WADD TECHNICAL REPORT 60-785
PART II

HYPERENVIRONMENT SIMULATION

Part II. Development and Design of Simulation Facilities For Space Vehicle Environment

T. M. McCoy

Northrop Corporation
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Flight and Engineering Test Group
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WRIGHT AIR DEVELOPMENT DIVISION
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

This report was prepared by the Norair Division of Northrop Corporation, Hawthorne, California under USAF Contract Number AF 33(616)-6679, "Hyper-environment Simulation," Project 1309, Task 13000. The effort was initiated by the Environmental Criteria Branch, Directorate of Laboratories, Wright Air Development Center in June 1959. ARDC reorganization of 1960 transferred contract management to the Environmental Branch, Flight and Engineering Test Group, Wright Air Development Division. Mr. R. K. Hankey was project engineer.

The work of this contract is reported in two parts. Part I, "Definition and Effects of Space Vehicle Environment - Natural and Induced," was prepared by the Engineering Laboratories Group under the direction of R. B. Jackman, Chief. This report, Part II, "Development and Design of Simulation Facilities for Space Vehicle Environment," together with the facility design specifications (under separate covers), completes the effort under the "Hyperenvironment Simulation" contract.

Personnel who contributed significantly to the effort summarized in this report were:

T. M. McCoy	Project management, and formal report.
F. Q. Banker	Overall facilities design and integration, cost estimates, and Design Specification for the Inertial Dynamic Facility.
C. J. Gordinier	Design Specifications and cost estimates for the Thermal-Mechanical Dynamic Facility and Acousti-Thermal Vibration Facility.
E. C. Fox	Design Specification for the Space Environment Research Facility.
E. N. Borson M. E. Carlisle J. G. Adams W. W. Kelly R. A. Kinney F. R. Hollopeter D. C. Skilling	Experimentation and development.
R. M. Daniel	Administrative direction, and editing.

Acknowledgement and gratitude are also extended to many individuals, both in government and industry, who were very accommodating in sharing acquired information and experiences pertaining to design, fabrication, and operational techniques for combined hyperenvironment simulation.

ABSTRACT

This report summarizes the approach, concept, design, and cost of hyperenvironmental simulation facilities for evaluating effects of space vehicle environment on specimens up to 250 pounds. With the objective of combining environmental variables wherever applicable and feasible, four basic facilities have been conceived with several environments each. Detailed design specifications for these facilities are contained under separate covers.

As part of the design back-up, some of the problems, methods and techniques of simulation are discussed. A summary is also given of the pertinent results of some experiments conducted to prove design feasibility in certain critical areas of simulation.

PUBLICATION REVIEW

This report has been reviewed and is approved.

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TABLE OF CONTENTS

Table of Contents
(Continued)

Page

Table of Contents
(Continued)

LIST OF ILLUSTRATIONS

INTRODUCTION

The "Hyperenvironment Simulation" Contract AF 33(616)-6679 established four work phases with objectives as follows:

Phase I	Survey the environmental field, and compile a general summary of all pertinent recent data.
Phase II	Determine and summarize known and probable effects of the various environments on components and materials.
Phase III	Determine the environments to be simulated and in which combinations. Design prototype facilities to simulate such environments, considering degree of simulation versus cost.
Phase IV	Estimate engineering, materials and construction costs of prototype facilities.

The final report covering the four work phases is divided into two principal parts. Part I, "Definition and Effects of Space Vehicle Environment - Natural and Induced", summarizes the work performed under Phases I and II. This document, Part II, summarizes the work performed under phases III and IV, and provides background information on simulation methods and associated considerations. It does not contain the design specifications per se for the four facilities that were conceived. Each design specification is provided under individual cover, but are all qualitatively discussed and summarized as part of this report. The respective numbers and titles of these reports are:

NOR-60-246	"Thermo-Mechanical Dynamic Facility Design Specification"
NOR-60-247	"Space Environment Research Facility Design Specification".
NOR-60-290	"Specification for Centralization and Installation of SERF and TMDF Hyperenvironment Facilities."
NOR-60-291	"Inertial Dynamic Facility Design Specification."
NOR-60-292	"Acousti-Thermal Vibration Facility Design Specification".

It may be noted that in a few instances information contained in this report partially conflicts with statements made in the detail design specifications. The intent is that any such information contained in this document should be interpreted as superseding the design specification information.

Manuscript released by the author December 1960 for publication as a WADD Technical Report.

I. OBJECTIVE AND APPROACH

The primary objective of the "Hyperenvironment Simulation" study has been to develop design concepts and working specifications for test facilities that could simulate space vehicle hyperenvironments in a realistic and practical manner. It was desired to combine the environments in their respective relationships and magnitudes wherever possible.

In order to accomplish this objective, the pertinent environments and apparent effects were initially predicted and defined (Part I Report). It has subsequently been determined which of these environments should be simulated, for what range of magnitudes, and in what combinations. Concurrently, a design and facility-utilization philosophy, including the 'a priori' postulates has been established. Finally, studies have been conducted to acquire a knowledge and understanding of the technological state-of-the-art in various engineering and industrial fields, pertaining to the design, construction, and operation of a complex facility.

The resultant ground rules and assumptions adopted for the design of the subject hyperenvironment simulation facilities are as follows.

A. Fundamental Assumptions:

a) The environments known to have important detrimental effects are those to be considered for simulation; however, simulation of any environmental variable is also to be considered if its effect is unpredictable as a single or combined environment.

b) The environments to be simulated will be combined in the same relationship as occurs naturally wherever practical.

B. Design Concept, Approach, and Philosophy:

a) Facility design to be within the state-of-the-art. This term is not necessarily intended to imply "off-the-shelf", but includes any method of simulation that can be readily devised within present limits of investigation and knowledge. Thus, in those areas where the exact method of simulation is not completely defined, it is assumed that a reasonable amount of investigation will yield a feasible solution.

b) Final design to be in the form of specifications which define the design concept, equipment configuration, spatial compatability, and functional and performance requirements.

c) New design concepts, or unusual application of basic designs or techniques to be further detailed so that particular adaptations or applications are readily understood.

d) "R & D" or experimentation to be performed as to establish a reasonable level of confidence for new design concepts or applications.

e) Installation, centralization, and other locale-dependent design aspects to be tailored for installation of the facilities at WADD, Building 45.

f) Facility designs and installations to be completely new; not the modification of some existing facility. However, the use of existing utilities to be encouraged.

g) Facilities to be designed and used for test of "blackbox" equipment, components and subsystems. Test specimen to be no larger than a two foot cube, or to weigh no more than 250 pounds.

h) Facility capability to include, where applicable and feasible, ability to reproduce the flight profile, or time history of typical vehicles.

i) Facility design to provide for future growth (additions of increased capability), whenever predictable and feasible.

Starting with the foregoing assumptions and philosophy, Table I summarizes the approach and fundamental steps followed in evolving specific facility configurations.

C. Table I Supplementary Information

o Column 1

This column itemizes the natural and induced* variables that need to be considered for simulation, as discussed in Part I report. Where a particular variable occurs in both the natural and induced environments, it is listed only once.

Three environmental variables have been specifically excluded from consideration for simulation. Nuclear radiation and zero gravity were categorically eliminated by the contracting agency at the start of the program. Nuclear radiation simulation requires a complex facility with remote controls which would isolate unproven prototype environmental facilities and test specimens. Zero gravity, singly or in combination with other environments, presents formidable simulation problems for ground facilities. A third environment, induced strong magnetic fields, has since been excluded because of the magnetic and electrical problems involved, especially those related to interference with other simulation equipment, and the lack of a definite requirement for such an environment. All three of the above environments were discussed in Part I of this report.

o Column 2

This column lists the approximate range of intensities for each variable, in some cases giving the combined range of variation for both the natural and induced environments.

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* Natural Environmental Variables - Those that exist in nature and are not dependent upon the presence of artificial objects. Induced Environmental Variables - Those that exist or are created by virtue of the presence, operation, or motion of a vehicle.

TABLE I

EVOLUTION OF FACILITY CONFIGURATIONS FOR COMBINED HYPER-ENVIRONMENT SIMULATION
(See text for supplementary explanations)

Column No. 1	2	3	4	5	6			7	8				9			
Environmental Variables	Variable Intensity & Actual Range	Orbit & Space Regime Variables	Hi-Alt. Cruise Regime Variables	Launch & Re-Entry Regime Variables	"Possible" Environmental Simulation Combinations Facility No.			Exclusions*	Practical Environment Combinations Facility No.				Adopted Facility Configurations With Intensity Range of Environmental Variables For Feasible Simulation			
					A	B	C		1	2	3	4	Fac. 1	Fac. 2	Fac. 3	Fac. 4
Low Pressure	760 to 10^{-12} mmHg	YY	YY	Y	y	n	y		y	y	n	y	760 to 10^{-9} mmHg	760 to 10^{-6} mmHg	---	760 to 3.5 mm Hg
Aerodynamic Heating	200°F to 5500°F	Y	YY	YY	y	y	y		n	y	y	y	---	2000°F	2000°F	2000°F
Low Temperature Sink	Ambient to -452°F	YY	Y	YY	y	y	y		y	y	n	n	-320 to 400°F	-320 to 400°F	---	---
Thermal Radiation	~ 130 watts/ft²	YY	YY	Y	y	y	y		y	y	n	n	130 watts/ft²	130 watts/ft²	---	---
X-Ray and U.V. Radiation	~ .025 watts/ft²	YY	Y	N	y	n	n		y	n	n	n	~ .025 watts/ft²	---	---	---
Varying Gaseous Composition	Many constituents- 10^2 to 10^{19} particles/cc	Y	YY	Y	y	y	y		y	n	n	n	5 gases	---	---	---
Dissociation & Ionized Gases	10^3 to 10^{15} particles/cc	YY	YY	YY	y	n	y		y	n	n	n	10^3 to 10^{11} p/cc	---	---	---
Sustained Acceleration	Up to 100g	Y	YY	YY	n	n	y		n	n	n	y	---	---	---	Up to 100g
Mechanical Shock	Up to 200g & 1-30 m secs.	Y	YY	YY	y	y	y		n	y	y	y	---	Up to 100g for 4-10 m sec		
Mechanical Vibration	Up to $\nless$ 40g & 5-3000cps sine; 30 $(\bar{g})^2$/cps random	Y	YY	YY	y	y	y		y	y	y	y	5-1000 cps $\nless$ 40g	5-1000 cps sine & random; $\nless$ 40g sine; .5 $(g)^2$/cps random		
Acoustic Vibration	Up to 185 db SPL & 20-10^4 cps	N	Y	YY	n	y	y		n	n	y	n	---	---	170 db O.A. 40-10000 cps	---
Atomic Particle Radiations	1.8 particles/cm²-sec; up to 10^{18} ev ave 10^9	YY	Y	N	y	n	n	X								
Hyper-Velocity Solid Particles	~ 10^{11} particles/cc & 1 to 10^{15} ergs per particle	YY	Y	Y	y	n	n	X								

* These environments excluded from combined environment simulation; see text.

Magnetic Fields
Gravitational Fields
Nuclear Radiation

These environmental variables categorically excluded from current simulation considerations; see text.

KEY

N	No; not significant, or non-existent environment.
Y	Yes; environment present and often significant.
YY	Yes!; environment has major influence - very significant.
n	No; environment not to be simulated in this facility: because not important, not practical to simulate in combination with some of the other environments, or is simulated in another facility and is suitably represented.
y	Yes; environment to be simulated in this facility.

o Column 3, 4, and 5

All high altitude and space flight regimes can be generally sub-divided into three categories, as indicated by the three column headings. Most flight vehicle profiles encompass at least two of the regimes. The double and single code letters respectively indicate relative or secondary effect of a specific variable in the particular flight regime.

o Column 6

Although from some aspects it would be desirable to simulate all environments in one facility, it is technologically and economically impractical, if not impossible. Therefore a grouping of environments has been made for separate facilities which will give the optimum balance of realism, utility, technical feasibility, and cost.

One means of deriving suitable combinations of variables which result in the least sacrifice, as far as interrelationships among the environments is concerned, is to take advantage of the natural division effected by the different vehicle flight regimes. Column 6 is an example of an environmental sub-division based upon this method of choice, the sub-column headings A, B, C, representing separate facilities approximating Columns 3, 4 and 5 regimes, respectively. It is apparent that many of the variables are important in more than one regime and can not be simulated in just one facility. This duplication results from similarity or interdependence between regimes, and is necessary if all of the significant combined effects are to be produced.

Superimposed on the flight-regime-grouping approach is that of satisfying a practical requirement of combining only those environments which involve methods of simulation that are compatible with each other. For example, it is not practical from an economical or technical standpoint to combine acoustic vibration and sustained acceleration. The equipment required to simulate either of these environments is too cumbersome to combine and still achieve the desired acoustic and acceleration intensity levels on a 250 pound specimen.

o Column 7

After deliberating some of the design and operational problems posed by the "possible" combinations in Column 6, it appears necessary to exclude hypervelocity solid and atomic particles from combined environment considerations at this time. The justification is basically the same for both variables: currently known methods of simulation are awkward, incompatible with the methods for simulating many of the other environments and do not yield the required level or range of environmental intensity.

Current methods of accelerating solid particles to high velocities discharge a considerable amount of gas and other contaminants. These conditions cannot be tolerated in an extremely high vacuum chamber. From a standpoint of realism and elapsed time for data acquisition, neither can the slow rate of fire of one shot (or particle) per hour to one shot per day. Further, no technique at present can achieve the minimum environmental velocity of 7 miles second, and still allow measurement of the inflight mass and velocity; and nothing approaches the more normal speeds encountered in the range of 30 to 50 miles/sec. Similarly, simulation of the atomic particle environment poses problems in relation to energy level and particle densities.

Thus in each case the true or equivalent environment condition cannot be achieved with current simulation techniques. In addition all known techniques are undesirable or incompatible for integration in an initially complex facility. Any attempt to simulate these in combination with other environments at this time would certainly lead to erroneous evaluations and conclusions.

It is recommended that experimentation involving these two environments be conducted on a separate basis, and only be integrated in a combined facility when more realistic values can be achieved and more suitable simulation methods developed.

o Column 8

Difficulties posed by the "possible" combinations proposed in Column 6 required that further sub-division be made toward less complex facility configurations. This resulted in the four facility approach summarized under Column 8. The particular choice of combinations shown provides a maximum capability for producing combined effects within the limits of current practical feasibility.

o Column 9

The feasibility of this four facility concept depends on the level of intensities to be simulated. Column 9 therefore specifies the range of each environmental variable that can be practically simulated in each of the proposed facilities.

Note that facilities 1 and 2 primarily simulate the orbital and spatial regime, while facilities 3 and 4 encompass the launch and re-entry flight regimes. Facility 2 can also simulate thermal transients from aerodynamic heating which will occur during skip-glide, post-launch, and re-entry, under vacuum conditions.

II. DISCUSSION OF SIMULATION METHODS

Simulation of any condition is a relative science. Often a given set of conditions need not be reproduced exactly, either in type or degree of stimulus, in order to obtain the same response as produced by the true conditions. The choice of simulation method often depends upon what is being sought.

Simulation of the space environment, even to an approximate degree, currently presents some real challenges. For some situations it is recognized that it is not necessary to reproduce the exact environment, but for many others it is not known what approximation is necessary. In these situations the initial approach must be to simulate the true environment as closely as possible, providing it is economically and technologically feasible. Later it may be proved that compromises of this approach are possible.

The following is a qualitative discussion of how the principal hyperenvironment variables can be simulated and is indicative to what degree simulation is currently feasible. It is presupposed that the reader is generally familiar with the conditions to be simulated, as discussed in Part I of this report, and as summarized in Table I of this document.

A. High Vacuum

The truth of the old adage, "Nature abhors a vacuum", has become more apparent and meaningful with the advance of vacuum technology in recent years. To date, the evacuation of small volumes (1-2 liters or less) has resulted in achieving pressures of the order of 10^{-12} Torr*. While this represents a significant achievement, it is still a long way from obtaining an absolute vacuum. As explained in Part I report, an appreciation and understanding of the significance of very low pressure entails a marked departure from the usual conceptions.

To achieve a good vacuum in a chamber involves combating many difficult effects: lack of pressure gradients (no flow), accelerated degassing and sublimation of all materials, and increased importance of even the smallest leak. As the chamber pressure is decreased, the contribution of gases from these sources becomes very significant because the gas volume to mass ratio increases tremendously. When the volume rate of gas evolvement equals the decreased volume pumping capacity of the vacuum system, a further reduction in pressure is impossible. This condition is also intensified by the accumulation of any unpumped constituents. In fact, if the total amount of any such gas is being increased through sublimation or leaks, the chamber vacuum will gradually deteriorate.

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*The Torr is numerically equal to the millimeter of mercury to the seventh decimal place. It is generally preferred as a pressure unit for international vacuum technology because it is independent of such physical properties as the density of mercury and the acceleration of gravity.

1. Pumping Systems

For many years mechanical rotary pumps have been the primary means of obtaining a vacuum. The minimum pressure capability for most such pumps is approximately 10 microns, or 10^{-2} Torr. Some special pumps have extended the range to 10^{-4} Torr. Steam or oil ejector pumps have roughly the same pressure range performance as mechanical pumps, but have a higher capacity for a given size. However, when operated near its ultimate pressure, the ejector pump will backstream some of the oil or steam into the vacuum chamber.

Oil diffusion pumping is the method most often used to obtain a vacuum below the range of mechanical pumps. Vacuum capability can thus be extended to 10^{-6} Torr, and if the inlet is baffled with a liquid nitrogen cold trap, the diffusion pump can achieve 10^{-8} Torr or better. The cold trap, employed to reduce backstreaming, also reduces the pumping speed by a factor of approximately two. The oil diffusion pump will not function at pressures above 10^{-2} Torr, and therefore must be discharged through a forepump, of mechanical or ejector type.

Other principal means for achieving extreme low pressure are cryopumping, ion or getter pumping. Gettering action is the chemical combination of the gases with some reactant element, and the condensation of this new compound on a cool surface. A certain amount of atomic or molecular burial of the gases also occurs. Originally the gettering action was accomplished by thermal means. In recent years a new development utilizing the same principles, but adding electric and magnetic fields to ionize and guide the gas particles, has greatly enhanced the pumping rate of such devices. Ion pumps, as the latter are called, theoretically have a constant pumping speed not limited by very low pressure. Another partial advantage is that they pump hydrogen more readily than any other gas. Ion pumps can not be used at pressures higher than 10^{-4} and operate best at lower pressures. In fact, the life of the pump is inversely proportional to the pressure at which they are used. Disadvantages of ion pumps are their relatively low capacity (esp. v.s. size), and the sensitivity to contamination. Although the latter can usually be overcome by proper trapping, this further reduces the pumping speed.

Vacuum cryopumping is the condensing or freezing of chamber atmospheric gases and vapors on a cold surface chilled by liquid hydrogen, gaseous helium, or other cryogenic liquids such as neon, oxygen, and nitrogen. Nitrogen has been the most widely used medium for cryopumping to date, not because it is the optimum fluid, but because it is the easiest to handle and the most economical. Cryopumping with helium and hydrogen is just in the process of development, but is recognized as possibly holding the greatest potential for achieving extreme low pressure and high evacuation rates. The reason for this optimism is the great pumping capacity of such systems; approximately 200 cfm/sec/ft^2 of condenser area.

The most effective cryogenic system configuration concept is one of making the whole chamber inner wall a condensing surface. Thus, the pump inlet literally surrounds the chamber volume and test specimen. If all, or nearly all, molecules leaving the test specimen 'stick' to the cold wall when they strike, then the apparent pressure seen by the specimen will be considerably lower (approaching zero) than the pressure measured by a vacuum gauge located between the specimen and the cold wall. This advantage in apparent pressure is limited, however. When the absolute pressure in the chamber decreases to the point where the condensation rate becomes equal to the approximately constant evaporation rate from the wall, the minimum possible chamber pressure is reached. Below a pressure of 10^{-4} or 10^{-5} Torr the sublimation rate is dependent upon the vapor pressure of the condensate, which in turn is dependent upon temperature. Thus for atmospheric constituents in the cryogenic temperature range the limiting pressure will usually fall between 10^{-9} and 10^{-12} Torr. This assumes that there is no relative or absolute increase in some unpumped gas such as hydrogen or helium in the chamber proper, (e.g. by use of ion pump) and that the cryogenic system is not activated above a pressure of 10^{-6} Torr. The pressure reduction can also be arrested if the condensate on the cold wall becomes thick enough to cause a marked temperature increase across it. This will allow the constituent with the lowest freezing temperature to start boiling off. To prevent a large condensate build-up, the cryogenic pumping system should preferably be activated at pressures below 10^{-6} Torr, and never before the mechanical roughing operation (10^{-2} to 10^{-3} Torr)is completed.

Disadvantages of cryopumping, particularly for a condenser at -423°F (20° K) or below, are high cost, selective pumping, and complexity introduced by large thermal gradients. The principal significance of this last item is the necessity of shielding a liquid hydrogen wall from direct ambient thermal radiation; probably with a liquid nitrogen wall in a Venetian blind type of arrangement. This is necessary to prevent the ambient thermal load from increasing the hydrogen wall temperature to the point that pumping of some gases is precluded. Since the LN_2 shield will be a partial obstruction to the gases pumped by the low temperature wall, the geometry of the shield must be designed to minimize this attenuation. One compensating factor in this respect is that the shield will supplement the pumping effect for all vapors with freezing temperatures above the boiling temperature of the shield fluid (-320°F for LN_2).

In summary, the type of vacuum pumping system to be used depends on the use requirements of the facility, the minimum pressure required, and the facility size. For pressures above 10^{-3} Torr, a mechanical and/or ejector roughing system will usually be sufficient. For pressures below 10^{-3} Torr some combination of vacuum pumping methods is virtually unavoidable, for all except very small sizes.

2. Low Pressure Measurement

All information on low pressure measurement underscores the fact that a considerable amount of caution must be exercised in the use of any pressure measuring instrument or technique. Two fundamental problems exist. First, at pressures below 10^{-4} Torr (Knudsen No. ≥ 1), different pressures can exist at different positions, or near different surfaces within the same volume. So care must be exercised in attaching too much significance to any single pressure reading. Secondly, and more important, is the fact that no currently conceived gauge or technique is free from inherent errors. The degree of error contributed by a particular type gauge usually varies depending upon its specific use at the time, and can vary considerably from gauge to gauge of the same type. The range of pressures to be measured, and the nature of the gases involved are perhaps the two most significant factors contributing to measurement variations. The many sources of possible error make the task of gauge calibration a very formidable one, and thus, the measurement of low pressures tends toward a relative, rather than an absolute science. However, at pressures above 10^{-5} Torr, the McLeod gauge has become a standard for calibration.

The primary difference in the various types of vacuum gauges is in the basic parameter, related to pressure, that is measured. For example the Knudsen gauge is momentum sensitive, the Pirani and thermocouple gauges are thermal conductive or electrical resistant sensitive, the McLeod gauge is volume sensitive (per Boyle's law), and the ionization gauge is current sensitive (due to positive-ion production). There are other basic types, and variations of each type. Again for example, the Bayard-Alpert and Nottingham type gauges represent recent improvements in the hot-cathode ionization gauge, and the Redhead gauge represents recent improvements in the cold-cathode, or discharge type (Philips) gauge. For any extensive or involved work, a mass spectrometer is also a valuable tool. It not only can be calibrated to read very low pressures, but it identifies each gaseous constituent and the amounts of each.

A discussion of the advantages, disadvantages, and best usage or combinations of the numerous pressure measurement devices is beyond the scope of this report. It is emphasized that many factors must be considered, depending upon the particular application, before an intelligent choice and use of pressure measurement instruments can be made.

3. Bakeout and Outgassing

As used in vacuum technology, bakeout is the heating of a solid material to drive off the surface and near-surface sorbed (absorbed and adsorbed) gases. This evolution of the sorbed gases is termed degassing. The term outgassing is usually limited to the natural evolution of sorbed gases as occurs at ambient temperature.

Many of the high vacuum systems currently in use have incorporated some bakeout provisions. Degassing by bakeout greatly decreases the time of surface gas evolution, and thus can shorten the subsequent evacuation operation considerably. When a surface has been degassed the ultimate low pressure can usually be extended another decade (factor of ten) than without degassing.

As beneficial as bakeout may be, it is not a provision that should be blindly incorporated in any system designed for pressures below some value. Too often referrence has been made to existing facilities that have bakeout provisions, and the requirement for similar capability has been automatically assumed. Not enough attention has been paid to the differences in facility application, and what effects these differences might imply.

More specifically, for relatively large multi-environment high vacuum facilities, where the test load in the chamber will be a complex 'black box' or missile section, the justification for bakeout rapidly diminishes. This reasoning is based upon the following considerations.

1) From 760 Torr down to 10^{-6} Torr outgassing is not particularly a problem. Present vacuum pumping systems are capable of handling the added load due to outgassing without becoming impractically large. That is, the original sizing and choice of a vacuum system for the 10^{-6} Torr range can be, and should be made, capable of handling all potential loads. Therefore, no bakeout is necessary.

2) A bakeout system can add considerable complexity and expense to a walk-in size vacuum chamber. The minimum useful bakeout temperature is generally considered to be about 400°F, and much higher temperatures are often used. In order to protect viewports, seals, and other temperature sensitive components, special cooling, expansion joints or other allowances must be provided. Further, the time to heat up the chamber mass, bakeout, and cool down, adds many hours to the vacuum pump-down operation.

3) For a walk-in size facility bakeout must necessarily be limited primarily to the shell. Much of the auxiliary chamber equipment (instrumentation and equipment for simulating other environments) and the 'black box' payload cannot be safely heated to 400° F or higher. Thus, usually a minor portion of the outgassing surfaces can be degassed and it becomes very questionable whether the added complexity and expense of a bakeout system is warranted.

4) If the preferred high vacuum operating technique of keeping the chamber under (some) vacuum at all times is followed, pump-down operation for a chamber will not be longer than the combined operations of bakeout and evacuation for some comparable chamber; that is bakeout is primarily applicable on the initial pump-down and thus becomes basically a one-shot operation.

5) Other techniques which tend to keep a vacuum chamber 'clean' once it has achieved a pressure compatible with its limiting characteristics (pumps, size, leakage, etc.) are the use of clean dry gasses for chamber pressurization, and use of an airlock for access. If a gas such as dry nitrogen is always used to return a chamber to sea level pressure (with a proper proportion of dry oxygen if human entrance is made), the adsorption of such gas by the chamber wall surfaces is much less than that for atmospheric gasses. Chamber cycling with a purging gas during pump-down will also assist in obtaining a lower vacuum. The use of an airlock, of course, will further isolate the chamber-proper from atmospheric contamination. Incorporation of an airlock is often justified for operational reasons as well.

6) A cryogenic cold wall (LN_2 etc.) currently being employed in many large high vacuum facilities has a dual benefit in achieving a low ultimate pressure. It not only assists in pumping the condensable vapors, but it reduces the outgassing from the chilled surface to a much lower value. At the temperature of liquid nitrogen (-320°F), it is estimated that the outgassing rate from a metallic surface is reduced by a factor of at least 10^{10} compared to one at 70°F. Thus, the complexity of chilled surface bake-out can not only be avoided, but is usually unnecessary.

Unless some special requirement dictates, it is therefore recommended that bakeout provisions be avoided for relatively large high vacuum facilities.

Situations where bakeout is virtually mandatory are in low pressure measurement devices, and in simple chambers where the primary objective is to achieve, the lowest possible pressure. Prior degassing is particularly important for vacuum measurement gauges because the molecules, or ions, evolved by the instrument cannot be differentiated from the 'ambient' particles.

4.Seals

The concept of sealing takes on added significance in high vacuum technology. It is not only a problem of sealing against a pressure differential, but one of combating deleterious effects on the molecular level. Volatilization and sublimation of materials exposed to high vacuum, including seal materials, are perhaps the most troublesome vacuum-degradation sources. Diffusion of vapors and gases through materials, and other random molecular motion effects, can also become significant at extremely low pressures.

Thus, high vacuum seals have to provide the best pressure seal possible, and must not in themselves be a significant source of absorbed gases, or volatile vapors. The use of metallic seals minimizes any such problems. However, this approach introduces another difficulty in that such seals must be crushed, or permanently deformed, in order to obtain the required sealing effect, and thus cannot be reused. The occasional replacement of a seal is not inconvenient for viewports, wall penetrations, or pump flanges which are semi-permanent installations, but are most inconvenient for access hatches or doors. Another approach has been to use double organic seals arranged so that they expose a minimum of area to the high vacuum, and incorporate an interseal guard vacuum. This makes a reuseable seal for frequently opened doors, but will probably limit the ultimate vacuum to the order of 10^{-9} Torr. Organic seals also present more of a problem if exposed to temperature extremes. Although metallic seals are not immune to high and low temperatures, they exhibit less dimensional change and degradation.

The low melting temperature seal is a variation of the metallic type. A metal that melts at a few hundred degrees is placed in a trough, and a lip from the mating closure part is immersed in it. The mating parts are opened and closed (sealed) by melting and freezing of the 'soft' metal.

In brief, the choice of high vacuum seals is a compromise, depending on requirements between sealing ability and convenience. The lower the desired ultimate pressure, the more restrictive the choice becomes. For example re-weldable joints have been used in some extreme situations.

Additional pertinent information that might be classified under high vacuum seals, has to do with permanent weld seams. Most ordinary welds are not vacuum tight, and in fact can be quite porous. To make a weld as impervious as the base metal it is necessary to take several precautions. As in all vacuum operations, cleanliness is a prime requisite. A corollary to this requirement is the use of inert gas arc welding to exclude atmospheric contamination. In addition, good craftmanship and special welding techniques must be developed and practiced in order to obtain the desired results. A final check should always be made with a helium leak detector, or equivalent.

B. Radiation and Temperature Control

Simulation of the radiation environment is confined to the electromagnetic spectrum. Although particle radiations can be simulated to some degree, such simulation has been temporarily excluded for the reasons indicated in the discussion of Table I (ref: Col. 7).

1. The Solar Spectrum

The reproduction of the geocentric spatial radiation environment becomes primarily a problem of simulating the energy and spectrum of the Sun. The Earth and other bodies are also significant radiation sources depending on proximity to them. While the solar irradiance at the distance of the Earth (130 watts/ft^2) is not difficult to duplicate, reproduction of the spectral irradiance (energy distribution versus wavelength) does present considerable difficulty. A close simulation of the solar spectral irradiance is required for spatial thermal balance analysis for a particular vehicle or system configuration. Reflectivity and absorptivity of any surface can vary with wavelength so that a material may be highly reflective in one portion of the spectrum and highly absorptive (poor reflector) in another portion.

As inferred from Figure 1, if an optically black object could be maintained at approximately 10,300°F (6000°K) without any intervening absorbing material, the simulation problem would be solved. This is not possible, on Earth at least, so that some compromise in method of simulation must be sought. A secondary but important consideration requires generation of parallel rays and uniform distribution of energy over the irradiated surface. And finally the radiant power of the source should be controllable over a relatively wide range ($\sim \not{\ge}$ 2.5 to 1) without a shift in spectral distribution.

For a major portion of the solar spectrum 2000 to 20,000 Å,* the carbon arc offers the easiest solution for some applications. If the arc source is

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* Å is the symbol for angstrom unit, which is equal to 10^{-4} microns, or 10^{-8} cm.

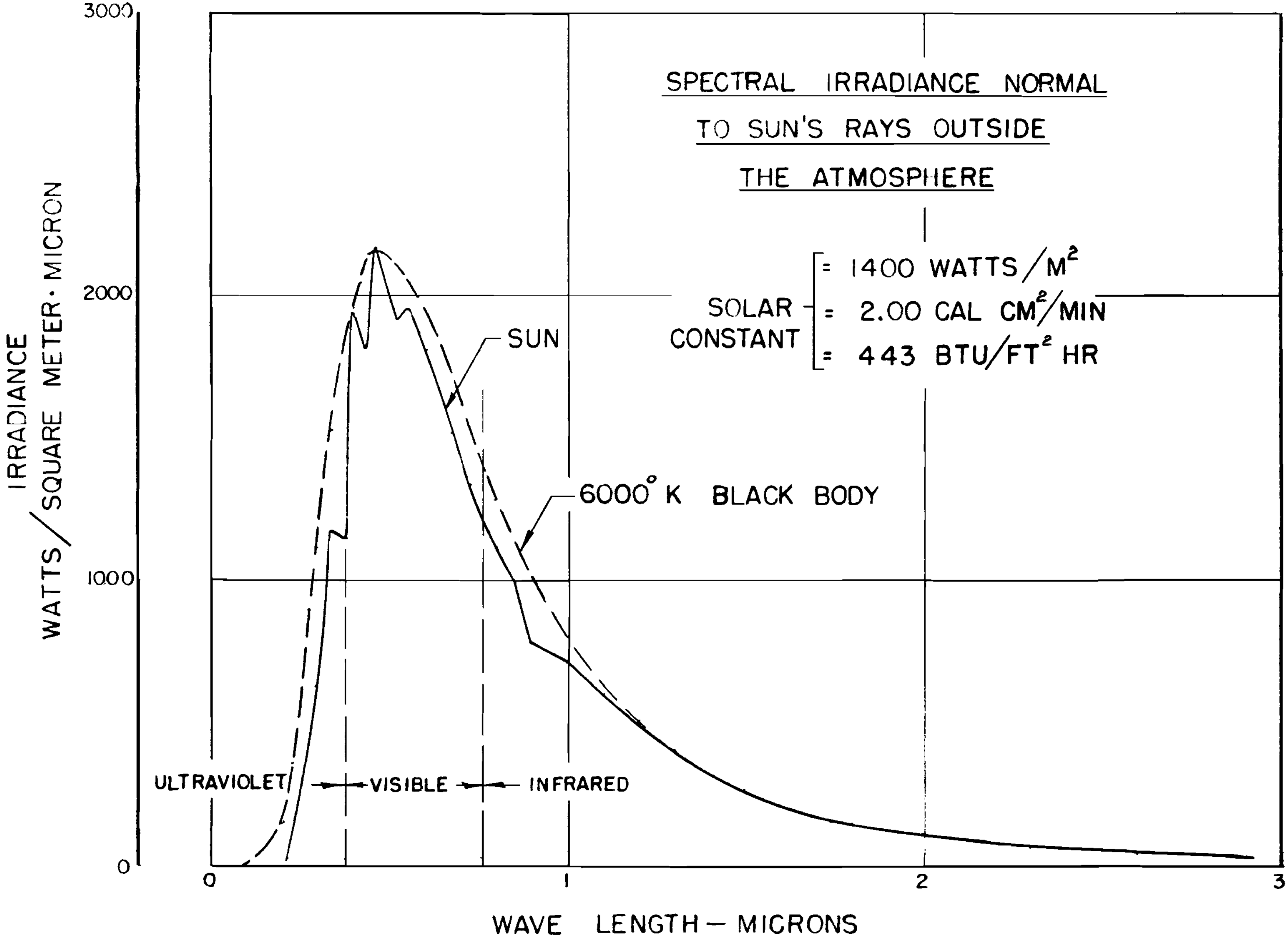

Figure 1. Spectral Irradiance Normal to Sun's Rays Outside the Atmosphere

constructed correctly, similarity of its output to the solar spectrum is quite good, as shown in Figure 2. The plotted data are based upon total energy over the band from 2000 to 14,000 Å. Several potential disadvantages of the carbon arc exist, depending on application. It cannot be practically operated inside a high vacuum chamber, and placing the lamp outside presents a difficult window problem. Performance-wise, burning of the carbon electrodes induces fluctuations in energy intensity and produces a dark spot in the center of the beam. In most present designs the electrodes are consumed in about twenty minutes, which may not be an absolute limitation, but is at least an inconvenience factor. A more practical simulation approach with spectral characteristics potentially equal to the carbon arc involves vapor arc lamps. One of the current problems with these sources is that they tend to radiate a major portion of their energy in one region of the spectrum. The radiated energy also tends to predominate in spectral lines rather than in a continuous emission. A more continuous spectrum can be produced at high vapor pressures ($>$30 atmospheres), but as shown in Figure 3 there is still much to be desired. Limited studies to date indicate that some combination of mercury, xenon, argon, krypton, or neon vapor in a sealed arc lamp envelope will probably provide adequate duplication of the solar spectrum. A single compact radiation source is required in order to achieve a practical collimation configuration. The combination of more than one source-type severely complicates the optical system.

The ultraviolet and x-ray portion of the spectrum (less than 2000 Å) is also of interest because of the chemical and quantum effects it can produce. Generation of this electromagnetic energy presents as difficult problems as those just discussed for producing the 'thermal' radiation spectrum. The most significant difficulty is that of transmission, particularly in the soft x-ray region (10 to 1000 Å) wherein all radiant energy is absorbed by even a slight amount of substance (gas, liquid, or solid). Thus, even though the desired wavelengths can be generated, they cannot be transmitted because of absorption by the source container or ambient atmosphere. There are at least three simulation approaches for generating soft x-rays that show good potential; 1) use of open (unsealed) low voltage x-ray tube devices operated in a chamber when the pressure is below 10^{-6} Torr; 2) irradiation of some suitable material with hard x-rays that will reradiate in the soft x-ray and ultraviolet regions; and 3) development of window materials that will transmit radiation in the desired wavelength range.

Hard x-ray and gamma radiations ($<$ 1 Å) are energetic enough to penetrate most materials so that the task of simulating this region of the spectrum is relatively simple. The problem is one of shielding and protection rather than transmission.

2. Cryogenic Cold Wall

To completely simulate the electromagnetic conditions of free space, particularly for the thermal effects, it is necessary to consider the radiated energy loss to space as well as the irradiated energy gain from the Sun and other bodies. To approach the true condition, no energy radiated by the test object should be reflected back on itself. Neither should it 'see' other warm objects, except those simulating the Sun, Earth, or some similar emission.

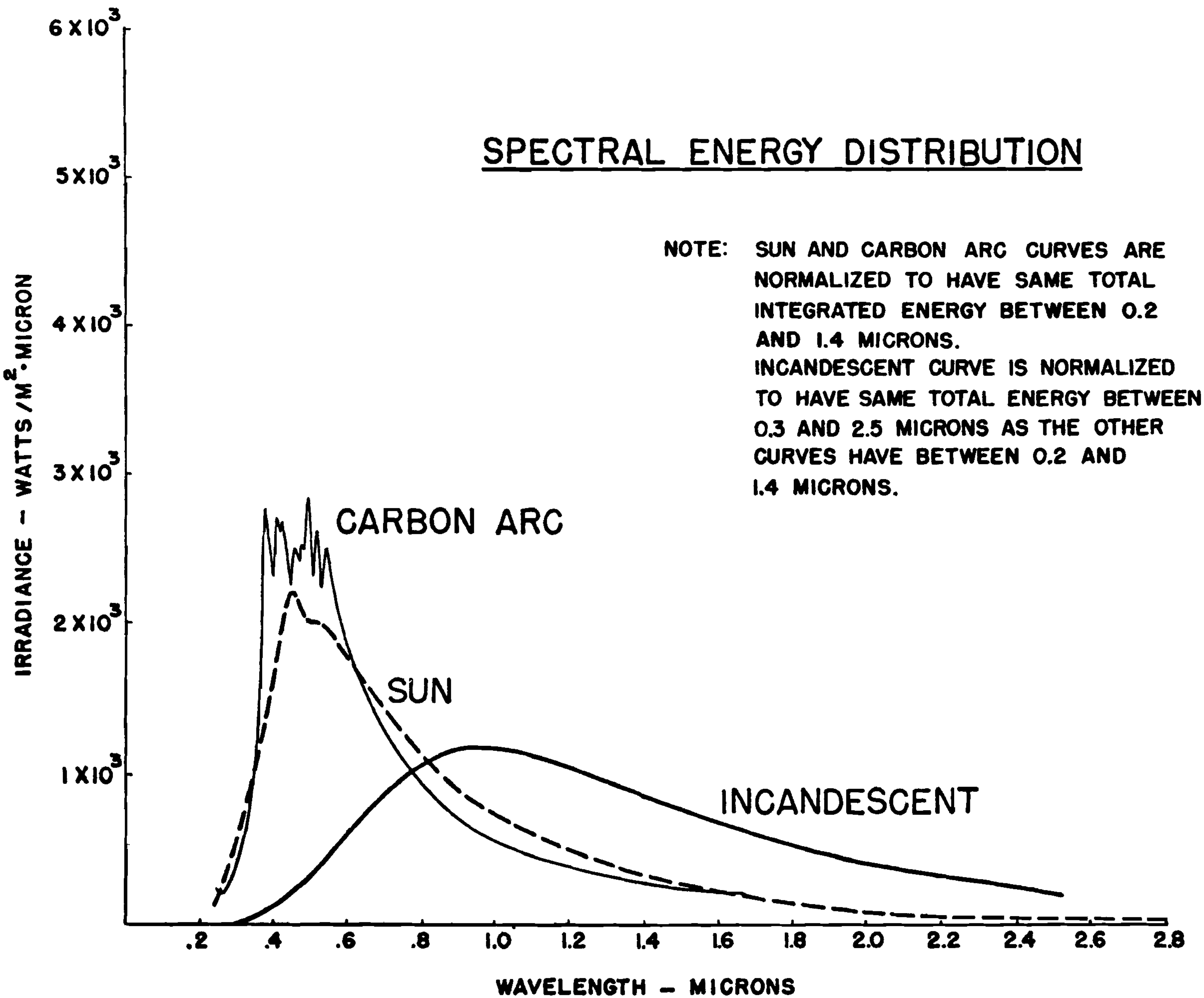

Figure 2. Carbon Arc and Incandescent Spectral Energy Distribution

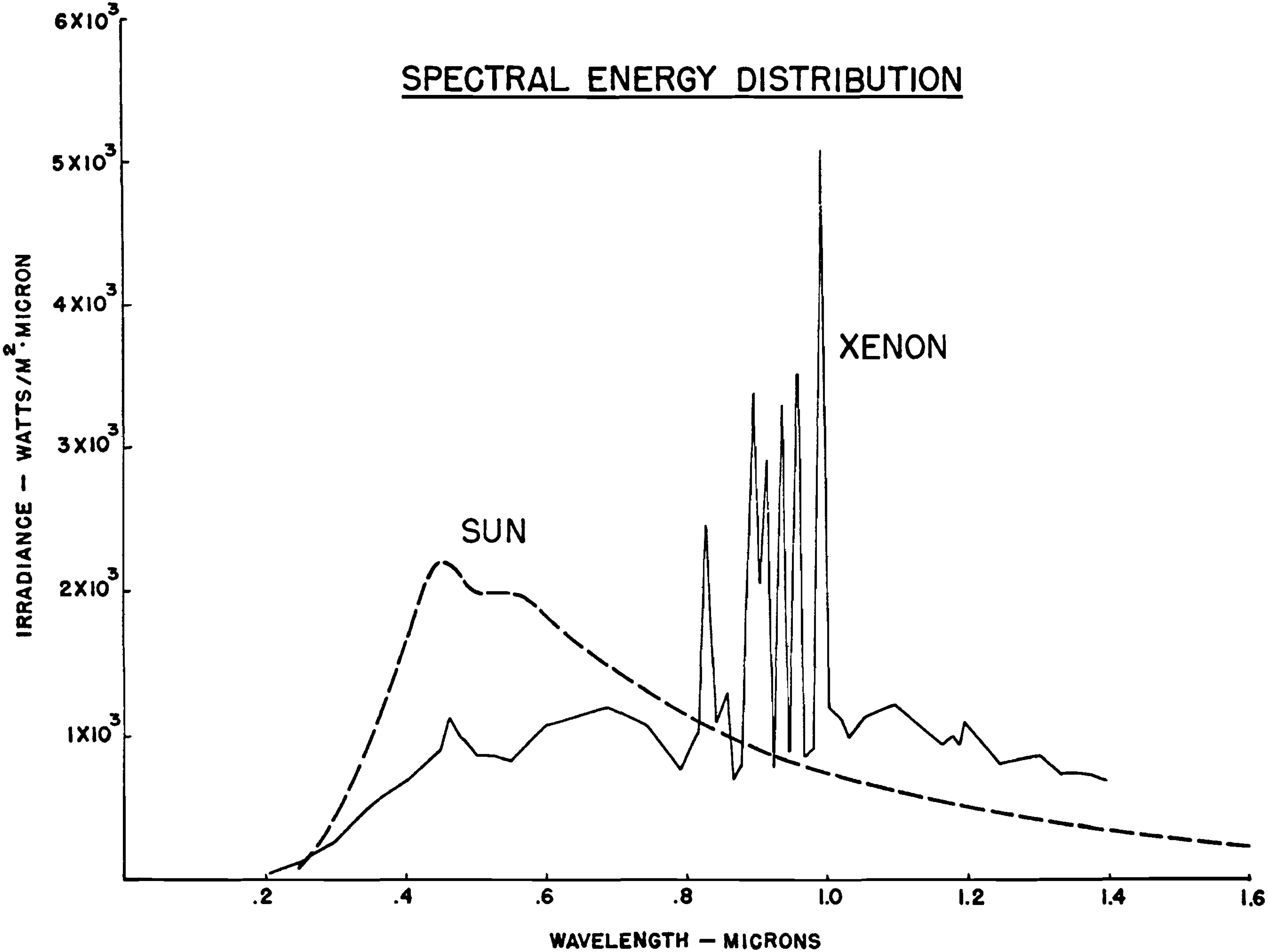

Figure 3. Xenon-Mercury Vapor Arc Energy Distribution

The most practical way to simulate the space radiation sink is with a highly absorptive cold wall. Although it would be very difficult to attain a wall temperature of -452°F (4°K) (the equivalent blackbody temperature of space), fortunately it is not necessary to do so. It is only important that the energy emitted by the wall is negligible in relation to that emitted by the test specimen, and that the reflectivity of the wall be as low as possible. For a chamber wall chilled by a cryogenic fluid, the emitted energy is so low compared to the radiation being received, that the wall radiation is not a significant factor unless the temperature of the test object decreases to the point where it approaches the wall temperature. As an example, the apparent absorptivity of a wall at -315°F (80°K) changes from some value like .98 (assuming reasonable conditions and a specimen temperature of 80°F) to an apparent absorptivity of zero when the specimen temperature approaches that of the wall. The most practical means of producing a simulated cold sink is with liquid nitrogen (-320°F). It is economical, stable, easily handled, and commercially available.

In addition to low temperature, the wall surface must have as low a reflectivity as possible. This characteristic can be achieved in two ways. The most obvious is to coat the wall with an optically black material (absorptivity approaching 1) that absorbs radiant energy over a wide range of wavelength. The coating should be durable and retain its optical properties throughout the operating temperature region. Assuming its use in a high vacuum chamber, the coating should also have a low vapor pressure, and not significantly contribute to the outgassing load through decomposition, or through sorption and desorption characteristics. (For more detail refer to Appendix I.)

A technique for increasing the apparent absorptivity of a surface is by use of special surface geometry. A surface composed of a series of deep convolutes is preferable to a flat or curved configuration. This causes much of the unabsorbed radiation to be re-reflected to another wall surface, rather than back into the chamber and possibly to the test object. (The same result is approached if the test specimen is small compared to the chamber. The energy intercepted by the specimen becomes very small and some energy is absorbed during each reflection from the wall. The net result is that nearly all of the energy is eventually absorbed by the wall.) A relatively high apparent absorptivity can thus be practically obtained by careful selection of surface coating and geometry.

C. Atmosphere Composition

In a facility which simulates combined space environment, it is often desirable to control the composition and state of the residual atmosphere. From environment simulation considerations, an atmosphere of controlled composition is required in order to simulate the spectrum of natural occurring constituents, vehicle induced conditions (as for gas control jets), natural or induced dissociated ionized gases, and possibly for simulating other planet atmospheres.

Variable composition of neutral gases can easily be attained by controlled injection of various constituents. Auxiliary equipment that is invaluable for this kind of work is a mass spectrometer. It can be utilized to identify each gaseous constituent and measure relative and absolute amounts of each gas as well.

Reproducing the dissociated or ionized state of the natural atmosphere at high altitude presents a somewhat difficult simulation problem. In a confined volume where the charged particles collide with interior surfaces, neutralization of the ionized molecules is quite rapid. In order to maintain a significant degree of ionization of the confined atmosphere, it is necessary to provide a continuous source of charged particles. This can be most practically accomplished by bleeding some selected gas at low pressure through an electric arc discharge tube; commonly termed an ion gun. Preferable gases are hydrogen or oxygen, since they are the predominate constituents of the upper atmosphere and are the easiest to dissociate and ionize.

Simulation of a locally induced charged atmosphere, such as the ionized sheath around a satellite, presents additional problems. A major difficulty is to ionize the gas with a minimum of energy. In the space environment the particles possess approximately 12 electron volts of energy.* It is difficult to artificially generate a stream of ionized particles without imparting double or triple this amount of energy. The extra energy may or may not result in different effects and until this is established caution should be exercised in the manner that the charged particles are produced.

A limitation of present technology is that simulation of an ionized atmosphere may be at some sacrifice to the ultimate chamber vacuum. While some degree of vacuum is necessary to generate and/or sustain an ionized residual atmosphere, the manner in which the charged particles are generated and subsequently neutralized may definitely limit the level of ultimate vacuum.

Again, a mass spectrometer is virtually indispensable in determining the state as well as composition of the chamber atmosphere.

D. Aerodynamic Heating

The term aerodynamic heating refers to the thermal energy generated during hypersonic flight of a body through an atmosphere. For shielded and semi-shielded vehicle components the exposure temperatures are only a few hundred degrees at most. In a combined environment facility, temperatures up to 1500° to 2000°F are readily obtainable. Although higher temperatures are possible for some conditions, the primary simulation requirement for components is below 2000°F.

Resistance, induction, and radiation heating are the basic means for producing high thermal energies required in simulation facilities. Each method has

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* One electron volt - equivalent to 1.6×10^{-19} watt-seconds.

particular advantages and limitations for any given application. However, where a wide spectrum of uses is anticipated with few details specified, radiant heating offers the most flexibility. Energy flux rates in excess of 100 btu/ft^2/sec are possible. For most materials and surfaces this will result in temperatures of 1500°to 2000°F, which is more than sufficient for most vehicle components. Radiant heaters, assumed here to be high temperature quartz lamps, can be controlled over a wide output range and operated in vacuum or atmosphere. Quartz lamp banks can be mounted some distance from the irradiated specimen for convenience and safety, and will heat any object regardless of its material type or configuration. Most important perhaps is the fact that it more closely resembles the true condition of a hot vehicle skin radiating to internally mounted components.

By contrast induction heating is much less flexible. Each specimen must be specially fitted (surrounded) with an induction coil, which must be mounted as close as possible to the object to be heated. If vibration or acoustic noise is required along with aerodynamic heating, the induction coil could be a serious handicap. Similarily restrictive is the fact that transfer of energy by induction requires a metallic specimen. Although this condition can be at least partially circumvented by special treatment of the specimen's surface, it further complicates and increases the cost of an already expensive and less efficient system. Also specimens sensitive to the induced electric and magnetic fields can not be induction heated.

Resistance heating also requires special set-ups for each individual situation and is more limited in its maximum possible temperature. Uniform heating, especially over a complex surface, is virtually impossible. A combination of resistance and radiant heating may prove advantageous for some applications. If, instead of attaching electrical heating elements to a specimen, an electric current is passed through some conductive panel so it becomes very hot or incandescent, the panel can be moved away from the specimen and allowed to radiate to it.

E. Mechanical Vibration and Shock

One of the principal simulation problems in providing vibration capability in a combined environment facility is integration of the vibration equipment without compromising performance due to the effects of the other environments. The most common type of vibration exciter, the electromagnetic or electrodynamic shaker, has been used with some success in combined environment testing. Principal advantages of this type of exciter are its relatively wide frequency range (up to approx. 3000 cps), its flexibility and controllability in reproducing any wave shape input. Thus, it is readily adapted to pure random vibration testing. However, this type of equipment has some serious limitations for combined environment applications. One problem is that of overheating and arcing of the coils when operated in high vacuum. Specially designed units have alleviated the difficulties to some extent, but not sufficiently to meet all requirements. Inherent limitations of large size versus force output capacity also definitely restrict the practical use of these exciters for many of the combined environment applications. Mounting the equipment external to the controlled environment area is prohibited because the added weight of the extended driving head would severely restrict the force output and frequency transmissibility performance.

The electrohydraulic vibration exciter is a recent development that lends itself more readily to combined environment simulation. While the hydraulic driving head assembly can function at very low pressures, it is still not advisable to do so from good vacuum practice considerations. Oil films on the driving head piston would lead to a contamination problem, and limit the ultimate vacuum at the lower pressures. However, because of its appreciable size, stroke and force output advantage, it is much easier to adapt the electrohydraulic system to the type of application being considered. The added weight penalty imposed by mounting the equipment outside of the environmental chamber can be tolerated by this equipment. Only the driving head (extension of the hydraulic cylinder) penetrates to the controlled environment area. The shaft penetration is vacuum sealed by means of a local doubled wall section with guard vacuum (for single walled chambers), and a metallic bellows appropriately secured to the shaft and inner chamber shell. For transmissibility reasons the shaft diameter must be increased considerably. The exact size depends upon the required length and exciter force output capability.

Where programmed shock as well as vibration simulation is required, an electrohydraulic system has a distinct advantage. A shock of any desired magnitude up to 100-plus g's can be obtained by virtue of the system's long stroke (up to several inches). A long stroke shock pulse can be generated separately, continuously, or superimposed on the vibration spectrum. Electrodynamic equipment is not capable of the long stroke required, nor can it match the force output of the electrohydraulic system. Both characteristics are important in order to produce the shock environment.

Again, in order to provide multiple axis vibration, electrohydraulic equipment has an advantage. Due to its small size and spatial orientation independence the hydraulic equipment can be readily mounted in any position or attitude.

Until recently, the inherent disadvantages of electrohydraulic vibration equipment have been its limited frequency range and its lack of flexibility in varying the waveshape input for random operation. The frequency spectrum had an upper limit of about 800 cps. However, a prototype design has been operated up to 2000 cps with both sine and random wave frequency inputs. Availability of suitable models incorporating this extended frequency response capability should be only a matter of time. It appears that simulation beyond a frequency of 2000 cps is not necessary, because of the extremely small amount of energy represented by the high frequencies, and the non-transmissibility of such high frequency energy. For the same reasons it is questionable in many situations whether it is necessary to test above a 1000 cps.

One item of the vibration and shock equipment which cannot be completely isolated from exposure to the other environments is the mounting table. Since the object to be tested must be attached to it, the table can be only partially shielded by mounting in a well. This does not alleviate its exposure to vacuum however. Because of this, Olite bearings or a slip table cannot be used to support the table in a high vacuum environment. It is necessary to use flexures, which have definite limitations, or to completely support the table and test specimen by the shaker driving head(s). With electrohydraulic equipment the latter approach has the least limitations.

F. Acoustic Vibration

The first consideration in simulating an acoustic environment is to determine the method of generation which most closely approximates the true service environment. Fundamentally, acoustic fields consists of either reverberant or progressive waves. Unlike a progressive wave field, a specimen located in a reverberant field experiences the same sound pressure level on all of its faces. Test specifications require that specimens be tested in six positions in a progressive wave chamber, while only one position is required for a reverberant field. The latter type of testing also has an advantage in that it takes less power to produce equivalent sound pressures levels than in a progressive wave chamber. As previously established in this report the test specimen under consideration is presumably a component part, which in the service environment means it will usually be subjected to a reverberant acoustic field.

The next simulation consideration is to determine which type of sound generating device should be used. The choice is governed primarily by the particular set of acoustic conditions desired. The space vehicle acoustic environment encompasses a broad band (random) frequency spectrum with pressure levels as high as 175-185 db. For simulation the level needs to be controllable above approximately 130 db SPL. These prerequisites preclude the use of hot and cold jet devices, loudspeaker systems, and single frequency sirens. The remaining choice is to use some device employing air stream modulation. A few of the designs utilizing this principle have attained sound pressure levels in excess of 170 db over a wide frequency range. Choice of a specific design is determined by characteristics of efficiency, economy, and ease of operation and maintenance. (For detail information on one specific design refer to Appendix I.)

A problem of any multi-environment simulation attempt, is resolving the incompatabilities among the various simulation equipment and the other environments. One such problem which needs to be considered in the case of acoustics, is that of providing aerodynamic heating capability in a reverberant chamber. Although aerodynamic heating is discussed separately in a preceding subsection, there are other factors to consider with the acoustical combination. From the standpoint of heating, high temperature quartz lamps are judged to offer the best potential. Assuming this simulation method is used, there is one particular problem that arises.

It is the problem of sound pressure attenuation by the lamp banks. The array of lamps must be large enough to provide the desired energy intensity over the required surface area. However, from acoustical considerations, the quartz lamps and reflectors should cover a minimum of chamber wall area, and should only be placed at certain locations. It is estimated that the lamp banks should be placed parallel to and against the chamber walls. The installation should be readily removable when not in use, with preferred mounting employing some means of suspension from the chamber ceiling. Approximate calculations indicate that the lamp banks should not cover more than 50 percent of the chamber wall area for five (out of 7) sides. To keep the acoustical attenuation to less than one decibel*, the blanked wall area should be somewhat less than this figure.

A related, if not an acoustical problem has to do with the durability of the quartz lamps in a reverberant field. Limited tests at 155 db and 160 db have shown that it is feasible to use these lamps in an acoustic chamber. Although some of the tested lamps failed in about three hours, the lamps are not usually used for more than five minutes at a time. On this basis a two or three hour life is not unreasonable. The tests also indicated that it may be possible to increase the life of the lamps to 10 to 15 hours.

Some detail information of these tests is also given in Appendix I.

G. Sustained Acceleration

Space vehicle accelerations are closely related to the size and mission of the vehicle, with values ranging from less than 10 to more than 100 g's.

Considered alone, simulation of the lower level accelerations is relatively simple, while the higher levels are only slightly more difficult. However, to simultaneously simulate other environments, such as aerodynamic heating and vibration, along with sustained accelerations the problems become numerous and complex. Complications arise primarily as a result of the way long term accelerations must be simulated; namely, by means of a centrifuge.

The centrifuge is virtually the only practical means for producing acceleration forces over any extended period of time. Long linear accelerators, such as rocket sleds, are feasible for periods only up to a few seconds. The limits of practicality and economy of such devices requires no explanation, especially for combined environment simulation. The only other method of producing an acceleration effect is by directly applying a load or force to the object to be tested. Of course, such an approach is only applicable where acceleration results in a static stress force, and the object is rigid enough so that the applied load is distributed uniformly throughout it.

Although the centrifuge represents a compromise in that it does not produce the facsimile desired of the actual environment, it offers the most practical and flexible means for simulating sustained acceleration in combination with other variables. Particular factors to be considered in the design of a large centrifuge facility pivot around the selection of the arm radius and RPM. In general it is more advantageous to have a relatively long radius and low RPM. At the sacrifice of increased size, mass, and structural requirements, several advantages are gained. The longer the radius the less the power required, and the simpler the bearing and swivel joint problems. Also significant where relatively large test specimens are involved, is the acceleration gradient

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*One db represents a power ratio of 1.26, or a power loss of 20%; 3 db represents a power ratio of 2, or a power loss of 50%.

across the specimen. The longer the radius, the less pronounced is the gradient.

For the situation where other environments are to be simultaneously reproduced along with sustained acceleration, the new problems and complexities introduced may completely alter the previous general design approach. For example, if vibration capability is added to that of acceleration, the problem of taking out the reaction forces becomes quite formidable. The problem of driving the additional mass of the vibration equipment (assuming electrohydraulic) is negligible compared to compensating for the large reaction forces. The only alternatives are to add huge energy absorbing masses, or to devise some method of transmitting the reaction forces to solid supports. For the acceleration and vibration equipment commensurable with a 250 pound test specimen, the first alternative is definately untenable. The second choice materially alters the basic centrifuge design.

Transferring the vibration reaction forces to stationary structure can be done by allowing the end of the centrifuge arm to ride on rails in both the horizontal and vertical planes. Fortunately, in doing this the structural requirements, and thus the mass and driving power for the centrifuge are lessened because the acceleration forces are also transmitted to 'ground'. The significant problem that has been added is that of the high speed and highly loaded bearing contact between the centrifuge arm-end and the retaining wall. In this situation the long arm length is no longer an advantage. The tangential velocity increases with increasing radius. The resultant decrease in required RPM only partially offsets the effect of the long radius. Because of the velocities and loads involved, the type of bearing to use should be carefully considered. Below approximately 150 feet/second rolling bearings, or wheels have the advantage; above 150 feet/second sliding, or slip devices (as rocket sled 'slippers') have the advantage. If it is necessary to exceed 300 feet/second aerodynamic drag forces become important, which might similarly alter the basic approach as in the foregoing example.

III. COMBINED HYPERENVIRONMENT SIMULATION FACILITIES

The primary objective of this study — design of combined hyperenvironment simulation facilities — has been accomplished through utilization of the information discussed and implied in the foregoing sections. Each of the four facilities conceived, is described in detail under separate cover in the form of a design specification (see Introduction). In the interest of continuity and convenience, this section summarizes the performance capability, general configuration, choice of simulation equipment, and estimated cost for each facility.

It should be understood that these designs are for the most part only representative of a practical approach and interpretation of technical concepts at some particular point in time. The exhibited designs are based upon current knowledge and engineering practices. New developments and ideas, or different requirements could radically change the whole approach and concept. Thus much of the information contained in the design specifications should not be automatically utilized for other applications without first fully investigating the effect of differences in requirements and new state-of-art developments.

A. Space Environment Research Facility (SERF)

This facility is designed to implement environmental effects research and component development for operations in geocentric space. In addition to mandatory compromises imposed by feasible and practical limitations previously mentioned, (ref. Table I discussion), one other partial compromise is currently necessary. Minimum operating pressure specified for the facility is greater than that of free space because it appears to be the minimum obtainable pressure, consistent with current technology, for a chamber of this size. However, for most experiments a pressure of 10^{-9} Torr or higher will be adequate in producing representative space pressure effects.

The general concept and configuration of the Space Environment Research Facility is shown in Figures 4 and 5; Figure 6 portrays an alternate design incorporating an airlock, which is recommended for operational flexibility in preference to the simplier design.

TABLE II
SERF PERFORMANCE SUMMARY

Environmental Variable	Range of Simulation	Simulation Equipment
Pressure	760 to 10^{-9} Torr	Mechanical, oil diffusion, and ion pumps, plus LN2 cold traps. (Supplement - LN_2 cold wall). Double walled, chamber.
Temperature	-320 to 400 $^{\circ}$F	Liquid nitrogen cold wall, and heated nitrogen gas.
Solar Radiation	130 watts/ft^2, 1 to 10^5 angstroms	Open x-ray tubes, vapor arc, and incandescent lamps.
Atmospheric Composition	1 to 100% of any stable gas	High pressure bottled gas, pressure regulators, throttling and metering valves, and vacuum pump.
Dissociated and Ionized Gases	5 to 90% of atm; ~10^4 to 10^{12} particles/cc below 10^{-4} Torr	Electric arc ion guns with output up to 10 cc/sec. each.
Vibration	For 250 lb specimen plus table and single axis excitation - Sinusoidal: 5 to 1000 cps, 1 inch min. double amplitude, $\leq$ 40g. Random: 0.5 $(g)^2$/cps, 20-1000 cps.	Electrohydraulic actuator, mounting table, hydraulic supply, electronic control equipment.

Estimated total cost of this facility is $600,000 as of September 1960. This amount includes some original design and limited development costs for the new applications and extended equipment capabilities specified. Detailed cost estimates are tabulated in Appendix II.

Anticipated growth capability for this facility is lower pressure, atomic particle radiation, and meteoroid particle impact.

(1) DIFFUSION PUMP
(2) ION PUMP
(3) ION GUN
(4) VIEW PORT
(5) SPECTROPHOTOMETER
(6) DOOR COUNTERWEIGHTS
(7) LAMP, POWER & COOLANT PORT
(8) MECHANICAL FOREPUMP
(9) DOOR ACTUATOR
(10) CONTROL CONSOLE
(11) DOOR SEAL COMPRESSOR
(12) HOLDING PUMP
(13) LN_2 PUMP & RESERVOIR

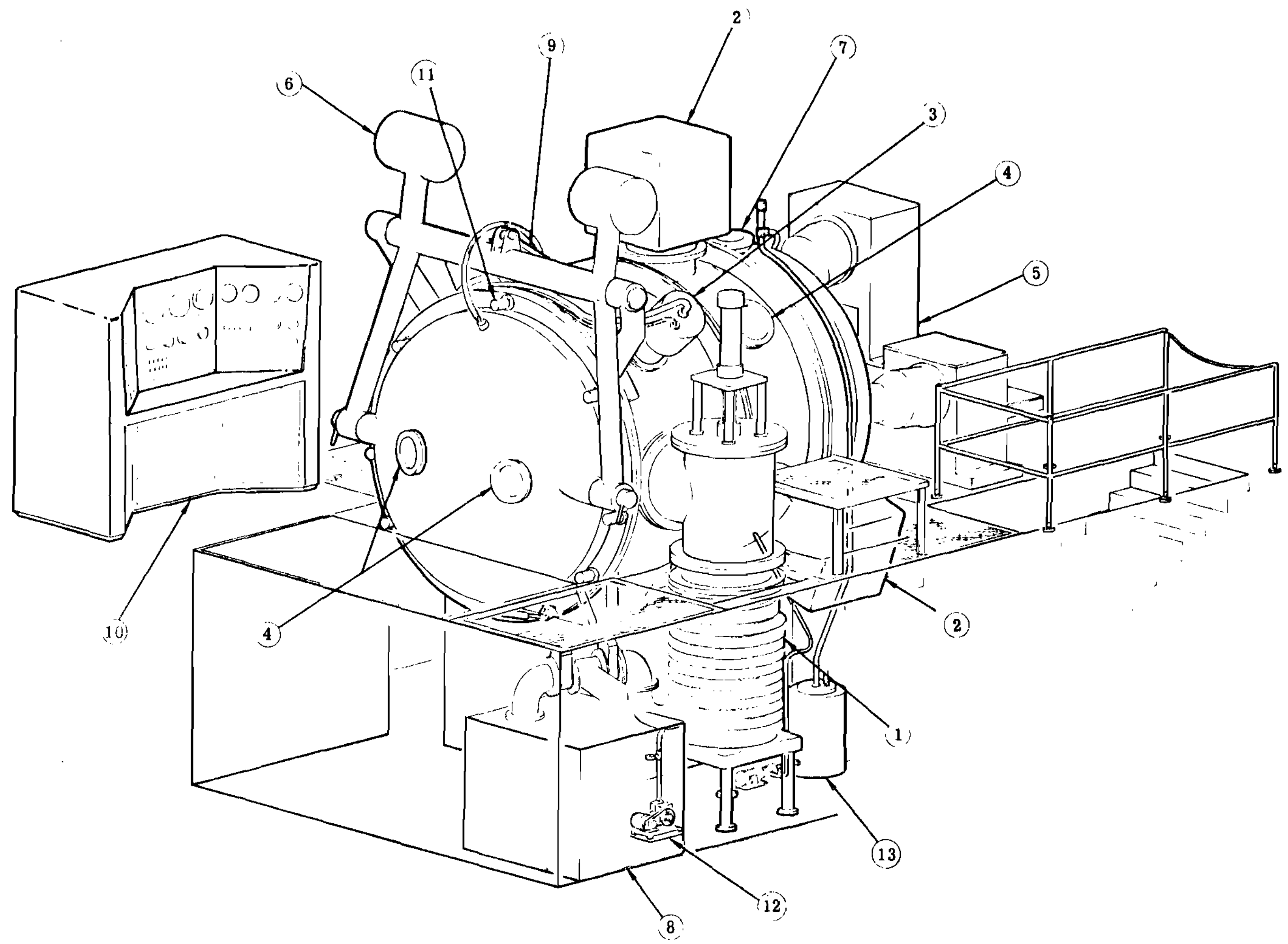

Figure 4. Space Environment Research Facility (SERF) Isometric View

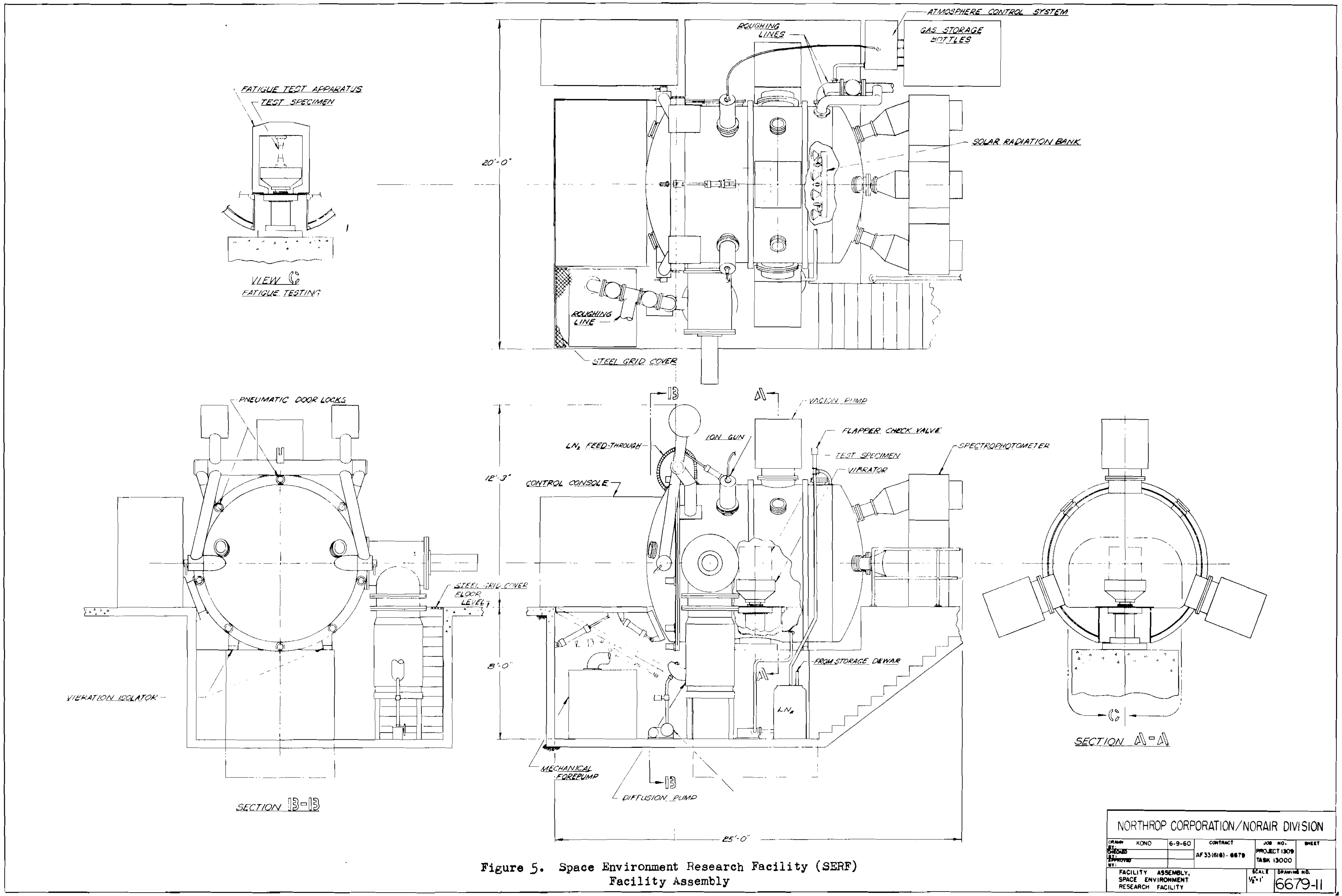

Figure 5. Space Environment Research Facility (SERF) Facility Assembly

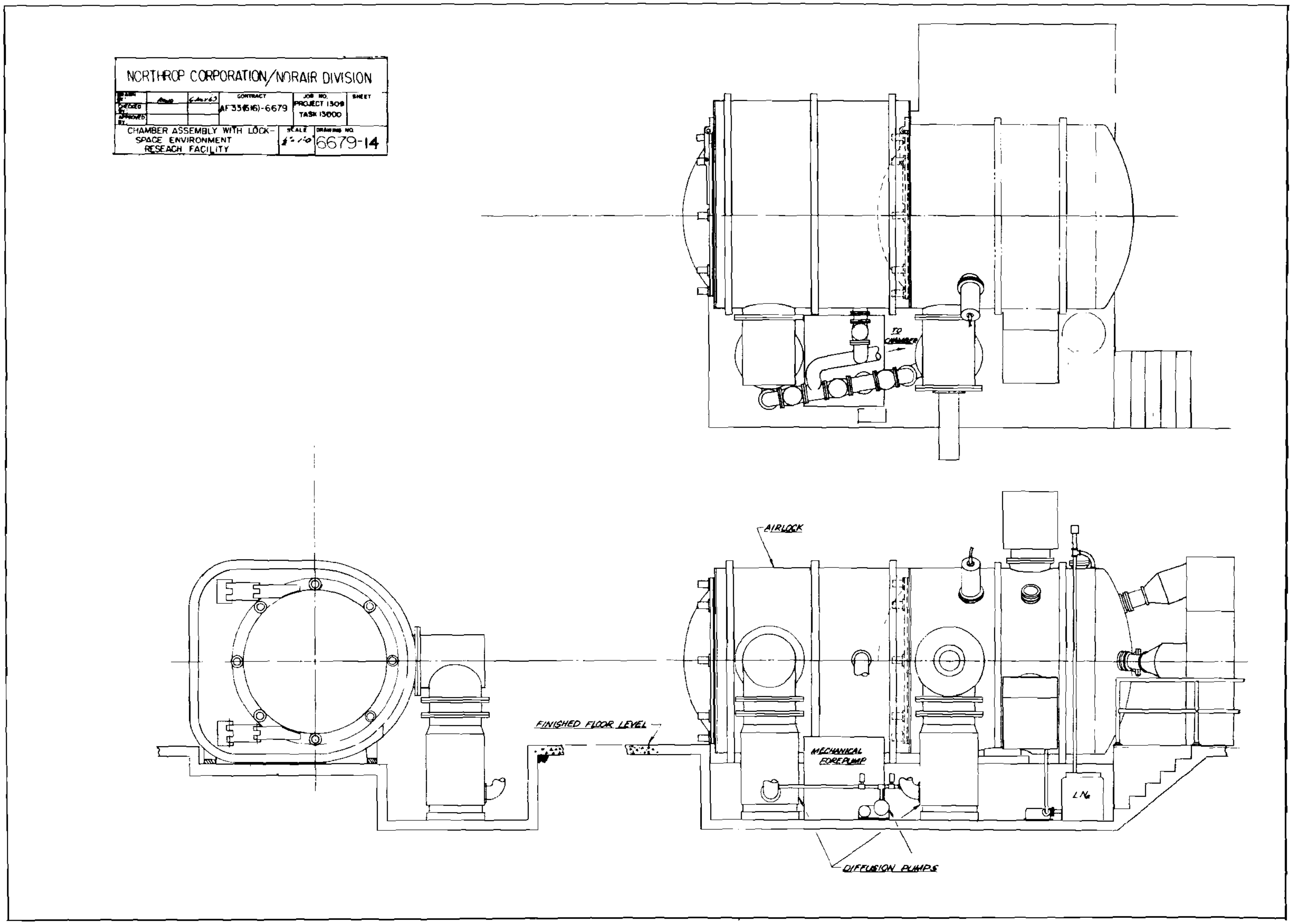

Figure 6. Space Environment Research Facility (SERF) with Air Lock

B. Thermo-Mechanical Dynamic Facility (TMDF)

The primary function of this facility is for simulating and evaluating a complete thermal balance of a component, or set of components, in free space. Additional capability makes provision for simulating the thermal and pressure conditions of launch and re-entry. This latter item includes the pumping capacity to duplicate the altitude pressure profile of major missile systems.

The specified pressure is limited to 10^{-6} Torr because all molecular collision dependent phenomena, such as pressure gradients, air damping, acoustic propagation, and convective processes, do not effectively exist below approximately 10^{-5} Torr. Thermodynamically, 10^{-6} Torr provides total space equivalence, and for the functional objective there is no requirement for lower pressure. Figures 7 and 8 portray the overall design and configuration of the Thermo-Mechanical Dynamic Facility (note airlock). A bleed and purge system for air, dry nitrogen and oxygen is provided not to simulate an environment par se, but rather for operational expediency and safety.

TABLE III
TMDF PERFORMANCE SUMMARY

Environmental Variable	Range of Simulation	Simulation Equipment
Pressure and Programmed Altitude Profile	760 to 10^{-6} Torr; 760 to 10^{-5} Torr in less than 6 min - rate controllable.	Mechanical, ejector, and oil diffusion pumps with LN_2 cold traps.
Temperature & Earth Emission	- 320 to 70° F	LN_2 cold wall, and heated nitrogen gas.
Solar Radiation	130 watts/ft^2; 2500 to 50,000 Å with rays parallel	Carbon arc lamps
Albedo Radiation	Up to 21.5 watts/ft^2, 3000 to 100,000 Å	Sealed reflector, mercury-xenon lamps or equivalent; and specimen axial spin mechanism (1 to 10 RPS)
Aerodynamic Heat	Up to approx. 10^5 watts/ft^2 (up to 2000°F)	Tungsten filiment, quartz tube envelope lamps with liquid cooled end seals and reflectors.

Environmental Variable	Range of Simulation	Simulation Equipment
Vibration	For 250 lb specimen plus table, and two axis excitation - sinusoidal: 5 to 1000 cps, ± 40 g. Random: spectral density 0.5 $(g)^2$/cps, 10 to 1000 cps.	Electrohydraulic actuators, mounting table, hydraulic supply (3000 psi, 150 GPM), and electronic control equipment. (Mass of specimen and table supported by 4 horizontally mounted exciters.)
Programmed Shock	0 to 100 g's, 4 to 10 millisecs.	Same electrohydraulic exciters as for vibration - 6 inch stroke capability, (short term capacity 205 GPM).

Estimated cost of this facility is $630,000 (see Appendix II for more detail). This figure includes estimated cost of design, material and construction. Design is used in its more inclusive sense of final development and detailing of specialized items.

To the anticipated question, if it wouldn't be more economical to combine this facility with the 10^{-9} Torr SERF, the answer is a qualified no. Economically it probably would be advantageous to construct and physically they could be integrated, but from operational considerations it would be much more expensive in both time and money. Normal requirements dictate many more tests to be conducted at pressures of 10^{-6} Torr or higher, than at 10^{-8} or 10^{-9} Torr. Greater simplicity alone, justifies having a separate facility for conducting the majority of required tests at 10^{-6} Torr. Additionally, investigations at 10^{-9} Torr are primarily long term tests involving several days, or longer. Thus another facility is virtually mandatory if the more routine tests are to be conducted without long delays, and without being in direct competition with the more exotic tests.

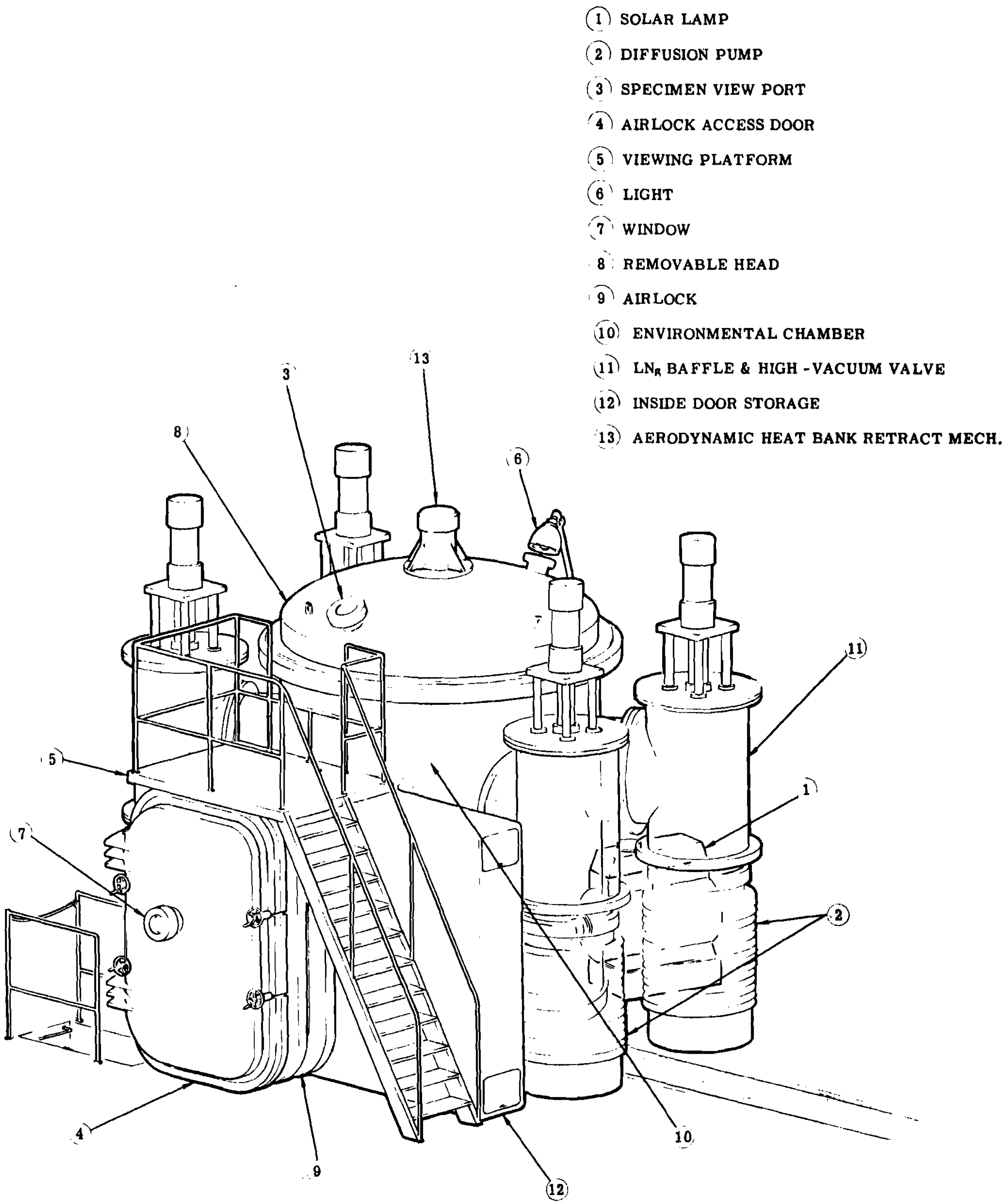

Figure 7. Thermo-Mechanical Dynamics Facility (TMDF) Isometric View

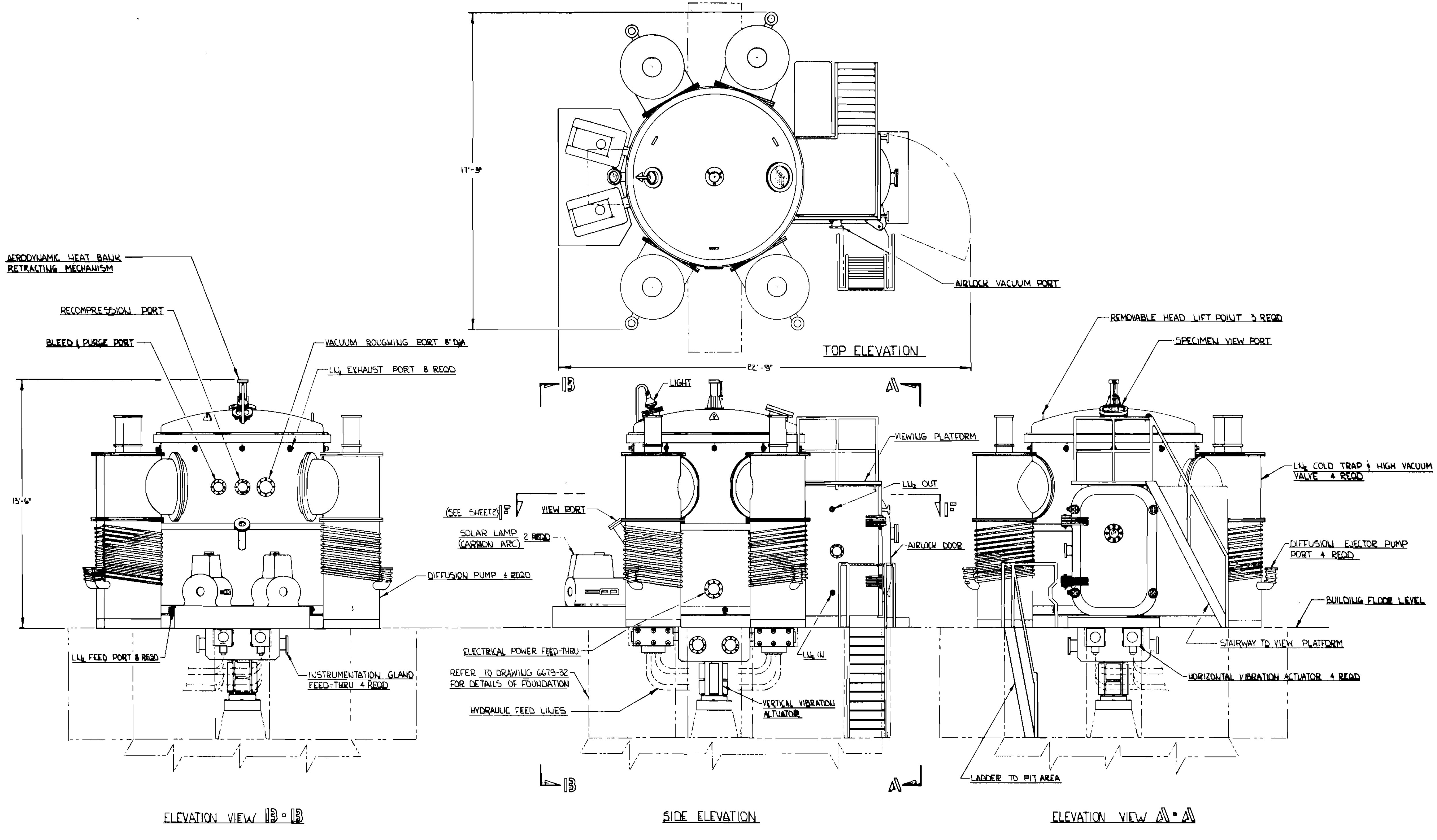

Figure 8. Thermo-Mechanical Dynamics Facility (TMDF)
Facility Assembly

NORTHROP CORPORATION/NORAIR DIVISION				
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APPROVED BY: F. G. BAHRER 7-20-60				
ENVIRONMENTAL CHAMBER ASSEMBLY - TMDF		SCALE ½" = 1'	DRAWING NO. 6679-31	

C. Acousti-Thermal Vibration Facility (ATVF)

The purpose of this facility is to simulate certain aspects of the flight transition environment, particularly the conditions of launch. Because of the awkward, if not impossible combination of sustained acceleration and acoustic vibration, it is necessary to divide the simulation of the transition environments into two facilities; one constructed around a centrifuge, and one around an acoustical chamber. The ATVF satisfies the latter requirement. Figures 9 and 10 depict the general facility concept and configuration. It should be mentioned that the exponential horn as shown is not to the correct scale; required horn length is approximately 10 feet.

TABLE IV
ATVF PERFORMANCE SUMMARY

Environmental Variable	Range of Simulation	Simulation Equipment
Acoustic Vibration	125 to 170 db SPL Overall; 50 to 10^4 cps	Air modulator driven by electromagnetic exciter (air; 90-100 lbs/min at 100 psig)
Mechanical Vibration	For specimen of 250 lb max. and two axes vib; 5 - 1000 cps and $\nless$ 40g sinusoidal; 0.5 $(\bar{g})^2$/cps spectral density and 10 - 1000 cps random.	Electrohydraulic exciters, hydraulic supply (3000 psi); mounting table and electronic controls.
Programmed Shock	0 - 100 g's in 4 - 10 milliseconds.	Same electrohydraulic exciters as for vibration; 6 inch stroke.
Aerodynamic Heating	Up to approx. 10^5 watts/ft^2 (yields up to 2000°F)	Tungsten filament, quartz tube envelope lamps; liquid cooled end seals and reflectors.

Estimated total cost, of this facility, design, material and construction, is $410,000. Detail cost breakdown is given in Appendix II.

(1) Reverberant Cell

(2) Electro-Magnetic Driver

(3) Acoustic Generator

(4) Exponential Horn

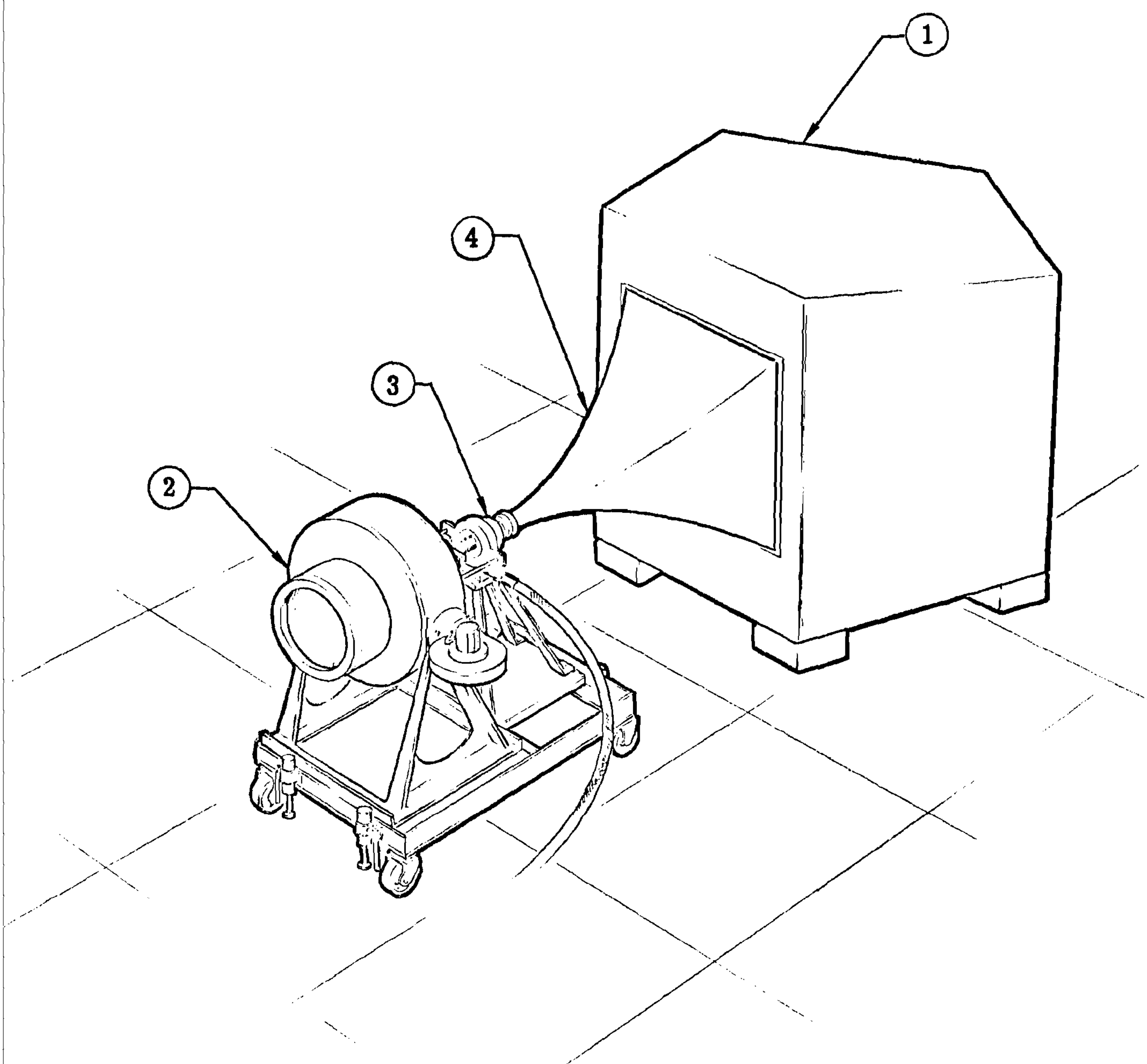


Figure 9. Acousti-Thermal Vibration Facility (ATVF) Isometric View

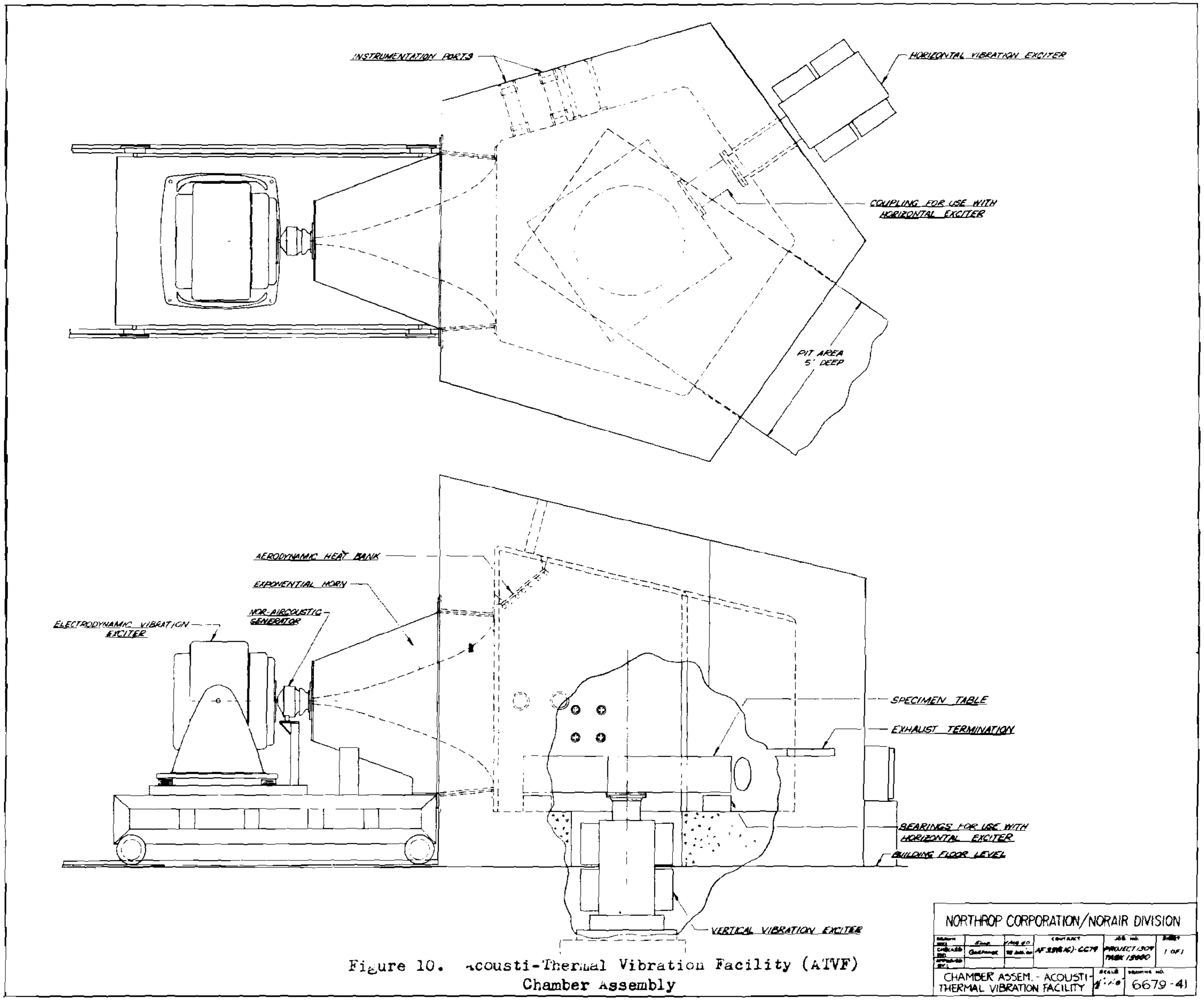


Figure 10. Acousti-Thermal Vibration Facility (ATVF) Chamber Assembly

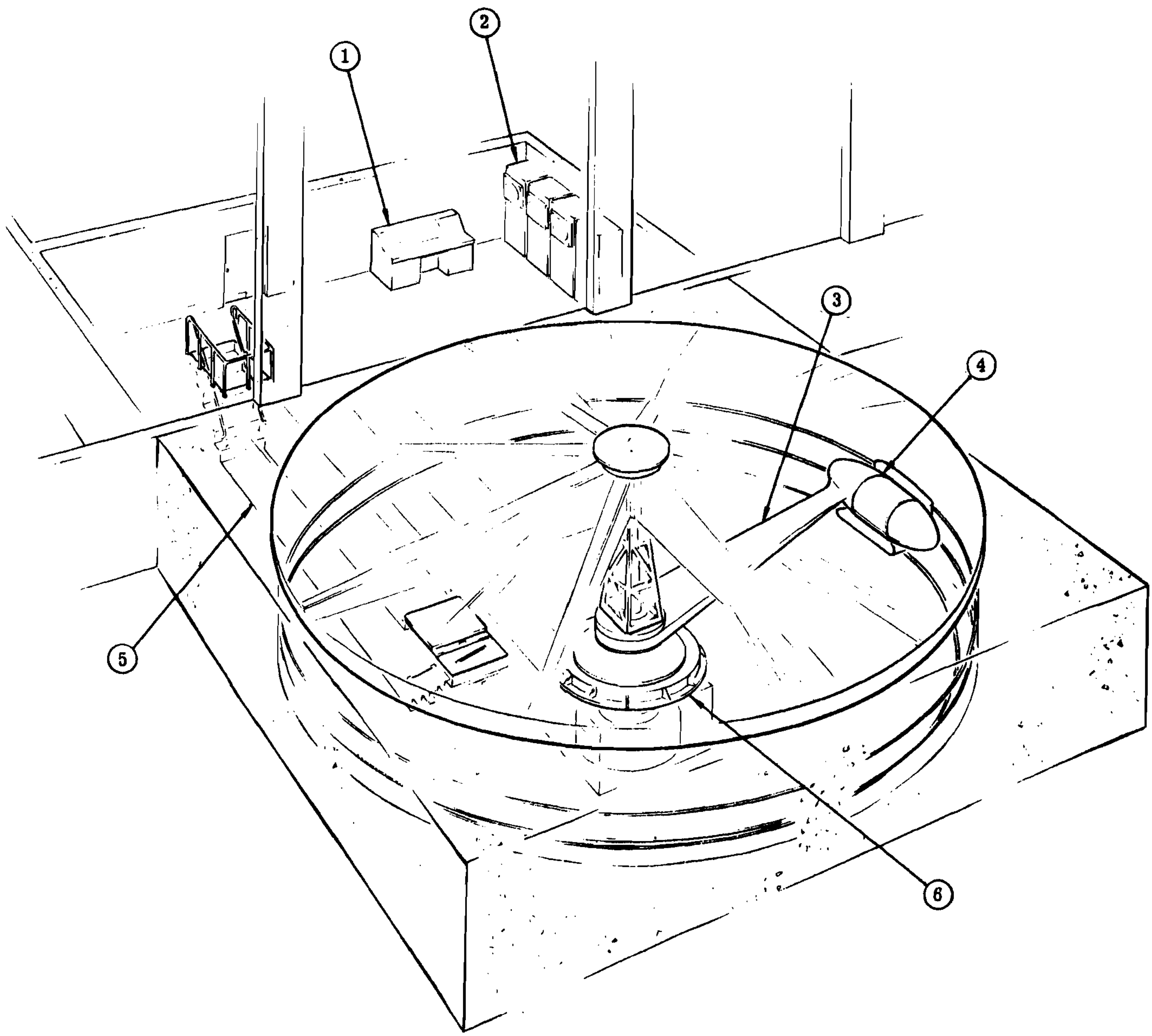
D. Inertial-Dynamics Facility (IDF)

The objective of this facility is to simulate the launch and re-entry environments exclusive of acoustic vibration. Capability for the latter condition, in combination with other variables, is provided in a separate facility (see ATVF). The facility concept and configuration is shown in Figures 11 and 12.

TABLE V
IDF PERFORMANCE SUMMARY

Environmental Variable	Simulation Range	Simulation Equipment
Sustained Acceleration	0 to 100 g's; maximum g force within 11 seconds.	20 ft radius; 120 RPM centrifuge; sliding contact with wall and floor rails.
Vibration	Two axes vibration; sinusoidal - 5-1000 cps, $\leq$ 40g; random - spectral density 0.5 $(\bar{g})^2$/cps, 10-1000 cps.	Electrohydraulic exciters.
Programmed Shock	0 to 100 g in 4 to 10 milliseconds.	Same exciter as for vibration - with 6 inch stroke double amplitude.
Aerodynamic Heating	Up to 10^5 watts/ft^2 for a minimum of 11 sec; and 5 x 10^4 watts/ft^2 for minimum of five minutes.	Electrical resistance tantalum strips; liquid cooled retainers and reflectors.
Pressure	760 to 3.5 Torr within 1.5 minutes.	Mechanical vacuum pump.

Estimated total cost of this facility, design, material, and construction, is $785,000. Detail cost breakdown is given in Appendix II.



(1) VIB. & SHOCK PROGRAM CONTROLS

(2) TEMP. & ALTITUDE PROGRAM CONTROLS

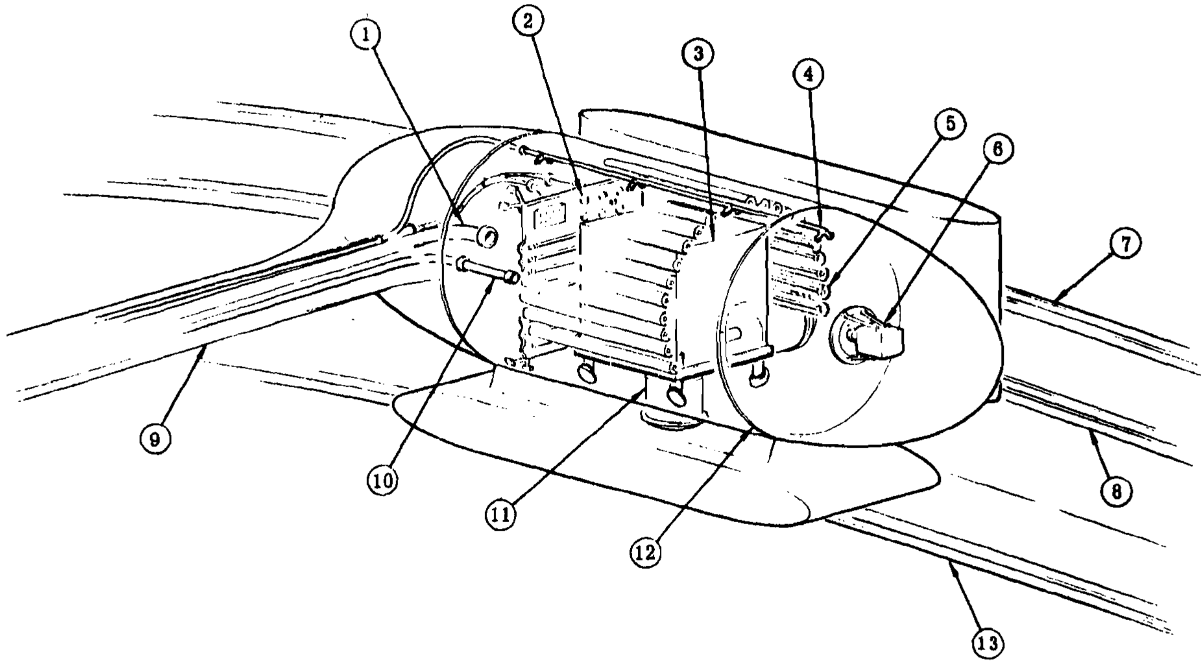
(3) INSTRUMENTATION BOOM

(4) SPECIMEN VEHICLE

(5) PERSONNEL INSTRUM. TUNNEL

(6) CENTRAL HUB & SLIP RINGS

Figure 11. Inertial Dynamics Facility (IDF) Isometric View



(1) VACUUM LINE
(2) INSTRUMENT. CABLES
(3) SPECIMEN
(4) CRYOGENIC INJECTORS
(5) RADIATION STRIPS
(6) TV CAMERA
(7) VERTICAL RAIL
(8) POWER RAIL
(9) INSTRUM. BOOM
(10) HIGH PRESS. LINE
(11) ELECTRO-HYD. EXCITERS
(12) VACUUM CHAMBER CELL
(13) HORIZONTAL RAIL

Figure 12. Inertial Dynamics Facility (IDF)
Specimen Vehicle Detail

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APPENDIX I

EXPERIMENTATION AND INVESTIGATION
FOR DESIGN BACKUP

A. Radiant Absorptive Coating

Test Objective:

Tests were conducted to examine the characteristics of two optically black coatings for use on LN_2 heat exchangers in a high vacuum facility. The desired coating characteristics were high absorptivity (low reflectivity), good durability against temperature and pressure extremes, and a coating easy to produce and maintain.

Description of Test:

Separate samples of four corrosion resistant steel alloys, 310, 316, 321, and 19-9DL, were each blackened by chemical means and by a high temperature (1000 - 1500°F) oxidation process. Normal diffuse and hemispherical* reflectance measurements were made over a wavelength range of 0.450 to 15.0 microns. Basic equipment was a Perkin-Elmer hohlraum cavity and spectrophotometer.

Reflective measurements were made on each sample after separate exposure to 1000°F, minus 320°F, and 2×10^{-5} Torr pressure.

Results of Test:

The heat oxidized coatings displayed better overall absorptivity than the chemically blackened surfaces. The type of steel did not appreciably affect absorptivity, nor did exposure to the temperature and pressure extremes.

Typical results are plotted in Figures 13 and 14, which show the ratio of reflected to incident radiation versus wavelength for 321 stainless steel. Figure 15 gives some comparison with previous measurements made on chemically blackened copper (note different ordinate scale).

Conclusions and Comments:

Both the chemically blackened and the high temperature oxide films showed good durability against mechanical and environmental stresses. The oxide film showed the best overall absorptivity, particularly for wavelengths above five microns, and should be suitable for use in high vacuum and low temperature simulation chambers. Its higher absorptivity was attributed to its relatively greater thickness. Estimated film thicknesses were 0.001 inch for the oxide, versus 0.00003 inch (25 vs 0.76 microns) for the chemical coating.

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* Diffuse refers to random reflections; hemispherical is the total reflected radiation over a solid angle of 2π steradians (hemisphere); specular refers to mirror type reflection, where the angle of the reflected ray is equal to the incident ray.

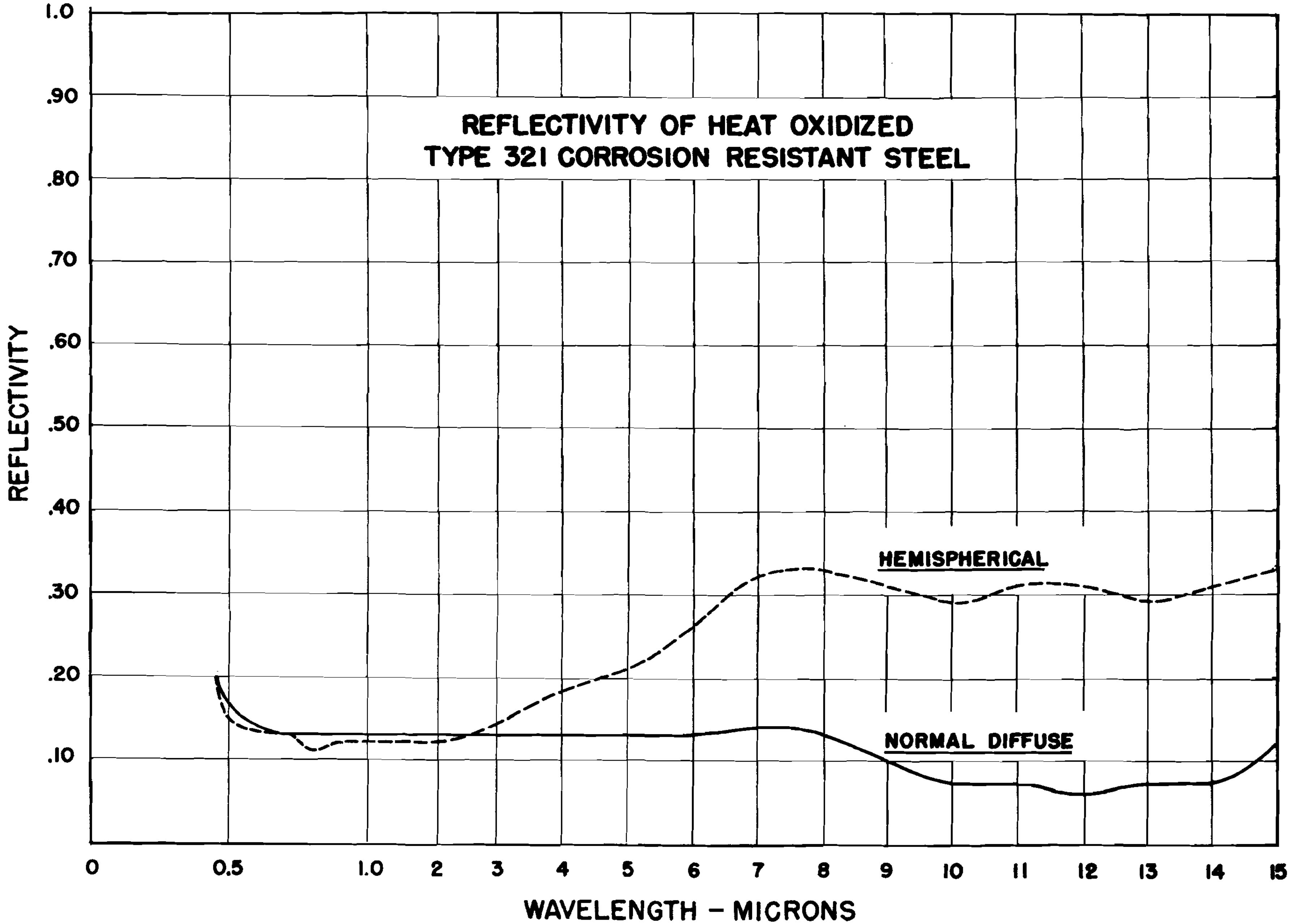

Figure 13. Reflectivity of Heat Oxidized Type 321 Corrosion Resistant Steel

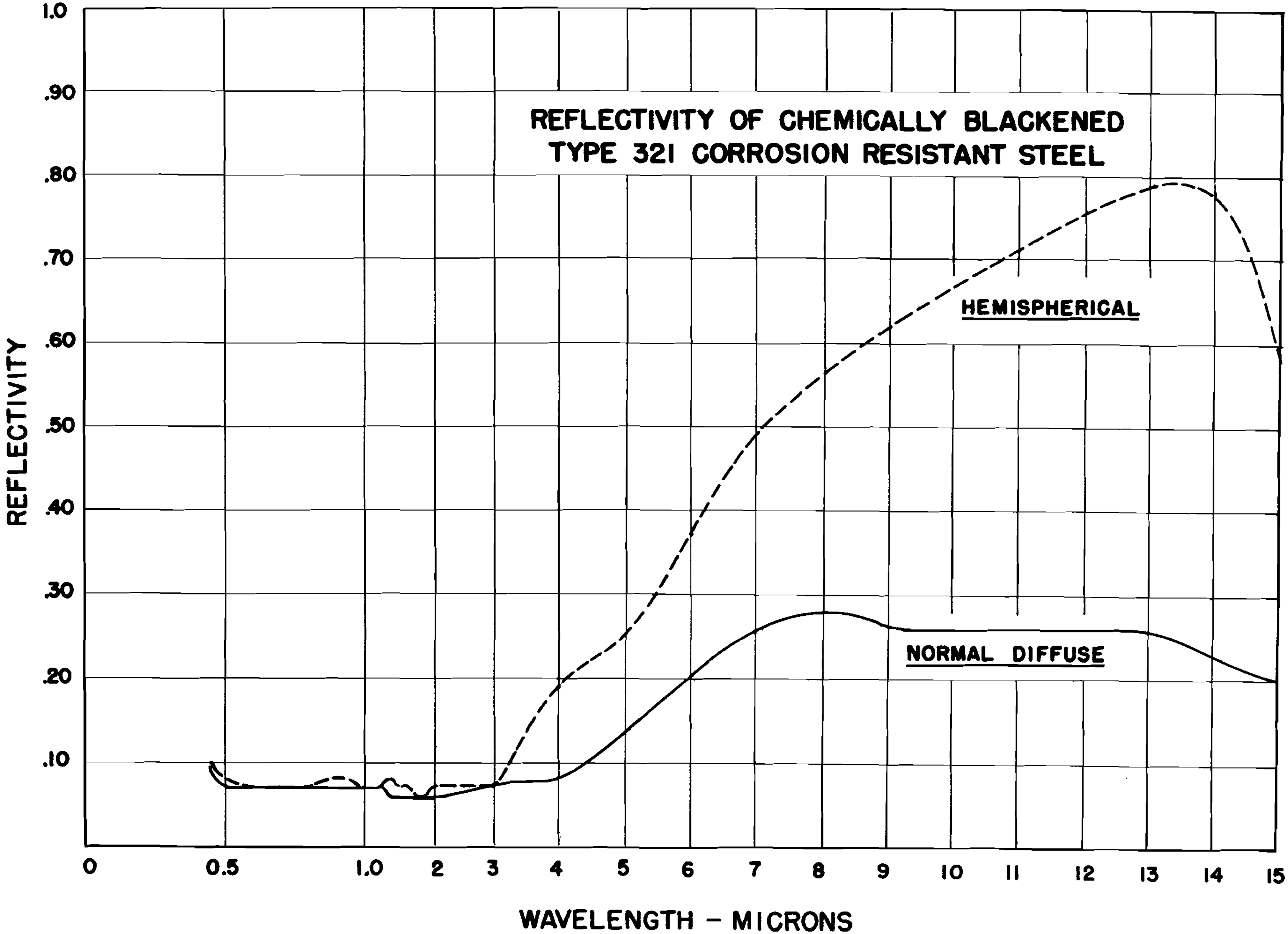

Figure 14. Reflectivity of Chemically Blackened Type 321 Corrosion Resistant Steel

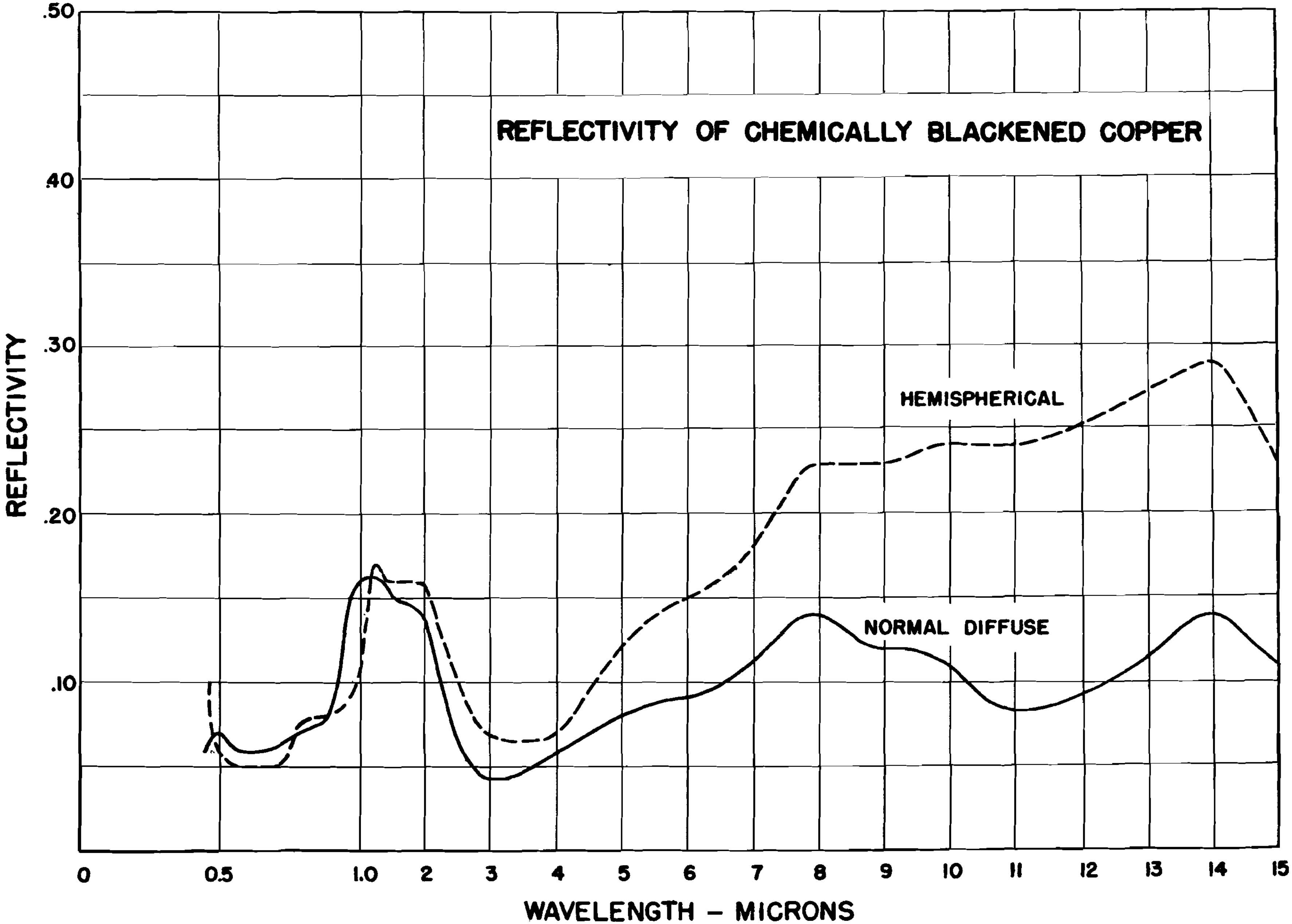

Figure 15. Reflectivity of Chemically Blackened Copper

B. Feasibility of Operating Quartz Lamps in Vacuum

Test Objective:

Tests were run to determine limits of the operating power level and time duration of quartz tube lamps (G.E. Type T3/CL and HT) in a low pressure environment, particularly as pertains to electrical arcing and over-heating of the quartz tube envelope.

Description of Test:

A water cooled holder and reflector was designed and built for the 10 inch length lamps (#1000 T3/CL). Seven lamps were arranged in a double bank with a slant center to center distance of 3/4 inches.

The test plan called for operation at 90,000 feet altitude, and power to the lamps at the rated 240 volts until temperature stabilization (approx. 5 min). After stabilization the voltage was to be increased to 150% of rated level and held for 15 minutes, then increased to 200% of rated level and held for 30 minutes, or lamp failure.

Considerable difficulty was encountered in accomplishing the desired sequence of events. Although the lamp holder design included provisions to prevent arcing, they proved to be completely inadequate. The formation of corona, followed by severe electrical discharges usually occurred whenever the voltage was raised above the rated level. A redesign of the holder and reflector alleviated the condition somewhat by prolonging the time before arcing occurred. The problem was not solved until the whole lamp and reflector assembly were electrically floated above ground potential at the level of the applied voltage.

A successful test was finally completed with a run of 40 minutes at 400 volts (167%), plus five minutes at 480 volts (200%). The test was voluntarily terminated due to overheating of auxiliary test equipment.

Test Results:

The quartz tube envelopes showed no signs of deterioration or discoloring due to over-heating in the non-convective, high altitude environment. Electrical arcing proved to be the more serious problem - and a very difficult one.

Conclusions and Comments:

Type T3 high temperature quartz lamps can be successfully utilized to simulate the residual aerodynamic heat flux in low pressure chambers. However, great care must be exercised in the reflector design in order to prevent electrical arc discharging, even though the assembly is electrically 'floated'. This technique is strongly recommended, and is believed will be virtually mandatory for operation at higher altitudes than the subject test altitude. Available information indicates that the severity of the arcing problem will increase up to a pressure altitude of approximately 250 miles.

C. Feasibility of Operating Quartz Lamps in An Acoustical Environment

Test Objective:

Tests were made to determine the feasibility of using quartz tube lamps (G.E. Type T3/CL) as a means of simulating aerodynamic heat while the lamps were exposed to a high intensity acoustic field.

Description of Test:

Three 500 T3/CL (5 inch lighted length) lamps were mounted vertically and exposed to a reverberant acoustic environment of 155 db SPL. In subsequent tests, using 3200 T3/CL HG lamps (16 inch lighted length) the acoustic intensity was increased to 160 db. Also, some of the lamps were modified by pinching, or dimpling the quartz tube around the tantalum supports in an effort to restrict the vibration of the filament and its support, and to eliminate the handicap of the vertical positioning. The tests were continued until destruction of one lamp occurred.

Test Results:

After 12 hours and 15 minutes of exposure to 155 db SPL, the 500 T3/CL lamps were still operating, although failures appeared imminent. For the 3200 T3/CL HT lamps exposed to 160 db one lamp failed after three hours; the others showed considerable damage. The cause of failure was elongation and sagging of the filament, which eventually came to rest against the quartz envelope, and thus burned its way through. The principal contributing factor was a rotation of the tantalum support disks so that they laid over parallel to the filament. Rotation and vibration of the disks emanated about a resonance point in the filament near its center. At the ends of the lamp the disk rotation and displacement was negligible. Chatter or abrasion marks on the inside of the quartz tube from the tantalum disks were quite noticeable, but appeared to have caused only slight damage.

Various configurations of dimples and ridgings in the quartz tube around the tantalum disks proved unsuccessful. (Tube modification done by Pek Labs Inc., Palo Alto.) It was difficult to appraise any difference in lamp life of the modified lamps over the unmodified ones; directly comparable tests were not made. It is believed that some dimpled configuration could be utilized that would contribute to a longer lamp life.

Conclusions and Comments:

Quartz tube lamps can withstand a severe acoustic environment, and thus the environments of aerodynamic heat and acoustic vibration can be simulated simultaneously. In order to prolong the life of the lamps, they should be mounted in portable banks and removed from the acoustic environment when not in actual use.

D. Solid Particle Accelerator Investigation

Objective:

A literature and industry investigation was conducted to evaluate present and potential methods of accelerating small solid particles to velocities approaching that of meteoroids, and to determine if such methods are compatible for combined environment simulation.

Discussion of Investigation:

Performance capabilities, principles of operation, and functional characteristics of several types of existing accelerators and guns were studied. Evaluation of such devices was based upon velocity performance and suitability for use in a combined environment facility. Only a few different types of accelerators exist, but many variations and combinations of each type have been built. The following is a brief summary of some of the pertinent information pertaining to the more common types of guns.

The Use of Explosive Charges is an extension of high velocity gunnery techniques. Specially formed charges with pellets embedded in the forward face, are detonated at targets a few feet away. Pellet velocities in the range of 10,000 to 20,000 feet/second are usually obtained.

Shaped charges yield higher projectile velocities than the blunt face explosives, extending the range up to approximately 30,000 feet/second. The shaped charge is so named because the directed end of the explosive is shaped in the form of an inverted cone. This cone, which usually contains a metallic liner, collapses in such a way when the charge is detonated that a well defined hypervelocity jet is produced. The gaseous jet, which leads the jet of liner fragments, obtains velocities in excess of 70,000 to 80,000 feet/second. Undoubtedly some microscopic liner fragments are contained in this gaseous jet, but are probably vaporized, and because of their obscurity are of little quantitative value. The jet velocity can be controlled by alternating the cone angle. Decreasing the included cone angle increases the jet velocity.

The primary advantages of the shaped charge technique are its relative simplicity and high velocity capability. Disadvantages are somewhat more numerous. The explosion and resultant products of combustion, tend to make instrumentation of inflight parameters difficult. The myriad of sizes and velocities of fragmentary projectiles, as well as the gaseous jet products and its effects, make analysis and evaluation of impact data ambiguous. Another frequent problem is caused by the high acceleration forces which result in particle breakup during flight. Although techniques have been developed to alleviate these various conditions, the problems have not been eliminated.

Light Gas Guns employ compression of hydrogen or helium to very high pressures by either an explosive charge, or a high voltage electric discharge. Aerodynamic pressure and drag propel the projectile to velocities up to approximately 20,000 feet/sec. The lightest gas is used so that the maximum amount of energy is available to accelerate the particle mass.

Advantages of the light gas gun are its ability to fire single particles of known mass and size, and its relative immunity from producing target and equipment contamination. For some applications its lower peak velocity and greater complexity, compared to the shaped charge, may be disadvantageous.

Electrostatic Propulsion techniques for accelerating pseudometeoroids to hypervelocities have met with limited success. Extremely small particles in the range of 0.1 to 10 microns must be used in order to get a high charge (energy) to mass ratio. Only then is it possible to obtain sufficient acceleration to achieve hypervelocity. The required voltages range up to 10 million and greater. One of the primary difficulties is obtaining and retaining the required charge. If achieved, the resultant electrostatic forces often leads to breakup of the particle.

Advantages of an electrostatic accelerator are its cleanness of operation, and its ability to fire more or less continuously. The principal disadvantage is its relatively low velocity, which at present has been limited to less than 10,000 feet/second.

Electromagnetic Accelerators are those devices which employ electric and magnetic induction to propel a metallic projectile to high velocity. This technique has been the least successful of any. Most devices have produced velocities of less than 3000-4000 feet/second. The problem is one of imparting sufficient energy in a very short time. The addition of more coils along the barrel in order to add more total energy is a self-limiting approach because of the distances involved, and the precision of timing and switching required. The induction heating of the projectile also becomes a problem.

Conclusions and Comments:

No existing acceleration technique or device has produced the minimum meteoroid velocity of 40,000 feet/second. While staging and/or certain combinations of methods may approach this velocity, it appears that a technological breakthrough will be required in order to obtain the mean meteoroid velocities of 100,000 feet/second or better, and reasonable particle impact incident rates. Improved acceleration methods are also required for combined simulation in a high vacuum multi-environment facility.

One particular development encountered during the course of the study employing a hybrid system showed impressive results. Designed and developed at the Aero-Space Laboratories of North American Aviation under contract to ABMA, particles of known mass and size (~ 100 microns) have been fired at velocities of 31,000 feet/second. Potentially the technique-concept is capable of velocities in excess of 40,000 feet/second. The method employs the electrical discharge of several thousand joules of energy into a small explosive charge. The resultant high energy density to mass ratio imparts enough energy to the small projectile through aerodynamic drag from the gaseous plasma to propel it to the desired velocity.

E. The NorAircoustic Generator

A description and discussion of a specific acoustic device is included in this report for two reasons. First, because it was requested by the contracting agency; and second because the particular acoustic generator under discussion best approaches the desired performance and simulation requirements.

Acoustic environment and simulation studies performed by Norair Engineering Laboratories in 1958 and 1959 proved the need for a new acoustic generator. A unit was required which was capable of producing sound energy with a broad band random frequency distribution, and an overall sound pressure level approaching, and if possible exceeding 170 db. Development of a new generator was subsequently undertaken.

The device developed utilizes the principle of modulating pressurized (60-120 psi) air flow. Unlike the siren which operates on the same principle, the Norair modulator varies the port area by an electromagnetic driver (instead of a rotor) which can be made to follow a complex, non-periodic electrical signal.

The major problem of such a design is the production of high frequency sound energy. The generated sound intensity is proportional to inlet air pressure and total open port area. These in turn are related to the linear displacement of the driver. Displacement available from an electromagnetic driver falls off with the square of the frequency; thus the higher the frequency, the less the modulation. The point at which effective air modulation ceases, establishes the high frequency cut-off.

The Norair modulator is designed to overcome this upper frequency limitation through production of high energy harmonics of the modulated signal. This is accomplished by an air valve which produces a square wave pressure output with sinusoidal displacement input. The displacement limit for effective modulation is approximately 0.01 inches. With present electromagnetic drivers the maximum frequency where it is possible to obtain this displacement is about 400 cps. However with the Norair generator appreciable acoustic energy is generated above 10,000 cps.

The modulator unit, shown in Figure 16, consists of a dual chambered valve driven by a 1200 force pound vibration exciter. A plenum chamber provides a means of smoothing the air flow and measuring upstream pressure. Maximum airflow is 90 pounds per minute at 120 psig. This represents approximately 175 db sound power level ($\sim$31 KW of acoustical power re: 10^{-13} watts). A picture of one of the generator prototype units is shown in Figure 17.

A frequency spectrum plot versus sound pressure level is given in Figure 18. The lower curve shows the RMS level within a series of one third octave frequency bands recorded with the generator driving a 150 cubic foot reverberant chamber using a hyperbolic horn. The upper curve is an extrapolation of the recorded data for the specified 80 cubic chamber in the ATVF (see page 34).

The NorAircoustic Generator is currently being used with a 150 cubic foot reverberant chamber, and a 20 foot long progressive wave chamber at Northrop Corporation, Norair Division, Hawthorne, California.

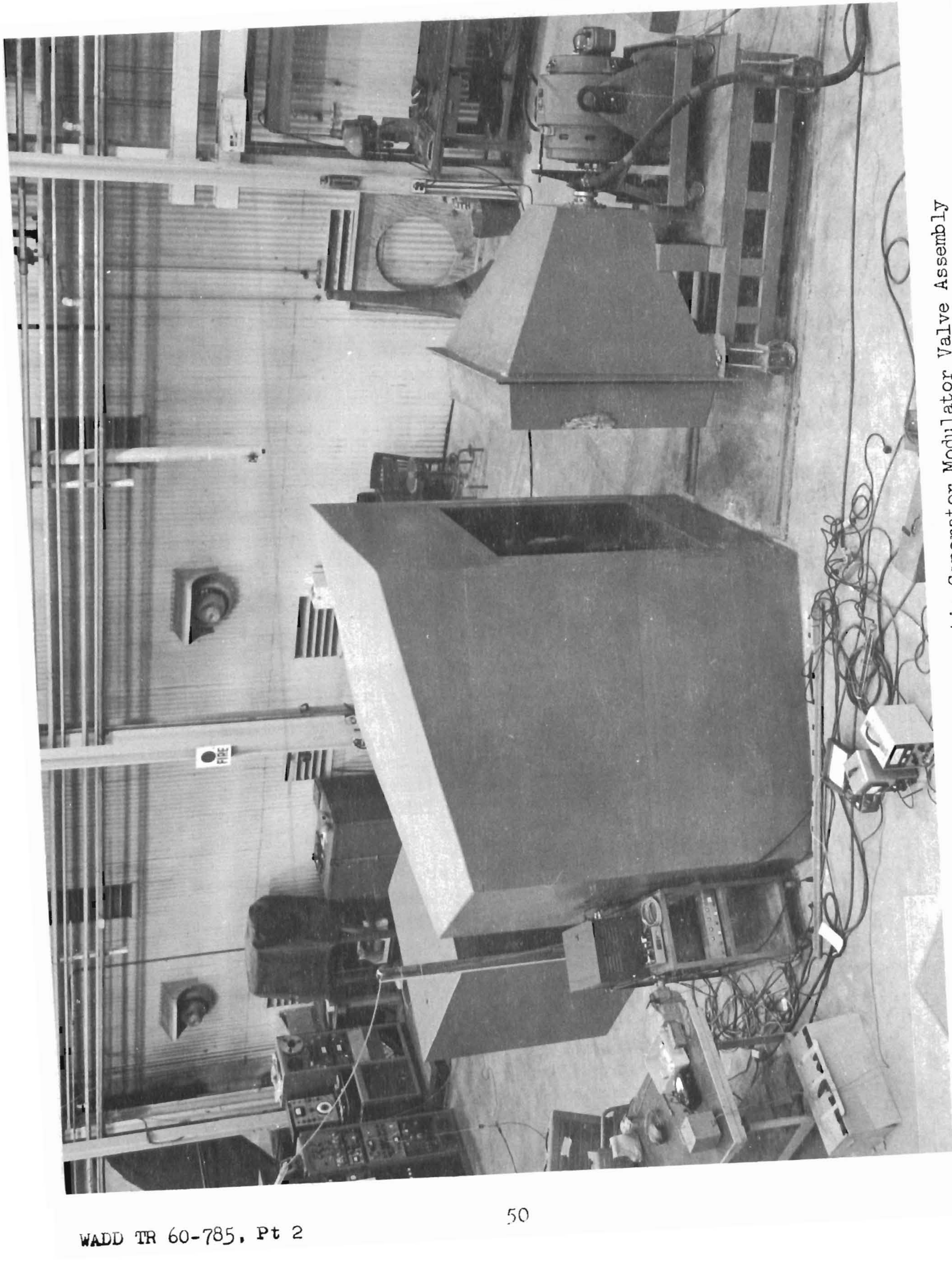

Figure 16 - The NorAircoustic Generator Modulator Valve Assembly

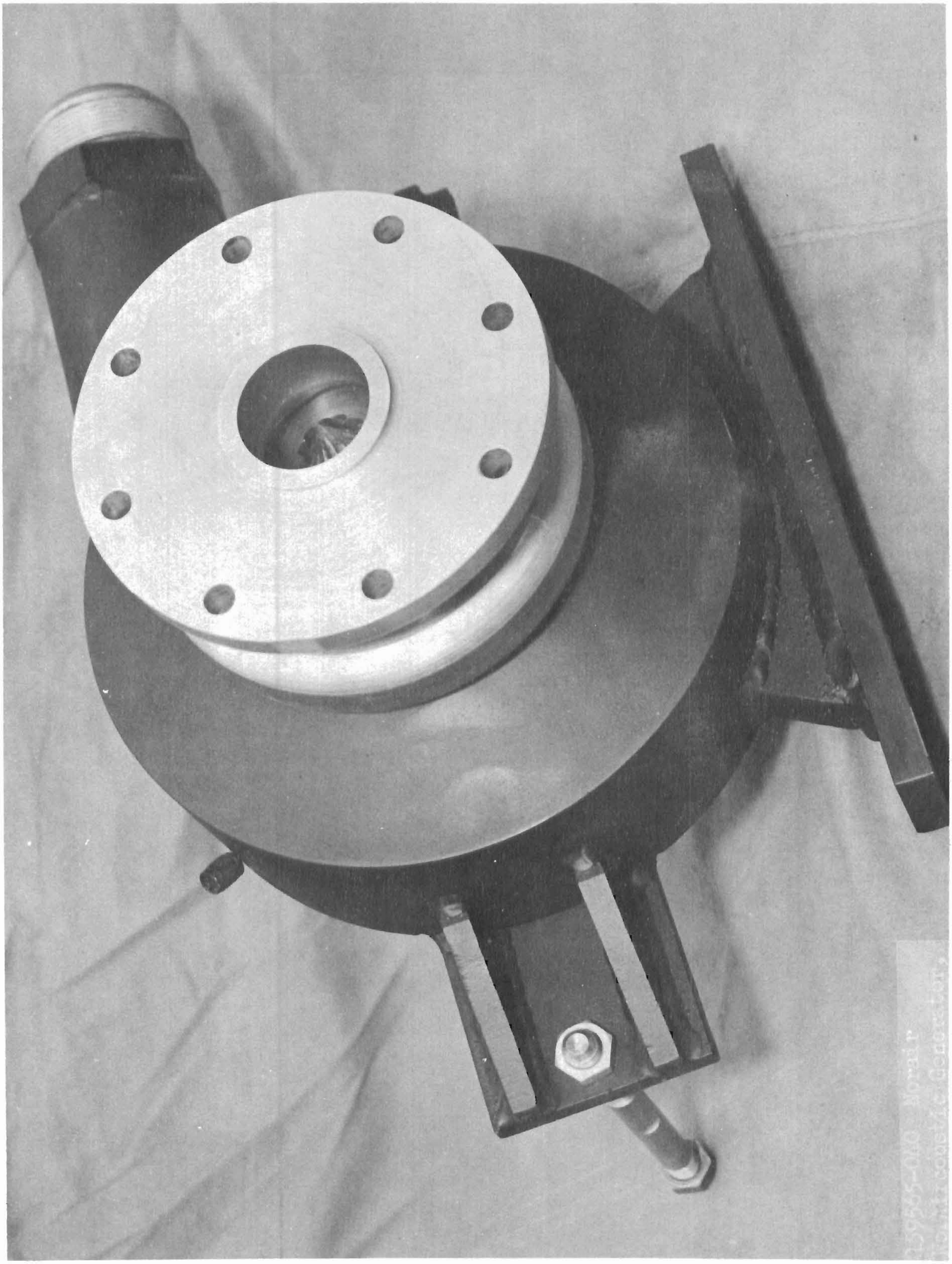

Figure 17 - NorAircoustic Generator Prototype

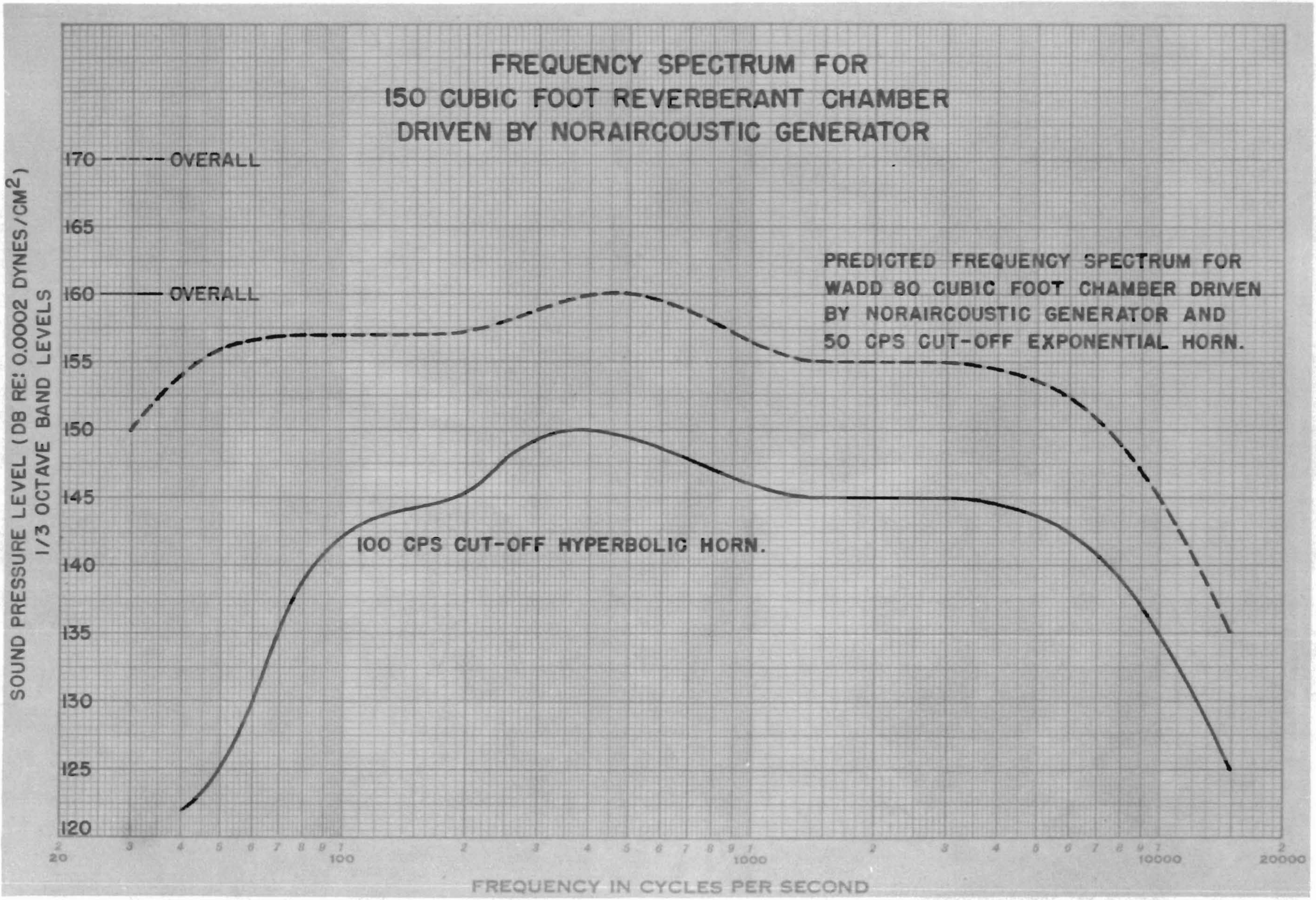

Figure 18. Frequency Spectrum for 150 Cubic Foot Reverberant Chamber Driven by the NorAircoustic Generator

APPENDIX II

COST ESTIMATE
HYPERENVIRONMENT SIMULATION FACILITIES

A. SUMMARY SHEET

Separate Cost

Space Environment Research Facility	$600,000
Thermo-Mechanical Dynamic Facility	$630,000
Acousti-Thermal Vibration Facility	$410,000
Inertial-Dynamics Facility	$785,000
Data Recording Center	$340,000
Total Separate Costs	$2,765,000

Limited Centralization Cost
(Details not itemized)

Space Environment Research Facility	$480,000
Thermo-Mechanical Dynamic Facility	$475,000
Centralization Provisions, per Bldg. 45, WADD	$245,000
	$1,200,000
Data Recording Center	340,000
Total Centralized Cost for SERF and TMDF only.	$1,540,000

B. SPACE ENVIRONMENT RESEARCH FACILITY

COST ESTIMATE

1. SERF Summary	Man Hours	Approx. $ Cost	Approx. Total $
Complete Facility			600,000
Material		465,000	
Design	3,500	50,000	
Construction	8,300	83,000	

2. SERF Sub-Systems	Man Hours	Approx. $ Cost	Approx. Total $
Foundations			19,670
Material		10,250	
Design	180	2,520	
Construction	690	6,900	
Chamber			52,190
Material		27,190	
Design	500	7,000	
Construction	1,800	18,000	
Vacuum Pumping			93,295
Material		80,355	
Design	460	6,440	
Construction	650	6,500	
Solar Radiation			36,727
Material		21,887	
Design	460	6,440	
Construction	840	8,400	

2. SERF Sub-Systems (Continued)	M-H	$ Cost	Total $
LN_2 System			54,880
Material		44,020	
Design	240	3,360	
Construction	750	7,500	
Atmosphere Control			47,239
Material		37,679	
Design	240	3,360	
Construction	620	6,200	
Spectrophotometer			130,720
Material		125,000	
Design	180	2,520	
Construction	320	3,200	
Vibration & Fatigue			109,005
Material		80,405	
Design	900	12,600	
Construction	1,600	16,000	
Electrical Install			51,420
Material		36,380	
Design	360	5,040	
Construction	1,000	10,000	

3. SERF Materials

	$ Cost	Total $
Foundations		10,250
Excavate, pour. incl. steel, attach plates	7,000	
Pit walls, floor, stair, hardrails	2,500	
Gutters, grating	500	
Lighting	250	
Basic Chamber		27,190
.625 st. stl. plate	6,300	
Flanged rings	2,000	
Dished head	2,400	
Inner shell - .035 st. stl.	400	
Surface treatment	650	
LN_2 tubing - .625 st. stl.	2,200	
Supports & standoffs, thermal sol.	600	
Expansion joints - all penetrations & joints	5,000	
Inner shell - .035 st. stl. (Door)	150	
LN_2 tubing	300	
Pneumatic actuator	125	
Door locks (Pneu.) 1000# & hardware	960	
Counterbalance mech., 6", 8" dia. pipe	850	
Seals - metallic, 9' dia.	175	
Inner floor - .035 alum. structure support brackets, latches	1,200	
View ports - flange, seals, glass - 8" dia.	880	
Specimen instr. ports - 10" dia. nickel plated sr, blind flange & seals	420	
24" dia. flange, st. stl.	630	
32" dia. flange, st. stl.	230	
8" dia. flange, st. stl.	120	
12" dia. port & flange, st. stl.	100	
8" dia. view port - flange, glass, seals	375	
6" dia. flanged port - feed throughs	125	
Misc. material	1,000	

3. <u>SERF Materials</u> (Continued)

	$ Cost	Total $
Vacuum Pumping System		80,355
Vac/on V-11430 pump	36,000	
CVC PMC-35000 pump	7,500	
KMB-1200 pump, KDH-130 pump, 2 stage unit	7,743	
1403-B pump	245	
24" dia. LN_2 baffle	2,100	
32" dia. LN_2 baffle	3,450	
8" dia. LN_2 baffle	800	
8" valve - ultra hi-vac	1,600	
32" valve, 90° air oper. ult. hi-vac	3,450	
1½" valve - hand oper. ult hi-vac	50	
½" valve - hand oper. ult hi-vac	45	
oil	400	
Ion pump power supply	11,000	
8" dia. st. stl. pipe	1,202	
Flanges, 8" pipe	960	
Tee 8"	240	
Ell 8"	240	
Misc. plumbing hardware (Cooling syst. & expan.)	1,500	
Ionization gage, single station 6 stage	1,374	
Thermocouple vac. gage, 2 station	127	
Pirani type, single station, 4 tube	329	
Solar Radiation		21,887
X-ray tubes, 1000 KV	3,000	
Hydrogen arc lamps w/lith. flouride windows	4,000	
Incandescent lamps, par reflector type	12	
X-ray controller & power supply & X-ray power supply rectifier	4,000	
Voltage control - incandescent lamps	250	
Volt. control & power supply - Hyd. arf lamps	4,000	
Lamp cooling syst. - temp. controller	1,200	
Lamp cooling syst. - heat exchanger	1,200	
Lamp cooling syst. - pump, filters, misc. hardware	950	
Lamp support structure	450	
Wiring & hardware	225	
Bolometers for total energy measurement	600	
Monitoring instruments for ultra-violet & x-ray	2,000	
LN_2 System (Inc. Heater)		44,020
Storage dewar	7,000	
Cent. supply pump	1,800	
Cent. circulation pump	1,800	
Liquid level control & reservoir	100	
Nitrogen heater	2,000	
Circulating blower	150	
Pressure relief valves, 1"	750	

3. <u>SERF Materials</u> (Continued)

	$ Cost	Total $
LN_2 System (Inc. Heater) (Continued)		
Shut-off valves, 2" manual	825	
Shut-off valves, 2" remote oper.	4,200	
Feed-through blkh'd. fittings, 2"	650	
Vacuum jacketed 2" s.s.	11,250	
90° ells, 2" s.s. - vac jacketed	8,500	
Valve insulation & supports	150	
Expansion joints, 2" tube	1,200	
Flanges, 2" st. stl.	2,000	
Tees, 2" st. stl.	400	
Ells, 2" st. stl.	750	
Cross, 2" st. stl.	125	
Temp. cutoff control 400° F	120	
Control console	250	
Atmosphere Control System		37,679
Mass spectrometer, incl pickup and controller	25,000	
Welch 1405 vac. pump	900	
Pressure regulator ¼" 150 psi	150	
Inter. press chamber	1,250	
Pneu. throttle valve ½" hi-vac	1,375	
½" st. stl. tubing	125	
½" tube fittings (weld joint) misc.	75	
¼" st. stl. line & fittings	125	
Misc. hardware	1,200	
Ionization gage, single station, 4 tube	329	
Ozone measuring equipment	1,200	
Nitrogen gas generator system	3,500	
Gas storage bottles & press. regulators	650	
Ion gun & power control	1,800	
Spectrophotometer		125,000
Model 13-U spectrophotometer (special) including temp. & humidity control systems & mounting struct.	125,000	
Vibration & Fatigue		80,405
Elect. motor, 300 H.P.	8,000	
Hyd. pump & reservoir unit, 250 GPM, 3000 psi	10,500	
Heat exchanger	1,200	
Hydraulic actuator & servo valves	5,400	
Accumulator	650	
High press. filter	1,250	
Low press. filter	650	
Relief valve 1"	160	
Hand valve 2" hi-press.	40	
Hand valve 2" lo-press.	200	

3. SERF Materials (Continued)

	$ Cost	Total $
Vibration & Fatigue (Continued)		
Check valve, hi-press.	70	
Specimen support table	2,500	
Exciter shaft hi-vac seal	150	
Fatigue mech. support table	650	
Fatigue mech., vert., torsional, bending	750	
2" st. stl. tubing, hi-press.	2,100	
2" st. stl. tubing, lo-press.	2,000	
1" st. stl. tubing, hi-press.	350	
Hyd. fittings & misc. hardware	2,100	
Hyd. oil	1,000	
Amplifier	2,100	
Noise generator	350	
Oscillator, auto-cycling	1,640	
Band pass & peak & notch filters	6,600	
Controller, programmer - tape	5,900	
Sine-noise mixer	270	
Equalizer	1,650	
Freq. counter	375	
Spectral density analyzer	17,800	
Transducers, accelerometers, misc.	4,000	
Electrical Installation		36,380
Motor control center	700	
Size #7 300 H.P. starter	7,330	
Size #3 40 H.P. starter	2,100	
Misc. control & starters	5,000	
Integ. grounding	1,250	
Main feeder ckt breaker	3,000	
2000 amp 3 conductor inclosed bus.	17,000	

C. THERMO-MECHANICAL DYNAMIC FACILITY

COST ESTIMATE

1. TMDF Summary	Man Hours	Approx. $ Cost	Approx. Total $
Complete Facility			630,000
Material		452,000	
Design	5000	20,000	
Construction	11,000	108,000	

2. TMDF Sub-Systems	Man Hours	Approx. $ Cost	Approx. Total $
Foundations & Struct. Stl.			18,225
Material		8,025	
Design	200	2,800	
Construction	740	7,400	
Chamber			41,960
Material		23,360	
Design	400	5,600	
Construction	1,100	1,100	
Vacuum System			148,360
Material		134,920	
Design	460	6,440	
Construction	700	7,000	
Cold Wall			26,700
Material		37,565	
Design	240	3,360	
Construction	680	6,800	

2. TMDF Sub-Systems (Continued)

	M-H	$ Cost	Total $
Aerodynamic Heating			36,820
Material		26,780	
Design	260	3,640	
Construction	640	6,400	
Solar Heating			21,370
Material		16,050	
Design	180	2,520	
Construction	280	2,800	
Albedo			11,040
Material		7,200	
Design	160	2,240	
Construction	160	1,600	
Vibration & Shock			195,275
Material		140,875	
Design	1,600	22,400	
Construction	3,200	32,000	
Specimen Spin			11,040
Material		3,120	
Design	180	2,520	
Construction	540	5,400	
Oxygen Purge			7,230
Material		2,750	
Design	120	1,680	
Construction	280	2,800	

2. TMDF Sub-Systems (Continued)

	M-H	$ Cost	Total $
Rapid Recompression			6,160
Material		2,200	
Design	140	1,960	
Construction	200	2,000	
Air Lock Evacuation			5,580
Material		700	
Design	120	1,680	
Construction	320	3,200	
Master Control			22,420
Material		6,420	
Design	500	7,000	
Construction	900	9,000	
Electrical Install.			56,220
Material		40,680	
Design	360	5,040	
Construction	1,050	10,500	

3. TMDF Materials

	$ Cost	Total $
Foundations & Struct. Stl.		8,025
Excavation, steel, form & pour	7,000	
Handrails, floor, ladders & platforms	450	
Floor grating & gutters	225	
Excavate & concrete for gutters	200	
Instrumentation ducting	150	
Chamber		25,360
Main shell (5/8 s.s.)	6,300	
Flange rings	2,000	
End bell	2,300	
Floor (3/4 s.s.)	2,200	
Air lock door frames	5,200	
Air lock doors	1,000	
Air lock structure (5/8 s.s.)	1,200	
Chamber sub-floor struct. (3/4 s.s.)	1,260	
Chamber sub-floor 3/8x4x4 L	240	
Chamber sub-floor 6" C	360	
Port flanges & windows	1,350	
Diffusion pump flanges	950	
Misc. hardware (Door actuators & track)	1,000	
Vacuum System		134,920
PMC-35000 diffusion pump (CVC)	30,000	
32" LN_2 Baffle (CVC)	12,800	
KS-2000 ejector pump (CVC)	11,920	
1403-B stand-by pump (Welch)	980	
32" Valve (DMV)	13,800	
8" LN_2 Baffle	2,400	
8" Valve (DMV)	3,200	
4" Valve (DMV)	1,200	
1½" Valve (Hand)	180	
12" Valve (DMV)	1,600	
Pump oil	1,440	
Flanges & gaskets s.s.	12,600	
Tees s.s.	2,240	
Ells s.s.	720	
Nuts & bolts	140	
Pipe 4-8" s.s.	6,000	
P Transmitter	400	
Intermediate press. controller	600	
Ion gage	1,000	
Programmer-recorder controller ($.01-10^{-6}$)	1,400	
Programmer-recorder controller (760-.01)	1,400	
Lines & fittings	500	
Gas generator & control	1,500	
Wiring & sequencing switches	700	

3. <u>TMDF Materials</u> (Continued)

	$ Cost	Total $
Vacuum System (Continued)		
KD 780 Mech. Vacuum pump (Kinney)	24,000	
12" pipe	200	
12" flanges, bolts, & gaskets	1,400	
12" fittings - tees & ells	600	
Cold Wall		37,565
Inner shell (.035 s.s.)	360	
Tubing (.50 dia. s.s.)	1,600	
Feed throughs & connectors	500	
Headers (2" dia. s.s. tubing)	100	
Hangers & hardware	300	
Liquid traps	430	
Relief valves	650	
Valve 2" DMV s.s.	1,400	
N_2 gas generator	600	
Temp. controller	3,600	
Nitrogen storage tank	7,000	
Vacuum jacket tubing 2" s.s.	11,250	
90° ells 2" s.s. vac. jacket	8,500	
Valve insulation & supports	150	
2" hand valves	825	
Misc. hardware, gaskets, etc.	300	
Aerodynamic Heating System		26,780
Plate coil (12x30 s.s. plates)	1,600	
Coolant pump & plumbing	600	
Heat exchanger (Tower water to coolant)	150	
Lamps 10" & retainers	4,000	
Structure s.s. L & C	200	
Guides, cables & hardware	300	
Electrical stabs & wiring	800	
Reflectors	3,600	
Power supply	2,030	
Temp. recorder & transmitter	4,800	
Program controller	8,000	
Sequencing switches & wiring	700	
Solar Heating System		16,050
Carbon arc generators & power	12,500	
Mounting structure	200	
Cooling system (Chamber window)	300	
Generator exhaust ducting	200	
Selector control (on-off)	150	
Radiation detector	1,000	
Radiation recorder	1,700	

3. TMDF Materials (Continued)

	$ Cost	Total $
Albedo System		7,200
Lamps, mounts & starters	1,800	
Support Brkt's. & wiring	2,500	
Power Supply	1,500	
Controller	700	
Sequencing switches & wiring	700	
Vibration & Shock System		140,875
Elect. motor, 300 H.P.	8,000	
Hyd. pump & reservoir base (3000 psi, 250 gpm)	10,500	
Press. regulator	500	
Heat exchanger, low press.	1,500	
Vertical actuator, valves & fixture	5,400	
Horizontal actuator, valves & fixture	32,500	
Vertical vibration table	2,500	
Horizontal vibration table	2,000	
Hi-vacuum bellows seals	320	
Hi-press. filter	2,500	
Lo-press filter	1,200	
Accumulator	7,800	
Relief valves, hi-press. & lo-press	640	
Manual shut-off valves, hi-press.	280	
Manual shut-off valves, lo-press.	600	
Check valves, lo-press	950	
High press tubing 2" dia. s.s.	4,500	
Low press tubing 2" dia. s.s.	3,800	
High press tubing 1" dia. s.s.	1,800	
Fittings & hardware	5,500	
Hyd. oil	1,000	
Amplifier	8,500	
Noise generator	350	
Oscillator, automatic cylcing	1,640	
Band pass, peak & notch filters	6,600	
Controller, programmer-tape	5,900	
Sine-noise mixer	270	
Equalizer	1,650	
Freq. counter	375	
Spectral density analyzer	17,800	
Transducers & accelerometers	4,000	
Specimen Spin Mechanism		3,120
Support mechanism, s.s. box	800	
Drive motor & gears	200	
Support table, shaft & brg's.	420	
Slip ring assembly, 8 rings	1,200	
Motor cooling system LN_2	50	
Speed control & indicator	150	
Hi-vac rotary shaft seal	250	
Wiring & hardware	50	

3. TMDF Materials (Continued)

	$ Cost	Total $
Oxygen Purge System		2,750
Pressure switch	50	
Oxygen analyzer MSA Co - Type C4	1,500	
Supply valve ½" DMV	200	
Supply regulator	150	
Controller	700	
Fittings & tubing	150	
Rapid Recompression System		2,200
Quick opening valve 6"	550	
Air supply tank	1,200	
Pressure switch	100	
Fittings & tubing	50	
Piping 4" s.s.	300	
Air Lock Evacuation System		700
Bleed valve (1½" DMV)	300	
Remote valve operator	150	
Press indicator (Thermocouple gage)	200	
Fittings & tubing	50	
Master Control System		6,420
Control consoles	2,520	
Switches & relays	500	
Wiring	1,250	
Indicator lights	2,100	
Pannels & internal structure	50	
Electrical Installation		40,680
Motor control center		
Size 7 starter (300 H.P.)	7,330	
Size 3 starter (40 H.P.)	2,100	
Misc. controls & starters	10,000	
Integrated grounding	1,250	
Main feeder circuit brkr.	3,000	
2000 A 3 conductor enclosed bus	17,000	

D. ACOUSTI-THERMAL VIBRATION FACILITY

COST ESTIMATE

1. ATVF Summary	Man Hours	Approx. $ Cost	Approx. Total $
Complete Facility			410,000
Material		275,000	
Design	3,700	50,000	
Construction	8,300	85,000	

2. ATVF Sub-Systems	Man Hours	Approx. $ Cost	Approx. Total $
Foundations & Struct. Stl.			18,170
Material		8,650	
Design	180	2,520	
Construction	700	7,000	
Reverberant Chamber			53,930
Material		37,610	
Design	380	5,320	
Construction	1,100	11,000	
Exponential Horn			8,665
Material		3,025	
Design	160	2,240	
Construction	340	3,400	
Noraircoustic Generator			31,180
Material		27,000	
Design	120	1,680	
Construction	250	2,500	

2. ATVF Sub-Systems (Continued)	M-H	$ Cost	Total $
Aerodynamic Heating			40,080
Material		25,280	
Design	450	6,300	
Construction	850	8,500	
Vibration & Shock			170,455
Material		117,975	
Design	1,600	22,400	
Construction	3,000	30,000	
Airflow System			24,360
Material		18,000	
Design	140	1,960	
Construction	440	4,400	
Master Control			18,680
Material		5,080	
Design	400	5,600	
Construction	800	8,000	
Electrical			42,570
Material		30,430	
Design	260	3,640	
Construction	850	8,500	

3. <u>ATVF Materials</u>

	$ Cost	Total $
Foundation		8,650
Excavation, steel, form & pour - Main chb'r.	6,000	
Minor foundations - Hyd. power, air supply	1,000	
Floor, track rails, gutters, grating	1,650	
Reverberant Chamber		37,610
Forms, steel, tie plates	5,000	
Concrete pour	5,000	
Surface finish	50	
Ports & glands - 3", 2", 1" pipe	75	
Door seal	75	
Muffler, structure	1,000	
Soundproof enclosure, lights, vents, exh.	20,000	
Microphones & power supply	1,200	
Audio spectrum analyzer & recorder (1/3 Oct.)	4,210	
Microphone calibrator & oscillator	1,000	
Exponential Horn Assembly		3,025
Form, wood & reinforcing steel	1,200	
Concrete pour	1,500	
Surface finish	50	
Moveable platform base - struct stl. 6"	75	
Wheels, fittings	125	
Horn support structure	75	
NorAircoustic Generator		27,000
Generator assy., incl. fittings	5,000	
Electro-dynamic driver, power supply & control	22,000	
Aerodynamic Heating		25,280
Plate coil (12x30 s. plates)	550	
Coolant pump & plumbing	550	
Heat exchanger	150	
Lamps 10" & retainers	4,000	
Support structure, str. stl.	100	
Electrical stabs & wiring	800	
Reflectors	3,600	
Power supply	2,030	
Temp. recorder & transmitter	4,800	
Program controller	8,000	
Sequence switches & wiring	700	

3. ATVF Materials (Continued)

	$ Cost	Total $
Vibration & Shock		117,975
Elect. Motor, 300 H.P.	8,000	
Hyd. pump & reservoir base (3000 psi, 250 gpm)	10,500	
Press. regulator	500	
Heat exchanger, low press.	1,500	
Vertical actuator & valves	5,400	
Vertical vibration table & suppt's.	4,500	
Horiz. actuator & valves	5,400	
Horiz. vib. table & suppt's.	4,500	
Filter, hi-press.	2,500	
Filter, lo-press.	1,200	
Accumulator	7,800	
Relief valves, hi & lo press.	640	
Manual shut off valves	900	
Check valves, lo-press.	950	
Hi-press. tubing 2" dia. s.s.	4,500	
Hi-press tubing 1" dia. s.s.	1,800	
Lo-press. tubing 2" dia. s.s.	3,800	
Fittings & hardware	5,500	
Hyd. oil	1,000	
Amplifier	8,500	
Noise generator	350	
Oscillator, auto cycling	1,640	
Band pass, pear & notch filters	6,600	
Controller programmer - tape	5,900	
Sine-noise mixer	270	
Equalizer	1,650	
Freq. counter	375	
Spectral density analyzer	17,800	
Transducers, accel. etc.	4,000	
Airflow System		18,000
Blower, motor, piping, controls 50 ppm @ 100 psig	18,000	
Master Control		5,080
Control console	1,800	
Switches & relays	500	
Wiring	1,250	
Indicator lights	1,500	
Panels & internal structure	30	
Electrical, Utility Installation		30,430
Motor control center - size 3 starter	1,400	
Size 7 starter (300 H.P.)	7,330	
Misc. controls & starters	8,000	
Integrated grounding	1,200	
Main circuit brkr.	3,000	
3000A, 3 conductor, enclosed bus	9,500	

E. INERTIAL-DYNAMICS FACILITY

COST ESTIMATE

1. IDF Summary	Man Hours	Approx. $ Cost	Approx. Total $
Complete Facility			785,000
Material		580,000	
Design	5,500	80,000	
Construction	12,500	125,000	

2. IDF Sub-Systems	Man Hours	Approx. $ Cost	Approx. Total $
Foundations & Structures			105,460
Material		86,560	
Design	550	7,700	
Construction	1,120	11,200	
Central Hub & Boom			37,860
Material		18,760	
Design	650	9,100	
Construction	1,000	10,000	
Vehicle & Carriage			43,310
Material		19,130	
Design	620	8,680	
Construction	1,550	15,500	
Vacuum System			19,395
Material		13,295	
Design	150	2,100	
Construction	400	4,000	

2. IDF Sub-Systems (Continued)	M-H	$ Cost	Total $
Aerodynamic Heating			52,440
Material		39,000	
Design	360	5,040	
Construction	840	8,400	
Vibration & Shock			161,810
Material		107,410	
Design	1,600	22,400	
Construction	3,200	32,000	
Hydraulic Power Supply			265,350
Material		234,390	
Design	640	8,960	
Construction	2,200	22,000	
Electrical Instal. Utilities			62,450
Material		44,850	
Design	400	5,600	
Construction	1,200	12,000	
Master Control			21,740
Material		5,740	
Design	500	7,000	
Construction	900	9,000	
Television Monitoring			11,615
Material		9,575	
Design	60	840	
Construction	120	1,200	

3. IDF Materials

	$ Cost	Total $
Foundations & Structures		86,560
Pit & walls	37,000	
Hub, tunnels, & control room	3,000	
Control room	30,000	
Roof	11,800	
Track	3,760	
Stairs - guardrails - doors - etc.	1,000	
Central Hub & Boom		18,760
Lower structure	750	
Bearings & housing	1,000	
Drive ring gear & pinions	280	
Slip rings	12,000	
Hydraulic swivel	1,150	
Boom assembly & fairing	500	
Upper structure	280	
Compound swivel	2,500	
Misc. hardware	300	
Vehicle & Carriage		19,130
Chamber shell	4,032	
Flanges & ribs	1,760	
Dished heads	568	
Ports & flanges	7,000	
Bellows (vib. shaft)	300	
Window & seal	150	
Door locks	200	
Hardware	300	
Carriage structure	420	
End bell fairing	1,000	
Carriage fairing	400	
Slippers	1,200	
Clamping cylinders & hyd. lines	1,800	
Vacuum System		13,295
KDH 530 vac. pump, kinney	6,500	
Valve 6" DMV	1,175	
6" AL tubing	450	
8" pipe	180	
8" flanges & gaskets	570	
6" fittings & gaskets	900	
Vibration isolators (8" pipe)	80	
Program-record controller	1,140	
Peizometer	600	
Misc. hardware	300	
Control console	360	
Exhaust filter	1,040	

3. IDF Materials (Continued)

	$ Cost	Total $
Aerodynamic Heating		39,000
Plate coil	1,600	
Heat exchanger	150	
Coolant pump & plumbing	1,200	
Heaters & retainers	4,000	
Support struct & shields	500	
Reflectors	4,000	
Wire, insulators & hardware	1,400	
Mercury Wetting Distribution & Storage System	850	
Mercury	1,750	
Power bus - 3 rail copper	7,000	
Power bus supports, insulators	850	
Program controller	8,000	
Power supply	2,100	
Temp. recorder & transmitter	4,800	
Sequencing switches & wiring	800	
Vibration & Shock		107,410
Vertical actuator, valves	5,400	
Horiz. actuator, valves	32,500	
Vertical vibration table	2,500	
Horiz. vibration table	2,000	
High press. tubing 2" dia. s.s.	4,500	
Low press. tubing 2" dia.	3,800	
High press. tubing 1" dia. s.s.	1,800	
Hydraulic fittings, check valves, misc.	5,000	
Hyd. oil - complete system	1,675	
Manual shut-off valves 1", s.s.	150	
Accumulator	1,000	
Amplifier	8,500	
Noise Generator	350	
Oscillator, auto-cycling	1,640	
Band pass, peak & notch filters	6,600	
Controller, programmer - tape	5,900	
Sine - Noise mixer	270	
Equalizer	1,650	
Freq. Counter	375	
Spectral density analyzer	17,800	
Transducers, accel., misc.	4,000	
Hydraulic Power Supply		234,390
Hyd. pump, PV 2500-FCEAB, 3000 psi, 576 GPM	180,000	
Elect. motor, 1000 HP, 900 RPM	25,000	
Elect. motor, 500 HP, 900 RPM	13,700	
Speed sensing motor	200	
Orifice controller - Programmer	500	
Control press. pump	200	

3. IDF Materials (Continued)	$ Cost	Total $
Hydraulic Power Supply (Continued)		
Back press regulator 4"	1,000	
Press. vessel 100 psi	700	
Heat exchanger (water)	500	
Pressurized hyd. reservoir	1,500	
4" dia. s.s. pipe	5,200	
90° ells, 4" s.s.	880	
Couplings 4" s.s.	920	
Filter, Lo-press	900	
Check valve	180	
System relief valves	90	
Hand valve, 4"	140	
Misc. fittings, tubing	1,500	
1.00 s.s. tubing & fittings	500	
Tee, 4" s.s.	780	
Electrical Installation - Utilities		44,850
500 KVA transformer	18,000	
13 KV, oil circuit breaker	8,000	
Fused disconnects	350	
Motor control	8,000	
5000 V cable	1,000	
4 KV breaker (line feeder)	7,500	
Bus & misc. hardware	2,000	
Master Control		5,740
Control consoles	1,800	
Switches & relays	500	
Wiring	1,250	
Indicator lights	750	
Panels & internal structure	300	
Accel. control (speed) & programmer	1,140	
Television Monitoring System		9,575
Camera - Kin Tel 1990 CT-3D Camera Control Unit - Kin Tel 1988 DCU 14" Monitor - Kin Tel 1986-3D Camera cable AC-59	9,500	
Supp't. struct., cable clamps, misc.	75	

F. CENTRALIZED FACILITIES BLDG. 45 SERF AND TMDF ONLY

COST ESTIMATE

	Man Hours	Approx. $ Cost	Approx. Total $
1. Complete Installation			245,000
Material		192,000	
Design	1,400	20,000	
Construction	3,200	32,000	

2. Centralized Sub-Systems	Man Hours	Approx. $ Cost	Approx. Total $
Vacuum (Roughing)			28,342
Material		21,142	
Design	200	2,800	
Construction	440	4,400	
Hydraulic Power			40,422
Material		29,422	
Design	300	4,200	
Construction	680	6,800	
Cryogenic			67,250
Material		56,650	
Design	300	4,200	
Construction	640	6,400	
Electrical Utilities			101,731
Material		79,231	
Design	600	8,400	
Construction	1,410	14,100	

3. <u>Centralized Materials</u>

	$ Cost	Total $
Vacuum System Centralization		21,142
Vacuum pump KD 780	16,000	
Exhaust filter	1,080	
Valves - gate, hand oper.	1,300	
Pipe 8" & 12" seamless steel	1,202	
Flanges	755	
Hangars, bolts, gaskets	280	
Vibration isolator	300	
Cooling water 3/4" piping, fittings, valves, etc.	75	
Cooling control valves	150	
Hydraulic Power Centralization		29,422
PV 2200-F**BB-13 Hyd. pump & suction boost	10,650	
500 H.P. Elect. Motor (See Electrical Utilities)		
Mounting base	400	
Reservoir, 100 gal.	225	
2" dia. pipe s.s. dbl x strong grade B	4,800	
4" dia. pipe s.s. dbl x strong grade B	7,800	
90° Ells 2" s.s. dbl x strong grade B	146	
90° Ells 4"	1,160	
Couplings 2"	61	
Couplings 4"	380	
Fittings, tube to pipe	500	
Heat exchangers, low press	550	
Filters, low press	500	
Filters, hi-press	500	
Press. relief valve	60	
Check valve	120	
Accumulator	450	
Hand valve, 2"	140	
Hand valve, 4"	480	
Oil, MIL-O-5606	500	
Cryogenic Centralization		56,650
Vacuum jacketed lines, 4" s.s.	13,500	
Valves, 4" gate s.s.	18,000	
Pump, 50 psi-100 GPM & 15 H.P. motor	2,000	
Valve insulation & supports	150	
90° Ells, 4' run - vac. jacketed	10,000	
Storage tank	13,000	
Pumping system included		

3. <u>Centralized Materials</u> (Continued)

	$ Cost	Total $
Electrical Utility Centralization		79,231
500 H.P. Elect. motor (For hyd. pump)	13,772	
4000A-DB-100 main feeder ck't. brk'r.	6,100	
4000A, 3 conductor, enclosed bus	33,128	
Size 7, 60,000 A int. cap. starter (500 H.P.)	7,331	
Motor control center - size 3 starter - 4 H.P.	1,400	
Misc. controls, starters, etc.	15,000	
Integrated grounding system	2,500	

G. DATA RECORDING CENTER

	M-H	$ Cost	Total $
Complete System and Installation			340,000
Materials		250,000	
Design	2,500	35,000	
Construction	5,500	55,000	

(Detailed breakdown not included)

APPENDIX III

INDUSTRIAL CREDITS LIST

The following is a credits list of various manufacturers, industrial representatives, and specialized technical firms who were contacted during the conduction of the "Hyperenvironment Simulation" study. Many of them gave valuable technical assistance, and some satisfied a specific equipment requirement as well. This compendium in no sense constitutes a complete listing of available firms or proffers specific recommendations.

Type of Equipment or Service	Name of Supplier
General Simulation Experience and Information.	Jet Propulsion Laboratory Pasadena, California
	Litton Industries Beverly Hills, California
	Lockheed Missile and Space Division, Sunnyvale, California
Vacuum Pumps; mechanical, oil diffusion and ion.	Consolidated Vacuum Corp. Rochester, New York
	F. J. Stokes, Corp. Philadelphia, Pennsylvania
	New York Air Brake Co., Kinney Division, Boston, Massachusetts
	NRC Equipment Corp. Newton, Mass; and rep., Carl Hermann Associates, Pasadena, California
	Ultek Corp., Palo Alto, California
	Varian Associates, Palo Alto, Calif; and rep. Neely Enterprises North Hollywood, California

Type of Equipment or Service	Name of Supplier
Vacuum Chambers and Associated Equipment.	Fluidyne Engineering Corp. Minneapolis, Minn.
	General Vacuum Corp. Boston, Mass; and rep. Loran Patrick Associates, Alhambra, Calif.
	Guardite Co., Wheeling Ill; and rep. A. Dale Herman Inc. Encino, Calif.
	NRC Equipment Corp. Newton, Mass.
	Scientific Engineering Laboratories, Berkeley, Calif.
	Tenny Engineering, Inc. Union, N. J.; and rep., Thorson Co., Los Angeles, Calif.
	W. K. Geist Company Glendale, Calif.
	Veeco Vacuum Corp. New Hyde Park, L. I. New York
Cryopumping and Cryogenic Equipment.	A. D. Little, Cambridge, Mass.
	Fieldtec Field Engineering Corp. Minneapolis, Minn.
	Linde Co., Los Angeles, Calif.
Solar Radiation Simulation Equipment.	Dunlee Corp., Chicago, Ill.
	Electro-Optical Systems Inc. Pasadena, Calif.
	Hanovia Lamp Div., Engelhard Industries Inc., Newark, N.J.
	Lamp Div. and X-Ray Div., Westinghouse, Electic Corp.
	Large Lamp Dept., and X-ray Dept, General Electric Co.

Type of Equipment or Service	Name of Supplier
Solar Radiation Simulation Equipment (Cont.)	National Carbon Co. Fostoria, Ohio
	Nortronics Div., Northrop Corp., Hawthorne, Calif.
	Plasmadyne Corp. Santa Ana, Calif.
	The Strong Electric Corp., Toledo, Ohio
	X-Ray Products Corp., Rivera, Calif.
Solid Particle Gun-Accelerators.	Aero-Space Lab, North American Aviation, Downey, Calif.
	Rhodes and Bloxom Applied Physics Research, Canoga Park, Calif.
Atomic Particle Generators.	Radiation Dynamics, Inc. Westbury, Long Island, New York
Vibration Equipment.	Ling-Altec Electronics Inc. Anaheim, Calif.
	MB Manufacturing Co., Inc. New Haven, Conn.
	Norair Div., Northrop Corp. Hawthorne, Calif.
	TEAM Corporation El Monte, Calif.
	Wyle Laboratories, El Segundo, Calif.
Acoustic Vibration Equipment.	Norair Div., Northrop Corp. Hawthorne, Calif.
Centrifuge and Associated Equipment.	Rucker Company, Oakland, Calif.
	Hycon Mfg. Co. Pasadena, Calif.
	Slip Ring Co. of America Los Angeles, Calif.

Type of Equipment or Service	Name of Supplier
Centrifuge and Associated Equipment. (Cont.)	Vickers, Inc. Detroit, Mich.
Metallic Bellows for vacuum, vibration, and thermal expansion seals.	Arrowhead Rubber Co. Downey, Calif.
	Flexonics Corp. Bartlett, Illinois