONS TO CONTROL SYSTEMS. DIRECT CONTROL AND PRESSURE DISTRIBUTION.
DIRECT FLOW TEST EFFECT OF RECESS CONTROL (WITH INLET). EFFECT OF VENT	1. CONTROL AUTHORITY 2. VERIFY GROUP RESPONSE 3. VERIFY STRUCTURAL INTEGRITY OF CORE, SUPPORTS, AND KEEL 4. WALL TEMPERATURE AND FLUX PERFORMANCE 5. ESTABLISH OPERATING AND SAFETY TECHNIQUES 6. DEMONSTRATE FUNCTIONAL OPERATION OF REMOTE COUPLING	12	8	SAME AS	0.8 TO 3.6 (SIM.)	1,000- 35,000	1457- 820	300- 15	2000- 100	0	

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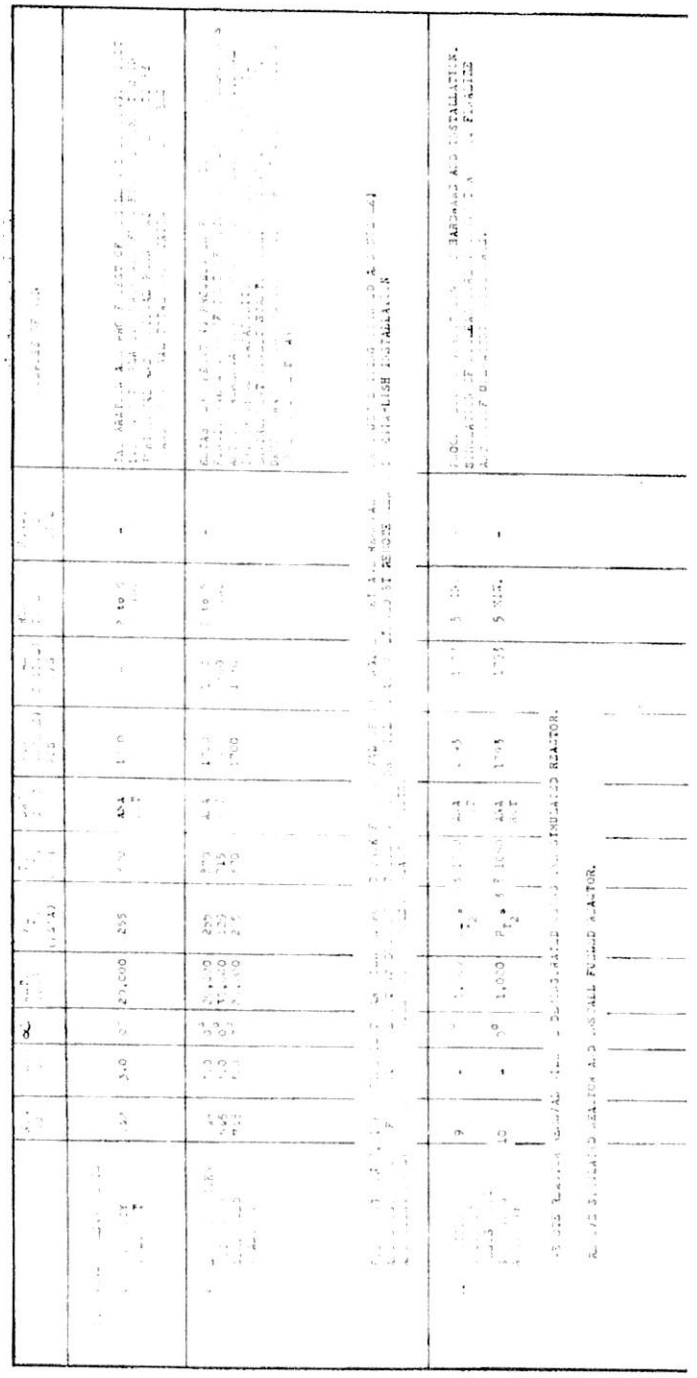

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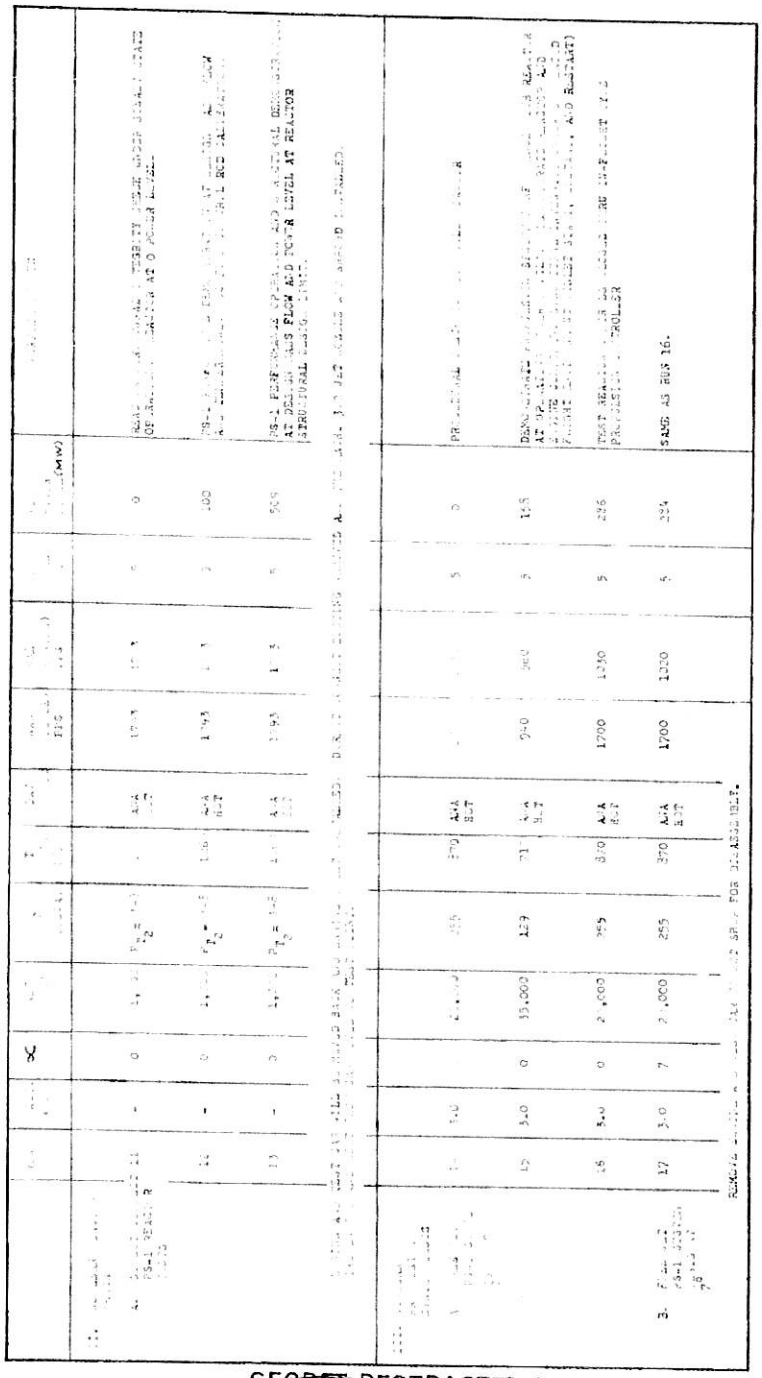

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TABLE VII

PERFORMANCE SUMMARY

SYSTEM - SUBSYSTEM PROPULSION	OBJECTIVE	NO. OF REINS	RUN TIME MIN.	N_o	h LBNDG FT	α, β ** METHOD	T_o LBS/A	T_o LBS	T_o LBS	SEC. REF.
I. PROPULSION SYSTEM	BOOST - MISSION HIGH ALTITUDE PERFORMANCE	1	-	P - 1.0	S.L. - 5	-	(PRIMARY PERFORMANCE)			-
	AND DYNAMICS	1	70	1.6	35	(-1° to +5°)	320	1000	600	-
	B. TAKEOFF,				10 - 15	(-1° to +5°)	PER	ENGINE		-
	CLIMB	1	27	1.0	35 - 2	(-1° to 0°)	BOOST	TAKEOFF		-
	LOW ALTITUDE CRUISE & DES.				1	(-1° to 0°)	THRUST	4 ENGINE		-
	1. ALTITUDE CAPABILITY	1	60	1.0	1	- (0° to 5°)	540	1670	1130	-
III. SUBSYSTEMS										
	IGNITION START - NO DAY	1	-	2.5	15	-	140	660	620	-
	EMERGENCY START - 2 MIN.	1	-	2.5	15	-	140	660	620	-
	WATER				30	(-1° to +5°)	350	810	670	-
	SHIMB				15		170	710	490	-
	HIGH ALT. CRUISE MANEUVER,	1	70	3.0	15		320	1020	650	-
	LOW ALT. CRUISE OR SPRINT &	3	90	1.6	15	(-1° to +5°)	540	1670	1850	-
	LEEWAY MANEUVER			1.0	1	-	190	710	490	-
					35	-				-
	HIGH ALTITUDE ENDURANCE	1	210	1.6	35	-	120	1520	600	-
	LOW ALTITUDE ENDURANCE	1	90	1.0	1	-	350	1670	1800	-
A. NOZZLE										
EXTENT REA OF CONTROL SYSTEM	CALIBRATION	1	-	-	-	-	-	1070	-	-
GROUND STARTING SYSTEM	CALIBRATION	1	-	-	-	-	-	388	-	-
FLIGHT AND BOOST	DURABILITY	5	300	-	-	-	-	170	-	-
	RADIO INTERFERENCE	1	-	-	-	-	-	-	-	-
ACTUATOR	ENDURANCE	5	300	-	-	-	-	1070	-	-
C. THRUST SUPPORT	DURABILITY	1	300	-	-	-	-	1100	-	-
								1400		
EXHAUST NOZZLE	DURABILITY	1	210	3.6	35	-	80	2100	600	-
		1	90	1.0	1	-	230	2560	1820	-

* VIBRATION TO BE THAT EXPECTED DURING FLIGHT

** α, β (TEST) = α, β (METHOD) X AMPLIFICATION FACTOR
+ 2* SAFETY MARGIN

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TABLE IX

FLIGHT ENGINE GROUND TEST FACILITY CRITERIA ALTERNATES COST SUMMARY

Type of Cell	Qual Closed	Closed Plus Non-Nuclear Test Point	Single Non-Nuclear	Single Closed	Single Open	Single Open	Single Open
Type of Air Supply	UAS	UAS	UAS	UAS	UAS	UAS	UAS
Minimum Available Air Supply, lbs	11,000,000	11,000,000	5,500,000	11,000,000	11,000,000	11,000,000	7,444,800
Total Air Stored, lbs	15,100,000	15,100,000	7,550,000	15,100,000	15,100,000	15,100,000	10,100,000
Days to Recharge	6	6	6	6	6	15	15
Average Available Run Time at							
1960 pps, min	93.5	93.5	47.5	93	93	93	63
2585 pps, min							48
Exhaust Handling System	Minimal	Minimal	None	Minimal	Minimal	Minimal	Minimal
Free Jet Angle of Attack Capability	±10°	±10°	±10°	±10°	±10°	±10°	±10°
New Hot Component Service Building	No	No	No	No	No	No	Yes
Air Heater System	Vitiated	Vitiated	Vitiated	Vitiated	Vitiated	Vitiated	Vitiated
STE Included	No	No	No	No	No	No	No
Service Buildings	Share with TORY IIC	Share with TORY IIC	Share with TORY IIC	Share with TORY IIC	Share with TORY IIC	Share with TORY IIC	R.R. Only Share W/TORY IIC
Number of Runs to Complete Trajectory at							
1960 pps, min	2	2	4	2	2	2	3
2585 pps, min							4
Air Supply System	18,117,500	18,117,500	11,136,300	18,066,800	18,065,000	17,275,300	11,871,500
Test Cell Instl. & Support Services	3,934,400	2,132,700	250,000	2,660,500	2,693,500	2,708,100	2,708,100
Exhaust Handling System	480,000	240,000	--	239,200	239,200	239,200	239,200
Instrumentation and Controls	1,674,600	2,062,300	561,300	1,193,500	1,243,800	469,600	469,500
Hot Component Service Building	--	--	--	--	--	--	2,945,900
Service Buildings	587,000	587,000	587,000	548,300	548,200	532,200	822,200
Site Development and Utilities	2,127,500	1,504,600	1,811,000	1,811,700	1,841,300	1,841,300	1,841,300
Required Facility Funding	26,821,000	24,644,000	14,345,600	24,520,000	24,631,000	23,066,000	20,897,700

Excludes all test item instrumentation.

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TABLE X

PRELIMINARY
COST ESTIMATE
TORY IIC MODIFICATION
FOR
FLIGHT ENGINE GROUND TEST

AIR MASS FLOW (w) = 1960 pps					
Run Time (Mins.)	0	15	45	90	180
Fixed Costs	$10,032,000	$10,100,000	$10,237,000	$10,442,000	$ 10,852,000
Air Storage Costs	-	6,550,000	24,140,000	49,500,000	103,278,000
Total Costs	$10,032,000	$16,650,000	$34,377,000	$59,942,000	$114,130,000
AIR MASS FLOW (w) = 2200 pps					
Run Time (Mins.)	0	15	45	90	180
Fixed Costs	$10,117,000	$10,186,000	$10,323,000	$10,528,000	$ 10,938,000
Air Storage Costs	-	7,910,000	27,660,000	57,350,000	116,590,000
Total Costs	$10,117,000	$18,096,000	$37,983,000	$67,878,000	$127,528,000
AIR MASS FLOW (w) = 2500 pps					
Run Time (Mins.)	0	15	45	90	180
Fixed Costs	$10,225,000	$10,293,000	$10,430,000	$10,635,000	$ 11,046,000
Air Storage Costs	-	9,540,000	31,990,000	65,700,000	133,090,000
Total Costs	$10,225,000	$19,833,000	$42,420,000	$76,335,000	$144,136,000

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TABLE XI

TORY IIC MODIFICATION
FIXED COSTS SUMMARY

BASE COSTS		1960 pps	2200 pps	2500 pps
Air Supply (without air storage)		$ 5,672,400	$ 5,758,348	$ 5,865,795
Test Cell Installation and Support Services		2,130,932	2,130,932	2,130,932
Exhaust Handling		239,112	239,112	239,112
Site Development and Utilities		907,897	907,897	907,897
Service Building		291,600	291,600	291,600
Instrumentation and Controls		789,507	789,507	789,507
SUB TOTALS		$10,031,448	$10,117,396	$10,224,843
RUN TIME DEPENDENT COSTS				
15 minutes	$ 68,409			
45 minutes	205,230			
90 minutes	410,456			
180 minutes	820,912			
TOTAL FIXED COSTS				
Base Costs		$10,031,448	$10,117,396	$10,224,843
Totals (including 15 minute run costs)		10,099,857	10,185,805	10,293,252
Totals (including 45 minute run costs)		10,236,678	10,322,626	10,430,073
Totals (including 90 minute run costs)		10,441,904	10,527,852	10,635,299
Totals (including 180 minute run costs)		10,852,360	10,938,308	11,045,755

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TABLE XII

TORY IIC MODIFICATION
AIR STORAGE COSTS SUMMARY

REQUIRED AIR FLOW - 1960 pps RUN TIME (min)	Total Air Delivered (lbs)	Additional Stored Air Required (lbs)	Additional Cost ($)
15	2.11×10^6	1.81×10^6	6,550,000
45	5.67×10^6	6.66×10^6	24,140,000
90	10.94×10^6	13.65×10^6	49,500,000
180	21.54×10^6	28.48×10^6	103,278,000
REQUIRED AIR FLOW - 2200 pps			
15	2.375×10^6	2.18×10^6	7,910,000
45	6.33×10^6	7.63×10^6	27,660,000
90	12.27×10^6	15.82×10^6	57,350,000
180	24.15×10^6	32.15×10^6	116,590,000
REQUIRED AIR FLOW - 2500 pps			
15	2.70×10^6	2.63×10^6	9,540,000
45	7.20×10^6	8.82×10^6	31,990,000
90	13.45×10^6	18.12×10^6	65,700,000
180	27.44×10^6	36.70×10^6	133,090,000

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TABLE XIII

PHYSICAL PROPERTIES
PHASE I CORE DRILLING PROGRAM CORE TESTS

TMC Core Hole No.	Core Sample Depth (Feet)	Unconfined Mod. of Elasticity (Compression) PSI	Poisson's Ratio	Unconfined Ult. Compress. Strength PSI
1	136.0 - 136.5	706,000	--	3,995
1	143	1,063,000	--	6,275
1	162.3 - 162.8	3,155,000	--	8,980
1	179.0 - 179.5	2,565,000	--	8,953
1	184.3 - 185.3	2,385,000	.080	8,760
1	187.0 - 188.0	2,532,000	.073	8,280
1	195.0 - 195.5	2,721,000	.162	8,280
1	201.3 - 201.9	1,724,000	.037	6,530
1	208.6 - 209.6	2,222,000	.108	6,540
1	218.2 - 218.9	2,548,000	.166	6,630
6	440.0 - 440.8	3,390,000	.163	9,889
6	447.5 - 478.3	5,030,000	.156	10,056
6	519.3 - 519.9	3,490,000	.151	8,774
6	560.0 - 561.0	2,500,000	.162	7,632
6	599.1 - 599.6	2,000,000	.206	8,000
6	639.3 - 640.0	3,100,000	.145	9,805
6	680.6 - 681.4	3,420,000	.133	9,136
6	717.5 - 718.1	3,830,000	.155	9,806
6	757.0 - 757.8	4,330,000	.142	11,856
6	799.8 - 800.8	3,910,000	.107	11,811
7'	437.7 - 438.4	2,059,000	.135	7,703
7'	480.9 - 481.5	2,238,000	.123	8,067
7'	516.3 - 517.0	1,065,000	.168	5,910
7'	559.8 - 560.9	2,155,000	.144	9,272
7'	591.3 - 592.1	2,175,000	.146	8,880
7'	638.0 - 639.0	2,690,000	.162	9,076
7'	686.2 - 686.8	4,330,000	.160	9,556
7'	719.5 - 720.4	2,930,000	.156	10,056
7'	759.0 - 760.2	3,380,000	.130	10,798
7'	798.6 - 799.4	4,290,000	.186	10,914
11'	440.6 - 441.8	2,550,000	.120	8,861
11'	485.0 - 485.7	3,640,000	.129	8,611
11'	519.0 - 519.8	1,920,000	.127	7,806
11'	559.5 - 560.0	1,633,000	.134	5,651
11'	600.1 - 600.9	1,865,000	.130	6,731
11'	642.0 - 642.9	1,770,000	.157	4,571
11'	683.5 - 684.9	3,810,000	.173	7,424
11'	721.5 - 722.0	2,380,000	.135	8,726
11'	760.7 - 761.3	1,760,000	.138	7,833
11'	799.1 - 800.0	2,580,000	.100	8,500

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TABLE XIII (Continued)

PHYSICAL PROPERTIES
PHASE I CORE DRILLING PROGRAM CORE TESTS

TMC Core Hole No.	Core Sample Depth (Feet)	Unconfined Mod. of Elasticity (Compression) PSI	Poisson's Ratio	Unconfined Ult. Compress. Strength PSI
13	440.3 - 441.5	2,220,000	.125	7,361
13	479.7 - 480.7	3,160,000	.113	10,250
13	520.1 - 521.0	1,780,000	.116	7,722
13	553.5 - 554.8	2,840,000	.113	9,778
13	587.7 - 588.6	2,465,000	.119	9,028
13	638.2 - 639.1	2,839,000	.139	9,000
13	677.3 - 678.0	2,310,000	.146	8,000
13	759.1 - 760.0	2,470,000	.086	9,333
13	798.8 - 799.4	2,880,000	.122	9,250
15'	440.1 - 441.0	3,300,000	.138	9,359
15'	480.0 - 480.8	2,370,000	.109	8,607
15'	525.8 - 526.4	2,740,000	.154	7,855
15'	556.0 - 556.8	3,030,000	.127	8,524
15'	599.9 - 600.7	1,430,000	.108	8,022
15'	644.0 - 645.1	2,730,000	.109	9,692
15'	680.0 - 680.8	1,800,000	.109	9,889
15'	720.0 - 720.9	3,170,000	.141	7,927
15'	759.8 - 760.8	3,910,000	.151	9,944
15'	797.7 - 798.9	2,560,000	.135	9,384
	Ave	2,780,000	Ave	.137
	High	5,030,000	High	.206
	Low	1,065,000	Low	.086

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TABLE XIV

PHYSICAL PROPERTIES
U.A.S. EXPERIMENT INSTRUMENTATION CORES

Instrument Assembly Numbers	Gage Numbers	Gage Orientation	Unconfined Mod. of Elast. (Compression) psi	Poisson's Ratio	Unconfined Ult. Compr. Strength psi
A	48	Radial	3,830,000	.211	8,669
A	49	Radial	4,390,000	.209	9,057
B	55	Radial	4,260,000	.153	10,962
B	56	Radial	4,580,000	.189	10,287
B	57	Radial	3,620,000	.163	9,569
B	52	Circumf.	4,090,000	.173	9,353
B	53	Vertical	3,400,000	.230	7,000
C	60	Radial	5,000,000	.174	10,526
C	64	Radial	3,940,000	.145	7,304
C	65	Radial	4,390,000	.151	12,050
C	61	Circumf.	2,900,000	.173	8,921
D	71	Radial	3,640,000	.111	7,305
D	72	Radial	3,790,000	.177	10,511
D	74	Radial	3,750,000	.171	10,463
E	85	Radial	2,370,000	.118	8,967
F	78	Radial	3,540,000	.172	8,698
F	79	Radial	3,690,000	.217	7,886
F	80	Radial	3,330,000	.181	9,489
F	76	Circumf.	3,620,000	.179	7,922
F	77	Vertical	3,620,000	.196	7,353
G	82	Radial	3,550,000	.144	8,000
G	83	Radial	2,120,000	.186	5,559
		Ave	3,700,900	Ave .173	
		High	5,000,000	High .230	
		Low	2,120,000	Low .111	

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TABLE XV

UNDERGROUND AIR STORAGE
LINER MATERIAL SELECTION TABLE

MATERIAL RATING FACTOR BASED ON ELASTIC
OPERATION OF WELD JOINT MATERIAL

Material	Yield Stress in Parent Metal F_{ty} (psi)	Modulus of Elasticity E (psi)	Yield Stress in Weld Metal F_{ty_w} (psi)	Weldability	Rating Factor R.F. = $\frac{F_{ty_w}}{E}$
Aluminum 6060-T6 or 6062-T6	40,000	10.0×10^6	24,000	Good	.0024
Aluminum 5456-0	23,000	10.3×10^6	23,000	Good	.00223
Steel USS T-1	100,000	30.0×10^6	100,000	Good (Spec. Method Required)	.0033
Steel 4340	99,000	29.0×10^6	99,000	Good (Pre-heat Required)	.0034
Manganese Bronze*	30,000	15.0×10^6	30,000	Good (Resist-ance Welding)	.0020
Phosphor Bronze Grade D*	28,000	16.0×10^6	28,000	Excellent (Resist-ance Welding)	.00175
Magnesium Alloy HK 31 A*	29,000	6.5×10^6	29,000	Weldable (I.G.S.A)	.00445
Titanium Alloy 13V-11CR-3AI*	135,000	14.3×10^6	135,000	Weldable (Fusion)	.00945

* High cost materials

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2. Aircraft nuclear power propulsion
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4. Propulsion system testing
5. Ground test facilities

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II. Contract AF 33(657)-8123
III. The Marquardt Corp., Van Nuys, Calif.
IV. L. E. McTaggart
V. TMC Rpt 6004
VI. Not in ASTIA
VII. Not aval fr OTS

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DEPARTMENT OF DEFENSE
WASHINGTON HEADQUARTERS SERVICES
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WASHINGTON, DC 20301-1155

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MEMORANDUM FOR DEFENSE TECHNICAL INFORMATION CENTER
(ATTN: DTIC-OQ INFORMATION SECURITY)
8725 JOHN J. KINGMAN ROAD, SUITE 0944
FORT BELVOIR, VA 22060-6218

Subject: OSD MDR Case 14-M-1508

We have reviewed the enclosed document in consultation with the Department of Energy and Department of the Air Force and have declassified it in full. If you have any questions please contact Mr. John D. Smith by email at whs.mc-alex.esd.mbx.records-and-declassification@mail.mil.

Sincerely,

George R. Sturgis
Deputy Chief, Records and Declassification Division

Enclosures:
1. MDR request w/ document list
2. Document 11