NASA CR-132457

SHUTTLE SORTIE ELECTRO-OPTICAL INSTRUMENTS STUDY

November 1974

(NASA-CR-132457) SHUTTLE SORTIE ELECTRO-OPTICAL INSTRUMENTS STUDY (Xerox Electro-Optical Systems, Pasadena) 131 p HC $5.75 CSCL 14B

N75-10406

Unclas

G3/35 52718

Prepared under Contract No. NAS1-12710 by

XEROX ELECTRO-OPTICAL SYSTEMS
Pasadena, California

Langley Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

This report was prepared by Xerox Corporation/Electro-Optical Systems (EOS) under Contract NAS1-12710 with NASA Langley Research Center.

The work was administered under the direction of the Langley Research Center Space Systems Division. Mr. Charles I. Tynan, Jr., of the Shuttle Experiments Office was the Program Director for Langley Research Center.

This program was a group effort headed by Mr. L. H. Reynolds, Program Manager. Major contributors include J. A. Carlson, J. L. Clayton, L. L. Davies, T. J. Dea, W. Liu, T. T. Miyakawa, and A. Von Theumer.

At the outset, and during the course of this study, NASA provided applicable documents to EOS which would define the environmental conditions to which the electro-optical instruments would be subjected and the Spacelab resources available to these instruments. Due to the dynamic nature of the Shuttle and Spacelab programs, the environmental conditions and Spacelab resources data were continually changing during the course of this five month study effort. Some applicable documents, such as Spacelab System Requirements, March 1, 1974, European Space Research Organization, and Interim Spacelab Reference Document, April 18, 1974, Marshall Space Flight Center, were available at the end of the period of performance for this study. Although the data from the most current documents are not totally reflected in this report, the data differences would not have any significant impact on the study results regarding instrument modifications.

ABSTRACT

Results are reported of a study to determine the feasibility of adapting existing electro-optical instruments (designed and successfully used for ground operations) for use on a Shuttle sortie flight and to perform satisfactorily in the space environment. The suitability of these two instruments (a custom made image intensifier camera system and an off-the-shelf Secondary Electron Conduction television camera) to support a barium ion cloud experiment was studied for two different modes of Spacelab operation - within the pressurized module and on the pallet.

CONTENTS

CONTENTS (Contd)

ILLUSTRATIONS

TABLES

SECTION 1

INTRODUCTION AND SUMMARY

1.1 OBJECTIVE OF THE STUDY

In October 1973, Xerox Corporation/Electro-Optical Systems (EOS), began a 5-month study for NASA's Langley Research Center relative to the Space Shuttle Transportation System. The objective of this study was to evaluate the feasibility of adapting two, specific ground-based instruments for use on a Shuttle sortie mission and to investigate the modifications necessary to enable the instruments to perform satisfactorily in the space environment.

As pointed out in the NASA Statement of Work which initiated this study, the Space Shuttle Transportation System will offer scientists and engineers the opportunity to perform a variety of experiments in a previously unobtainable environment. When the Space Shuttle and Spacelab are used in the sortie or "research" mode, the shirtsleeve environment will enable non-astronauts to be on board to actually operate their own instruments. To make maximum use of the Shuttle Spacelab concept, the cost of these instruments must be reduced as much as possible. Obviously, one way to reduce costs is to use existing equipment previously designed for ground-based operations.

The Spacelab which will be used in the sortie mode will be designed, developed, and constructed in Europe by the European Space Research Organization (ESRO). The Spacelab will be carried into near-Earth orbit mounted in the payload bay of the Shuttle Orbiter, always remaining attached to the Shuttle Orbiter throughout its flight. Spacelab will consist of two elements: (1) a pressurized module which is a manned laboratory providing a shirtsleeve environment for the crew, and (2) a pallet which is an unpressurized platform for mounting instruments and equipment requiring direct exposure to the space environment. On a given flight, the Spacelab configuration can be comprised of a pressurized module only, a pallet only, or a combination of a pressurized module and a pallet, depending upon the specific flight objectives.

The Shuttle Orbiter can carry 65,000 pounds into orbit but it is being designed to operationally de-orbit and land with a 32,000 pound maximum payload weight. For most Spacelab sortie flights the return payload weight limitation is the most significant constraint, and the payload return weight will generally be about the same as the payload launch weight, minus experiment consumables.

The two instruments evaluated during this study effort were:

1. An image intensifier camera system designed and built for NASA/Wallops Flight Center by EOS in 1969-1970.

2. A Secondary Electron Conduction (SEC) television camera, Model STV-614, manufactured by the Westinghouse Electric Company.

The above two systems were chosen by NASA because they represent two different classes of instruments: (1) an off-the-shelf system (the SEC camera), and (2) a specially-designed system (the EOS camera). Both systems were used for the Barium Cloud Experiments conducted by NASA, and it has been proposed that a similar experiment be performed from the Space Shuttle. As a ground rule for the EOS study, it has been assumed (after discussions with NASA personnel) that the technical performance of the instruments should be as good in the Shuttle as it was on the ground.

The suitability of these instruments was studied for two different modes of operation. The first, and easiest mode, will be that in which the instruments are located in the Spacelab pressurized module along with the crew. In this mode, the instruments will look through windows in the pressurized module. For the second mode, the instruments will be located on the Spacelab's pallet in the unpressurized Shuttle payload bay and will be operated remotely by the crew. In this mode (pallet) the instruments will be subjected to all or most of the rigors of space. A baseline shuttle sortie mission of 30° to 60° inclination, 100 to 300 nautical miles altitude, and 7-day duration was employed for this study.

The technical approach adopted by EOS during the study involved the following four major tasks:

1. A determination of the environmental limits that each instrument could withstand, along with the resources (power, cooling, etc.) required by each instrument.

2. A compilation and evaluation of the environmental conditions to which the instruments will be subjected, and the Spacelab resources available to the instruments.

3. A comparison of the instruments capabilities and needs versus the Spacelab constraints and resources.

4. A formulation of potential problems and an investigation of possible solutions.

During the study, considerable time was spent and emphasis placed on arriving at a single set, as complete as possible, of environmental constraints applicable to instruments used in the Spacelab, and the various resources which the Spacelab can provide these instruments. Toward this end, many documents and reports were reviewed. The various specifications, predictions, data, etc., contained in these reports have been combined into a single document designated as Functional Design Criteria. This document has been prepared as stand-alone data and is included as Appendix A to this report. The data condensed in this document provided for the formulation of the ground rules against which the evaluation of instrument feasibility has been accomplished. EOS recognizes the on-going dynamic nature of such a document, and we expect the design criteria to change as the Shuttle and Spacelab designs are refined and frozen. In many cases, the data from various documents is in conflict. However, EOS has tempered this data with our own space experience.

The Spacelab was the major area of concern of this study effort because the instruments would be mounted either in the pressurized module or on the pallet and would utilize Spacelab resources. However, the pallet is exposed to the Shuttle Orbiter payload bay environment and much of the environmental data used in this study (applicable to the pallet-mounted instruments) came from Shuttle Orbiter program documents.

At this point, a "road map" outlining the organization of this final report is in order. Paragraph 1.2 presents a brief summary of the overall results and conclusions obtained during the study effort. Paragraph 1.3 describes the basics of the ground-based Barium Cloud Experiment. It is assumed that the experiment will be approximately the same when conducted from the Space Shuttle. In Section 2, a description is given for the two instruments studied and documentation of the pertinent starting point information available on these instruments is provided. Section 3 summarizes our approach to the compilation of the design requirements imposed on instruments by the Space Shuttle Spacelab. This section is an introduction to the Functional Design Criteria document presented as Appendix A to this report.

Sections 4 and 5 outline potential problems of the two instruments when used in the Space Shuttle Spacelab environment. Section 6 analyzes some of these potential problems in more detail and discusses tradeoffs and recommended approaches. In Section 7, estimated costs associated with appropriate changes are summarized. The baseline for this cost estimate is the initial cost of the instruments. In Section 8, a brief look is taken at the technological advances realized since these instruments were initially designed. These continuing advancements in the state-of-the-art must be considered when NASA reaches the point of deciding upon what instrumentation should go into the sortie missions. Section 9 provides a bibliography of applicable material reviewed or consulted during the study effort. Aside from being contractually required, this listing should be beneficial to others engaged in similar study efforts.

1.2 SUMMARY OF RESULTS

A brief summary of the results obtained and conclusions reached during the study is presented below.

1. Neither instrument could be used as is for either the pressurized module or pallet environment.

2. The image intensifier camera could be used in the pressurized module environment after minor modifications, primarily in the materials area. More substantial modifications are desirable, but not required, to reduce the weight, power consumption, and cooling requirements. These same modifications are mandatory for the pallet environment. The most important of these recommended modifications is to replace the electromagnetic focusing coil with a permanent magnet. This reduces the weight of the image intensifier camera by 23.7 Kg and its power consumption by over 500 watts (60% reduction), with a commensurate reduction in cooling requirements. The only negative effect of this modification is the loss of the variable gain capability of the image intensifier. This feature, however, was never used in the field for the actual Barium Cloud Experiments. Thus, the compromise is easy to make.

3. Extensive modification and repackaging is necessary to make the TV camera suitable for the Shuttle Spacelab environment. There are many known problems in the mechanical, thermal, packaging, and high-voltage areas that must be overcome, but these problems can be solved by straightforward engineering. In essence, EOS views the present state of the TV camera as essentially a breadboard from which a space suitable

instrument would be designed. It must be emphasized (at this point) that this TV camera is an off-the-shelf item and was never intended to encounter the rigors of rocket launching or space environment. Therefore, these conclusions should not be surprising. The TV camera is an excellent performer in its intended regime.

It should be noted that EOS does not consider the instruments to be in competition with each other since each would do a unique job in the Barium Cloud Experiment.

1.3 DESCRIPTION OF THE BARIUM CLOUD EXPERIMENT

The purpose of the Barium Cloud Experiment is to perform basic research on the earth's magnetic field and convective electric field. Magnetometers carried aboard satellites and rockets have added considerably to our knowledge of the earth's magnetic field and its distortions due to the impinging solar wind. However, this approach has a shortcoming in that one cannot distinguish between spatial inhomogeneities and temporal changes as the magnetometer moves along a single trajectory. Conventional probe measurements of the electric field are inaccurate at great distances in the magnetosphere. Thus, the barium cloud technique is a unique and powerful tool for studying the distant magnetosphere.

In the early 1950s, scientists at the Max Planck Institute (MPI) for Physics and Astrophysics, in Germany, began working on an experiment to produce an ion cloud in interplanetary space as a basic research tool. In the early 1960s, scientists at the NASA Langley Research Center became interested in ion cloud techniques and in 1966 a joint effort was initiated between NASA and MPI. These joint efforts have lead to several successful experiments including a major one in September 1971. The same type of experiment has been proposed for a Space Shuttle Spacelab flight wherein the observing instruments would be located aboard the Spacelab instead of being ground based. A brief summary of the September 1971 experiment is described in the following paragraphs. We assume that future experiments will be similar.

The experiment consisted of forming a Barium Ion Cloud at five earth radii over Central America. The barium gas created a glowing white cloud visible throughout the western hemisphere. The cloud was formed by the release of about 16 Kg of a mixture of barium chips and copper oxide powder, carried in a Scout rocket launched from NASA/Wallops Flight Center. The barium vapor becomes ionized by ultraviolet radiation from the sun and emits radiation at 4554Å and 4934Å. The individual ions spiral along the magnetic field lines and produce an elongated cloud, which is viewed against a dark night sky background. Thus, the position and shape of the cloud as a function of time yield data on the earth's magnetic field and the drift motion of the cloud is a measure of the electric field. The cloud, in a sense, is being used in much the same way as iron filings to map the shape of magnetic field lines.

The cloud, when first released, is bright enough to be seen by the naked eye, but becomes invisible to the unaided eye approximately 20 minutes after barium release. The useful life of the cloud can be extended to about 2 hours by the use of low light level equipment; hence, the use of the instruments evaluated during this study.

The position of the cloud in space was determined by triangulation from widely separated earth observation sites. The Space Shuttle's orbital motion can obviously generate these triangulation data automatically.

SECTION 2

DESCRIPTION OF THE TWO INSTRUMENTS STUDIED

2.1 THE EOS IMAGE INTENSIFIER CAMERA

The EOS Image Intensifier System (figure 1) is a low light level device incorporating an f/1 objective lens, f/1 relay lens, and a 2-stage magnetically-focused image tube. The system provides the capability, when coupled with a film camera, of photographing distant objects at very low intensities. Figure 2 shows the system with the NASA-furnished camera installed. This 70 mm film camera was built by the Flight Research Division of the Geotel Corporation. Figure 3 is a simplified schematic of the total system. The objective lens gathers light emanating from the scene and focuses it on the cathode of the image intensifier tube. The photoelectrons generated by this light are electromagnetically focused onto the anode (or phosphor) of the image tube and generate more photons than were initially incident on the photocathode, resulting in a light gain. Two such stages are used to give a larger light gain.

The relay lens transfers the phosphor image to the film plane of the camera. The camera shutter can remain open for as long a period as desired to allow long integration times for very faint objects. The limitations to the integration time are: (1) relative motion between the object and the camera, resulting in image blur, or (2) film fogging due to sky background or due to dark emission by the photocathode.

An electromagnetically focused image tube was chosen for the system because of superior resolution and distortion characteristics, compared to the simpler electrostatically focused tube.

2.1.1 MAJOR COMPONENTS

The EOS System consists of the following major components. (See figures 4 and 5.

a. Objective Lens

   The f/1 objective lens is a high speed refractive telescope objective, designed for the S-20 spectral region and optimized for 4554 Å and 4934 Å. The objective lens is mounted in a housing that can be adjusted (tilted) to compensate for nonparallelism between the input face and output face of the image intensifier tube. Three sets of coil springs are provided to preload the mechanism to prevent movements that would cause a focus change.

b. Filter Tilter

   The filter tilter and iris assembly is fitted over the objective lens housing and is retained with three setscrews. The NASA-furnished filter is held in a mechanism that can be externally adjusted to tilt the filter 15 degrees with respect to the system optical axis. This

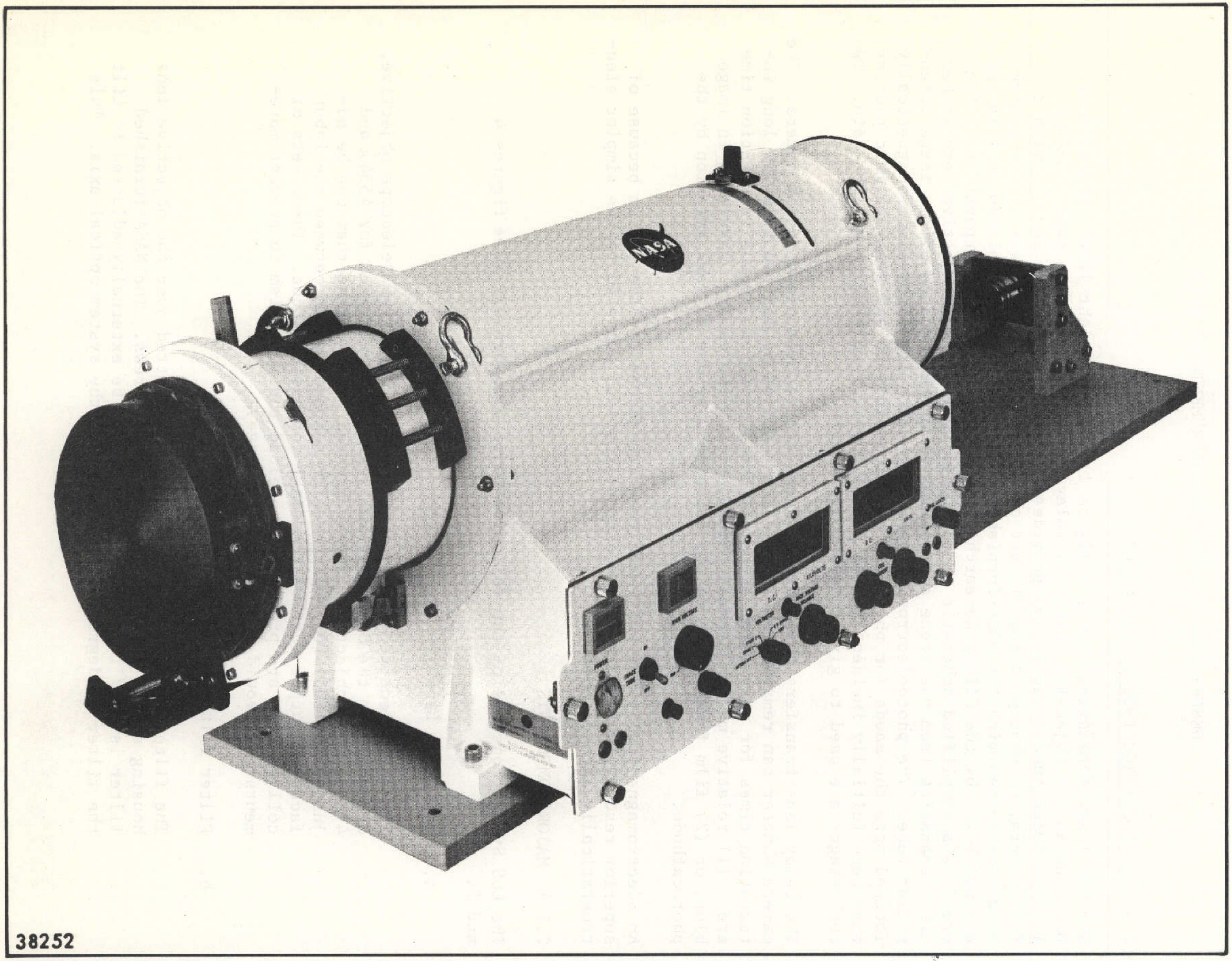

Figure 1. EOS Image Intensifier System

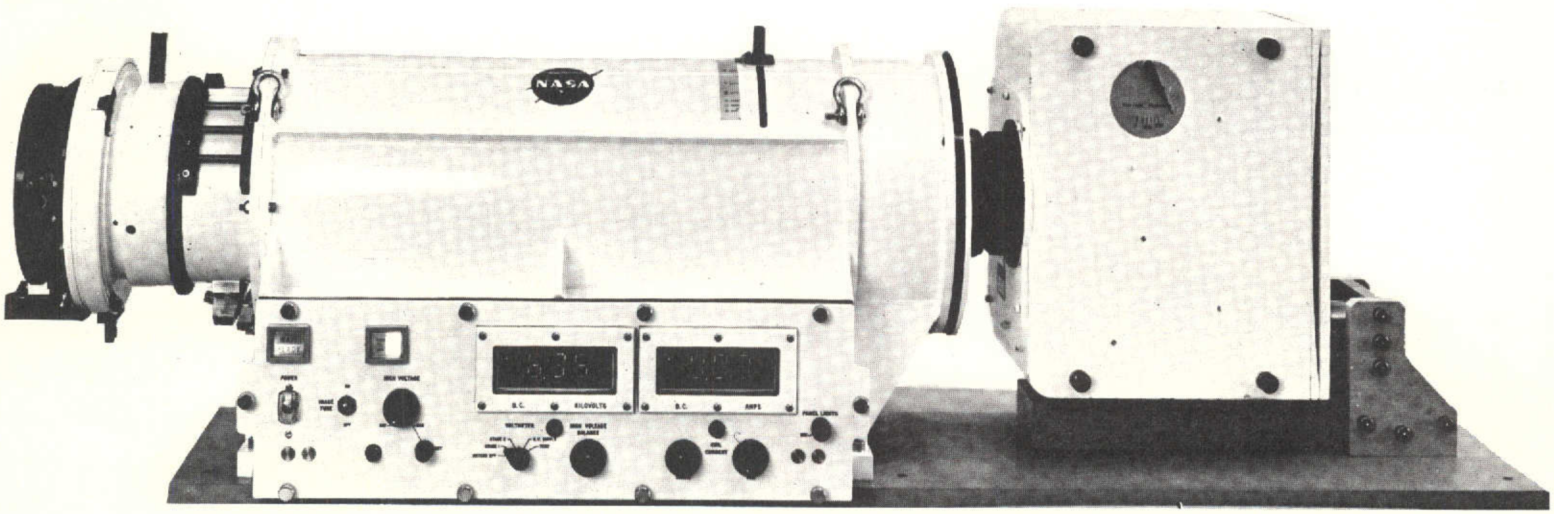

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Figure 2. Image Intensifier System with Camera

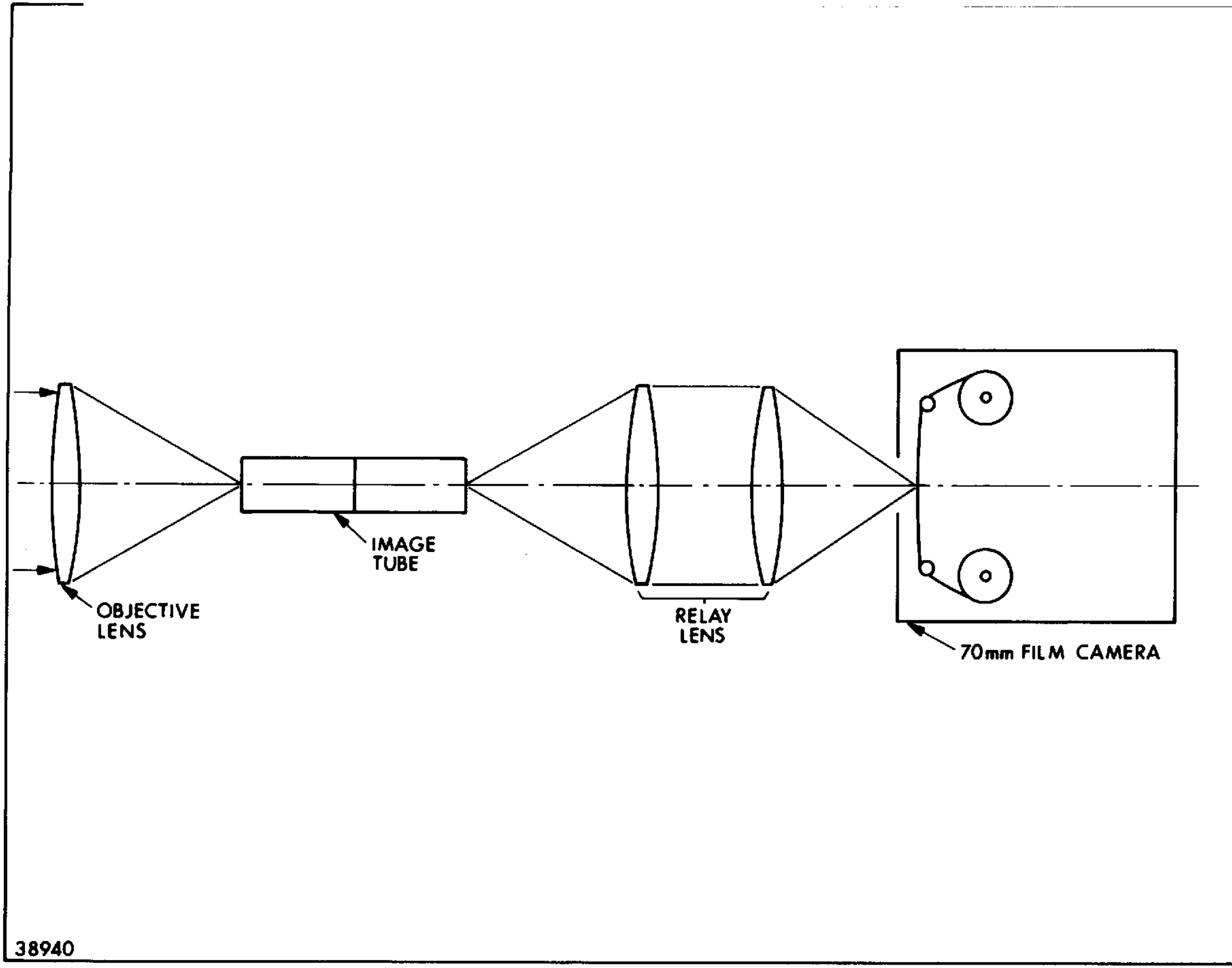

Figure 3. Simplified System Schematic

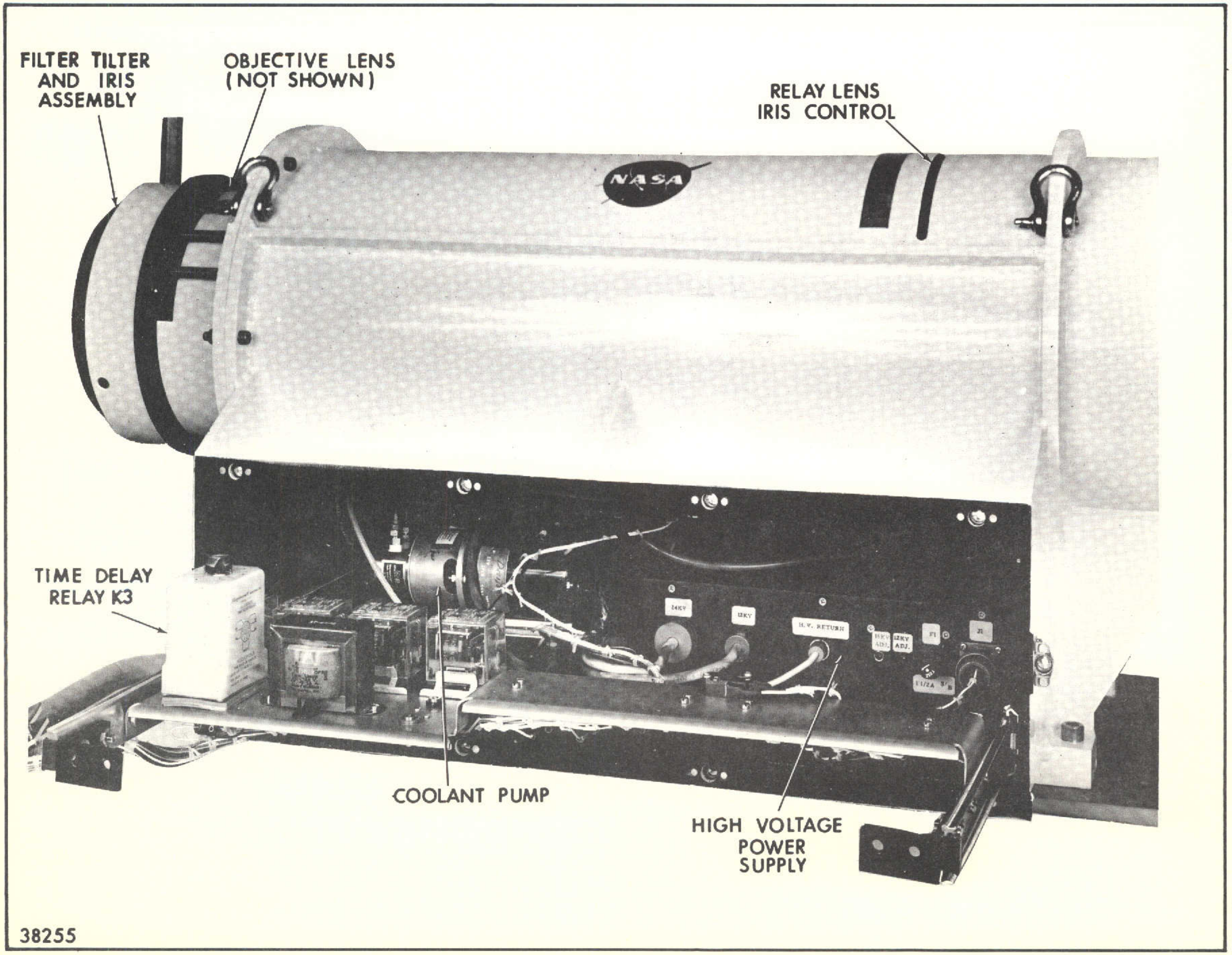

Figure 4. Image Intensifier System Component Locations (Left Side)

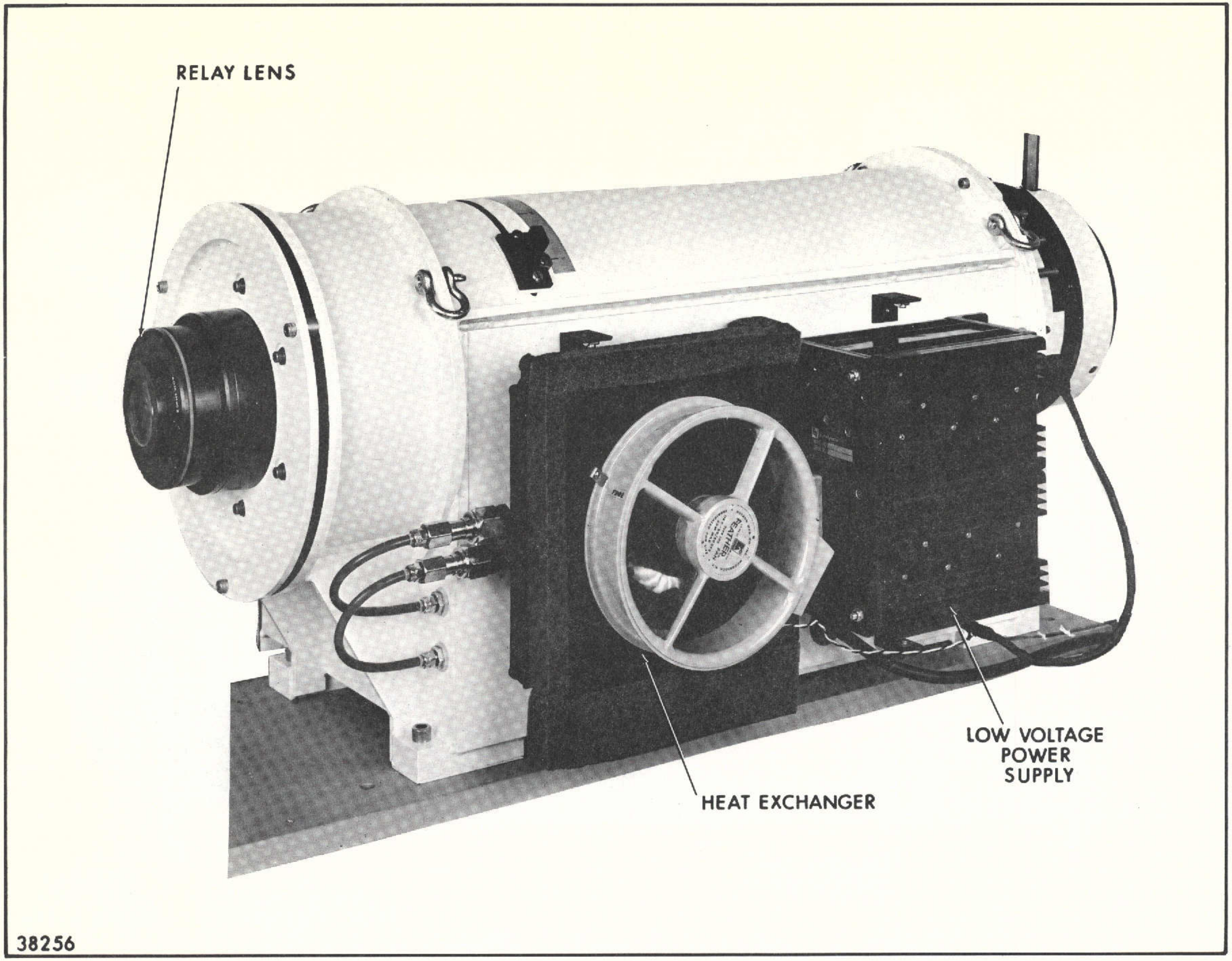

Figure 5. Image Intensifier System Component Locations (Right Side)

provides a method to fine tune the optical passband. The iris diaphragm is actuated with an external knob to stop down the lens as required. F/stop numbers are provided to show the setting of the iris.

c. Image Intensifier Tube and Focusing Coil

The image tube is a 40 mm two-stage magnetically focused device manufactured by RCA. The cathode has an S-20 spectral response and the output is a P11 phosphor. Tube resolution on-axis is 50 lp/mm and 45 lp/mm at the edge. The tube will operate at either single node or double node, and the node of operation and image tube focusing is controlled with a large 400-gauss electromagnet surrounding the tube.

d. Relay Lens

The f/1 relay lens transfers the image from the image tube to the film plane of the camera. The relay lens operates at a true f/1 (0.5 numerical aperture) at a magnification of 1:1. An iris diaphragm is built into the relay housing and an externally actuated knob can be adjusted to any desired f/number from f/1 to f/16. The f/number markings are provided to show the setting of the iris diaphragm.

e. Power Supplies

The system contains two power supplies. The high voltage supply powers the image intensifier tube and provides 12 kV per stage or 24 kV total. The focus coil power is provided by a low voltage supply. The coil current is adjustable from 0.9 to 3.8 amperes. Normal operation requires about 1.4 amperes for single node operation and 2.8 amperes for double node operation.

f. Cooling System

The cooling system is composed of a pump, heat exchanger, fan, cooling coil (potted around the focus coil), and connecting plumbing. The system was designed to operate at temperatures up to 323^{o}K (122^{o}F) by protecting the image tube from heat generated by the focus coil. The cooling system also is utilized to reduce the operating temperature of the low voltage power supply. A baffled cover is used to deflect some of the airstream from the fan to the power supply.

g. Main Housing and Control Panel

The main housing is a solid cylindrical structure to which the basic system components are mounted. The power supplies and associated electronics are mounted in a drawer which in turn is mounted on slides to the main housing. Components such as switches, meters, and potentiometers are located on a control panel on the front of this drawer. Two digital readouts on the control panel allow the high voltage applied to the image tube and the current applied to the focusing coil to be monitored.

h. Mounting Plate

The image intensifier system is mounted on a solid aluminum baseplate, which also accepts the film camera. This baseplate helps maintain the proper alignment and focus of the overall system. In NASA's use of the system, the baseplate is attached directly to a tracker mount.

There are no electrical interfaces between the EOS system and the film camera.

2.1.2 MAJOR CHARACTERISTICS

Table I shows the major system characteristics and table II reflects the nominal performance characteristics. Typical test data for an RCA image intensifier tube is given in table III. The calibration of the nonparallelism between the input and output windows is required to properly align the objective lens with the image tube face.

TABLE I - MAJOR SYSTEM CHARACTERISTICS
EOS IMAGE INTENSIFIER SYSTEM

Item	Parameter	Specification
System	Largest Diameter	0.51m (20 in.)
	Length (without baseplate)	1.02m (40 in.)
	Weight	108 Kg (238 lb)
	Field of View	14.2° with 38 mm nominal diameter image tube
	Photographic AWAR (area weighted average resolution)	30 lp/mm on SO-243 film
	Focus Range	1.5m (5 ft) to infinity
f/1 Objective Lens	Weight	8.5 Kg (18.8 lb)
	Diameter	0.175m (6.9 in.)
	Length	0.246m (9.7 in.)
	Focal Length	153.2 mm
	Spectral Correction	S-20
	f/number	f/1
	T/number	T/1.16
	BFL	3 mm
	Field of View	$\pm 7.5^{\circ}$
	Format Diameter	40 mm

TABLE I - MAJOR SYSTEM CHARACTERISTICS
EOS IMAGE INTENSIFIER SYSTEM (Concluded)

Item	Parameter	Specification
f/1 Relay Lens	Diameter	0.55m (21.6 in.)
	Length	0.165m (6.5 in.)
	Weight	13.4 Kg (29.5 lb)
	Format Diameter	40 mm
	Magnification	1 to 1
	f/number	f/1 (0.5 numerical aperture on each side of relay)
	Spectral Coverage	P11 Phosphor
	f/Stop Range	f/1 to f/16
Image Tube (RCA)	Diameter (potted)	0.108m (4.25 in.)
	Length (potted)	0.184m (7.25 in.)
	Weight (potted)	1.25 Kg (2.75 lb)
	Resolution	50 lp/mm on-axis

TABLE II - NOMINAL SYSTEM PERFORMANCE CHARACTERISTICS
EOS IMAGE INTENSIFIER SYSTEM

Parameter	Specification
Objective Lens	
Effective Focal Length	153.2 mm
f/number	f/1
Transmission	73%
T/number	T/1.16
Field of View	$\pm 7.5^{\circ}$
Distortion	-1.3% at 7.2° Field Angle
Relative Illumination	68% at 7.2° Field Angle 64% at 7.5° Field Angle
Spectral Coverage	S-20; 4934Å; 4954Å
Relay Lens	
Magnification	1 to 1
f/number	f/1 (0.5 numerical aperture on each side of relay)
Format Diameter	40 mm
Distortion	< 0.5%
Transmission	58%
Spectral Coverage	P-11 Phosphor
System	
Field of View	$\pm 7.2^{\circ}$ with 38 mm nominal diameter image tube
Focus Range	1.5m (5 ft) to infinity
Resolution (axial)	35 to 42 lp/mm on Plus-X film with objective lens and relay lens operating at f/1; image tube limited at 45 to 50 lp/mm with the relay lens aperture reduced to approximately f/1.6

TABLE III - TYPICAL IMAGE TUBE DATA
(RCA TUBE TYPE C33011)

Parameters	Measured Data
Sensitivity	
Luminance (to 2870° tungsten light)	
Unfiltered	175.0 microamps/lumen
Corning 2418 (red) filter	55.0 microamps/lumen (on filter)
Corning 5113 (blue) filter	10.0 microamps/lumen (on filter)
Radiant	
4200 angstrom	85.0 milliamps/watt
5000 angstrom	60.0 milliamps/watt
7000 angstrom	25.0 milliamps/watt
Operating Characteristics	
Radiant energy gain	5187 (watts/watt at peak sensitivity)
Input equivalent of screen background	6.9×10^{-15} watts/sq cm
Non-parallelism between input/output windows	1.27×10^{-4}m (0.0050 in.) over 40 mm diameter

2.2 THE WESTINGHOUSE SEC TV CAMERA

The Westinghouse Model STV-614 television camera (figure 6) is a low light level camera which incorporates an intensifier secondary electron conduction (SEC) television pick-up device. This camera is intended for general commercial applications where low-lag (low residual signal) and high sensitivity are required.

2.2.1 GENERAL DESCRIPTION

The camera is contained in three interconnected units. These units are; the basic sensor head, which contains the intensifier SEC tube and associated deflection assembly and electronics; the camera control unit, which houses the primary power supply and video processor; and the synchronizing signal generator.

2.2.1.1 Sensor Head

The primary component contained within the sensor head (figure 7) is the intensifier-SEC tube combination and the SEC deflection assembly. The Westinghouse WL-3200 intensifier SEC camera tube is a fiber-optically coupled 25 mm SEC tube and a WL-30677 40 mm input, 25 mm output image intensifier. The tube, deflection assembly, and video preamplifier, are contained in a subassembly mounted to a slide rail (figure 8).

The cylindrical housing (fabricated of glass-epoxy with a molded-in electromagnetic shield) provides electrical insulation to the image section of the tubes. The photocathode of the tube may reach a potential of -23 kV and the anode a potential of -8 kV under high-sensitivity conditions.

A synchronized ac to dc converter supplies the high voltage dc power to the image tubes. The high-voltage section, the module developing voltages in excess of 400 volts, is encapsulated in RTV and contained within an aluminum can.

Two printed circuit (PC) boards contain circuits for SEC horizontal (frame) deflection, blanking, and video signal amplification. The PC boards, one located on each side of the image tube assembly, plug into a socket-card retainer assembly.

2.2.1.2 Camera Control Unit

The camera control unit (figures 9 and 10) consists of a chassis-mounted power supply transformer and filter, and a printed circuit-card file. The 10 cards provide video processing, voltage regulation, and automatic or manual integration functions. The circuit cards are retained by nylon slides on two sides and function off the connector plug.

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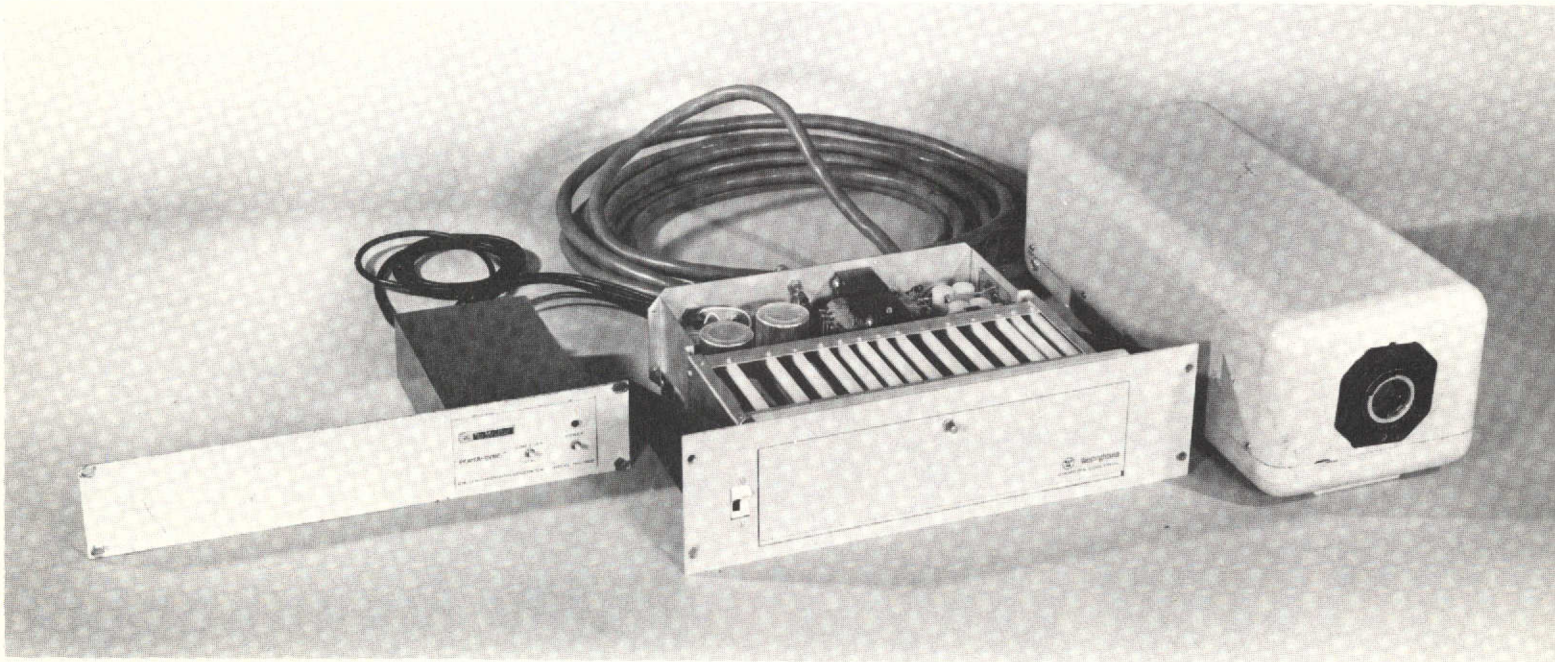

Figure 6. Westinghouse SEC TV Camera

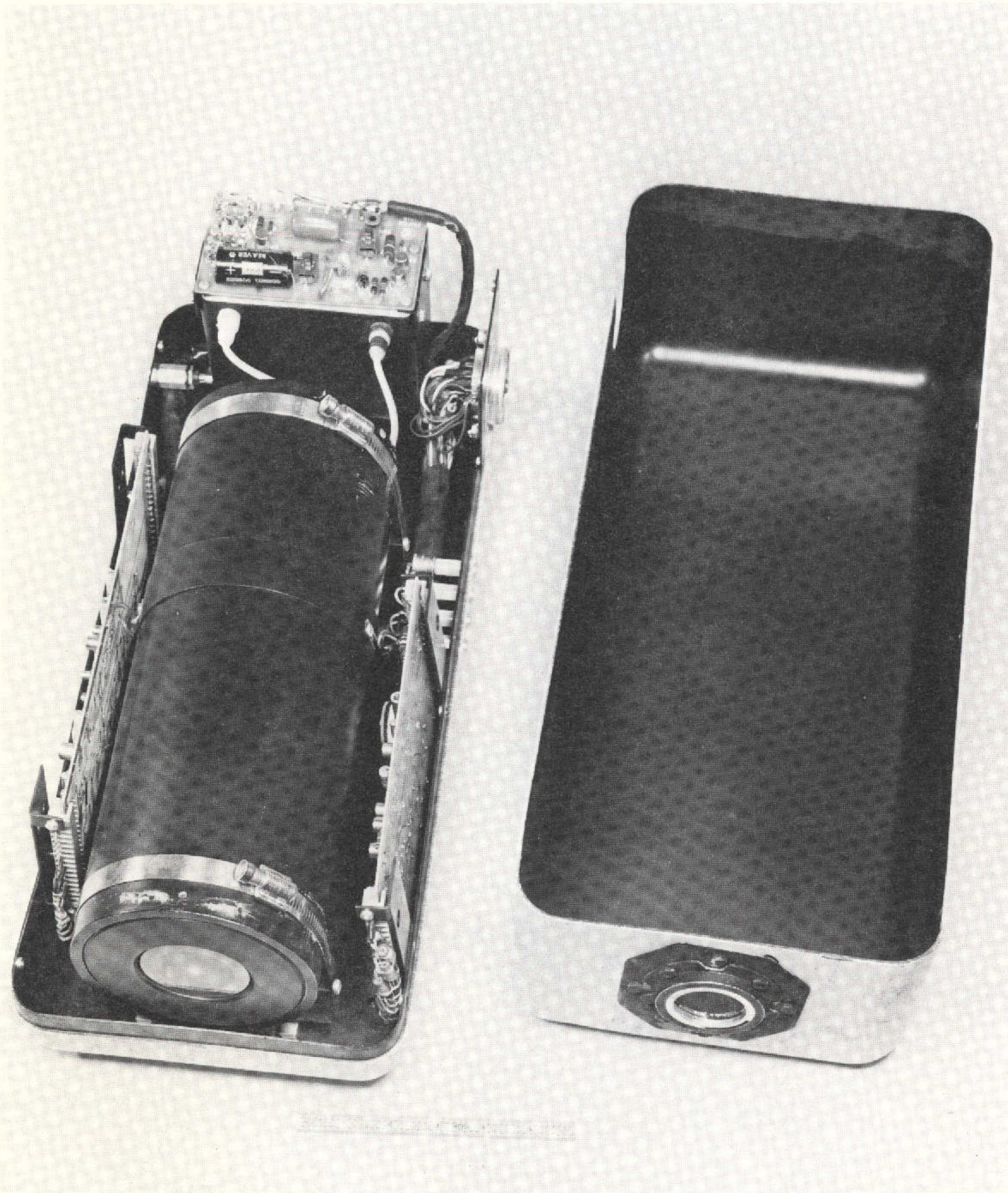

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Figure 7. Camera Head with Cover Removed

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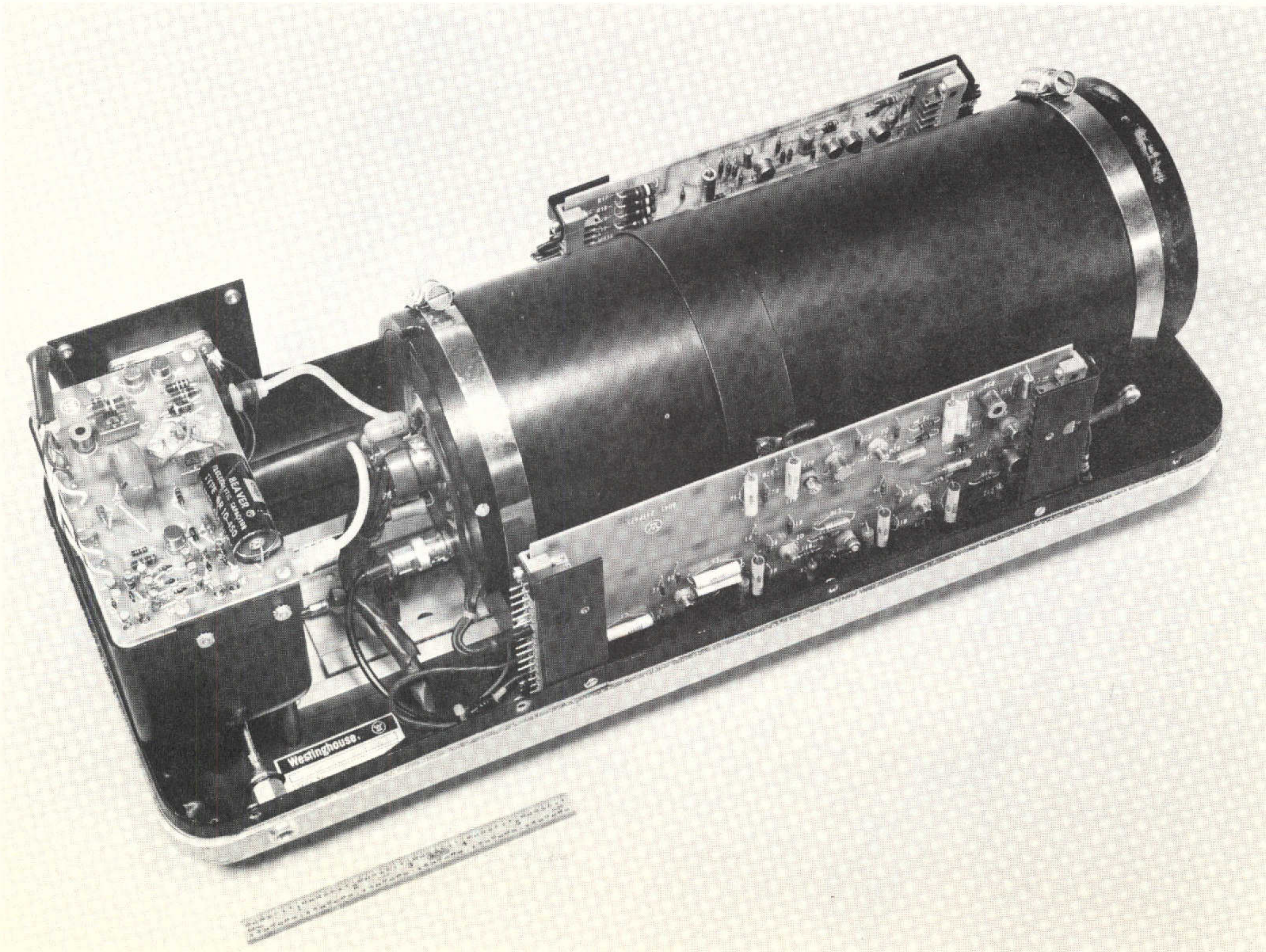

Figure 8. TV Tube and Electronics

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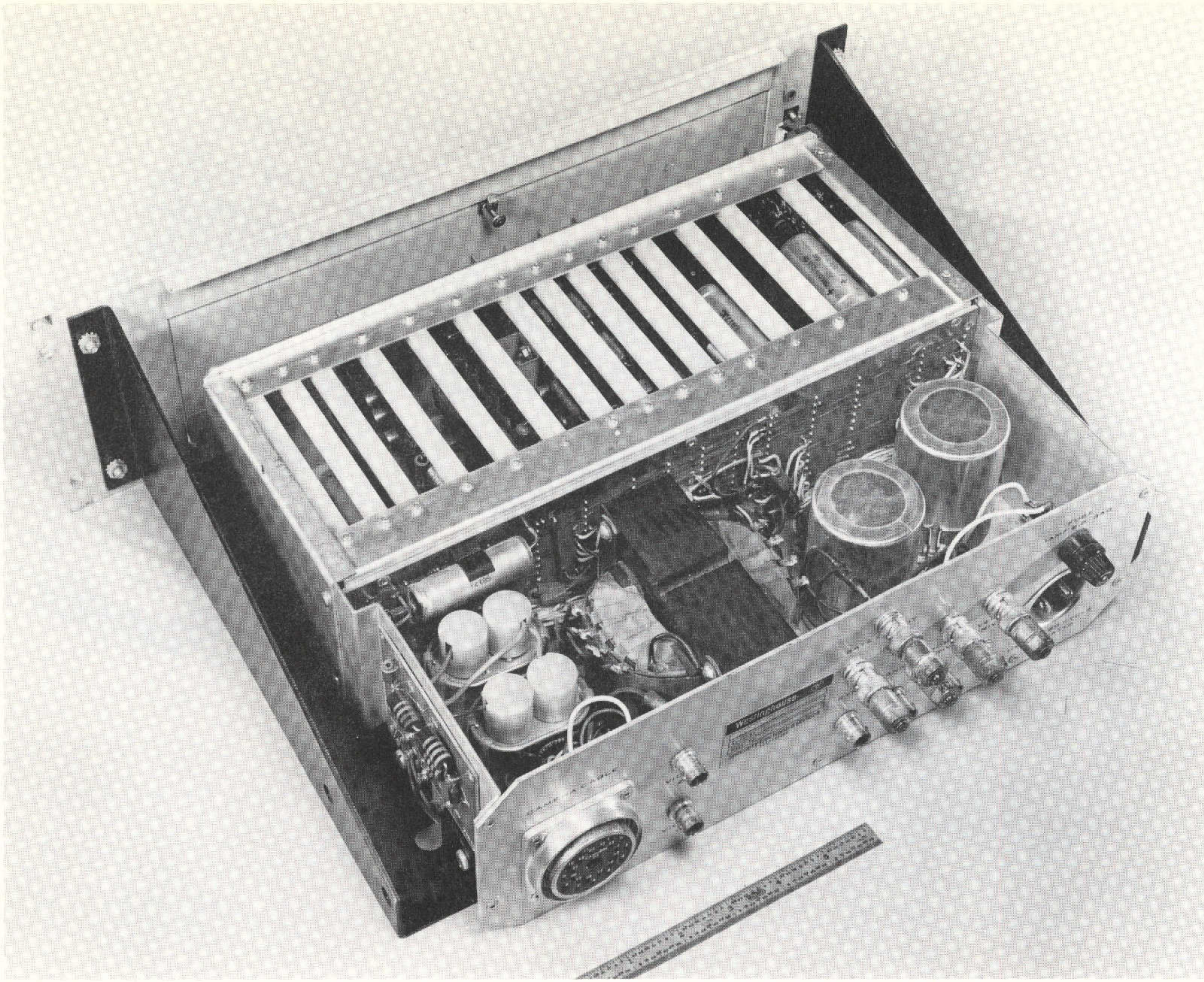

Figure 9. Camera Control Unit, Front

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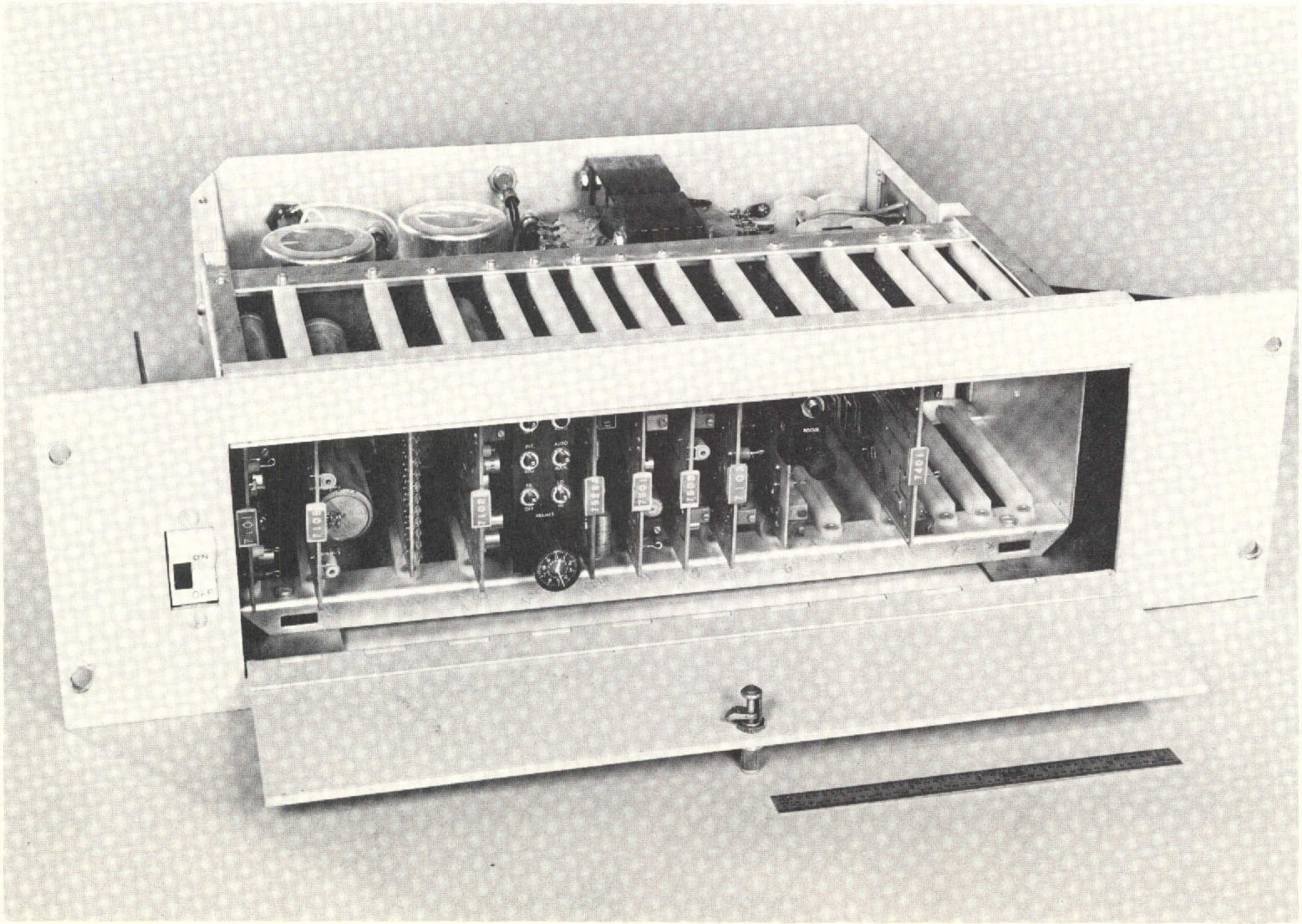

Figure 10. Camera Control Unit, Rear

The power supply operates from 115V ac or 225V ac, 50 or 60 Hz. A power transformer provides plus and minus low voltages as well as the high voltage to the power conditioning circuits, which are contained, for the most part, on the circuit cards. Physically-large filter capacitors and some power transistor regulators are also chassis-mounted.

There is space and interconnections provided for the synchronizing generator to be located within the camera control unit. The four coaxial cables, which provide synchronizing signals to the camera from the separate TeleMation synchronizing generator, could be deleted and the system simplified if the synchronizing generator functions were located within the camera control unit.

A multiconductor cable electrically connects the control unit to the camera head. Functions carried by the cable include SEC, G-5, G-4, G-3, G-2 potentials, heater power, blanking, vertical deflection, horizontal drive, and low voltages for circuit operation.

2.2.1.3 Synchronizing Generator

The TeleMation Model TSG 1000 EIA synchronizing generator provides horizontal and vertical drive, composite blanking, and composite synchronization to the camera control unit. A separate 115V ac power supply provides the dc voltages to the generator electronics. The synchronizing generator provides the option for referencing the generator to the power line frequency or to referencing the generator to a crystal stabilized oscillator frequency. The crystal oscillator mode is best suited for the space application where there may not be 60 Hz power.

SECTION 3

FUNCTIONAL DESIGN REQUIREMENTS OF THE SPACE SHUTTLE SPACELAB

To evaluate the suitability of the two instruments, we needed to know the requirements the instruments must meet. Thus, the first task at the start of our study efforts was to compile and evaluate the constraints imposed by the Shuttle Spacelab, including the resources that the Spacelab could offer to potential instruments. This task turned out to be perhaps the major task of the entire study. In pursuing this goal, we obtained and digested many reports from NASA and from other groups, although we realize that we did not obtain all pertinent reports. In Section 9 there is a bibliography of material reviewed during the course of this study.

In some cases, the environmental constraints predicted by various NASA agencies were in conflict, as should be expected from the present state of the Space Shuttle Program. During the course of this study, two European consortiums were engaged in definition/design studies vying for a follow-on contract for the development and construction of the Spacelab. Much of the details of their design approaches were either not generated or were unavailable due to the competitive nature of their studies. Therefore, much of the design data utilized in this study evolved from NASA's in-house studies of the Sortie Laboratory concept. NASA's Marshall Space Flight Center (MSFC) was the major source of applicable data regarding Spacelab (nee Sortie Lab) environmental constraints and available resources. NASA's Johnson Space Center (JSC) was the source of some applicable data regarding environmental constraints for the unpressurized pallet.

In cases of conflicting predictions, the data have been tempered with our own experience in space hardware. In cases where there is no mention in the documents of a particular requirements (fungus, for example) we have relied on existing military standards. This may result in a constraint that is too severe, and, if it is, it is hoped the constraint will be lessened by additional study. Otherwise, the use of existing instruments will be greatly curtailed. Our guideline is that the design requirements should be as tolerant as possible consistent with the safety of the Shuttle. The reliability of the experiment instrumentation is not as paramount as it was in other space missions.

For our study efforts, we organized the design requirements into seven different phases:

- Design
- Transportation
- Storage
- Prelaunch
- Launch
- Orbit
- Reentry and Landing

We have condensed our findings into a stand-alone document entitled Functional Design Criteria. This document is included as Appendix A and includes the pertinent references for the data used in its generation.

The Functional Design Criteria document should be viewed as a dynamic document, with changes and refinements expected as the Space Shuttle program moves toward final design.

SECTION 4

POTENTIAL PROBLEMS OF THE IMAGE INTENSIFIER CAMERA

After the establishment of the functional design criteria which are presented in Appendix A, an evaluation was made on the ability of the image intensifier camera system to meet the design criteria for the pressurized module and pallet environments. The evaluations in this report were made on (1) potential problems, (2) recommended changes, and (3) tradeoffs. Table IV provides the mechanical description and requirements of the camera system. The following paragraphs summarize the potential problems.

TABLE IV

DESCRIPTION OF IMAGE INTENSIFIER CAMERA SYSTEM

Item	Image Intensifier System	Camera	Entire System
Size	1.02m (40 in.) Length	0.25m (10 in.) Length	1.27m (50 in.) Length
	0.72m (28.5 in.) Width	0.30m (12 in.) Width	0.72m (28.5 in.) Width
	0.41m (16 in.) Height	0.38m (15 in.) Height	0.41m (16 in.) Height
Weight	108 Kg (238 lb)	23 Kg (50 lb)	158 Kg (349 lb)*
Electrical	105 to 125V ac	Motor: 115V ac	115V ac, 60 Hz
	57 to 63 Hz	60 Hz, 2 Amp	12 Amp Max.
	10 Amp Max.	Clutch: 24V dc	24V dc, 0.19 Amp
		0.19 Amp	
Heat Rejection (Watts)	645	Motor: 180 Clutch: 5	830

* Includes baseplate and dovetails

4.1 PRESSURIZED MODULE ENVIRONMENT

4.1.1 OUTGASSING

All components will under normal operational conditions not be exposed in vacuum. If an accidental depressurization occurs, the nonmetallic materials will outgas and suffer weight loss in the hard vacuum of space. This loss can result in changes in the mechanical or electrical properties of the materials. The volatile outgas constituents may condense on optical surfaces which might cause a loss of resolution or may violate the class 100,000 cleanliness requirement in the module. Therefore, the stringent requirements of MSFC 50M02442 should be used wherever possible in the selection of nonmetallic materials. Materials, such as RTV-102 and RTV-108, should be replaced with lower outgassing materials.

4.1.2 AGE CONTROL FOR SYNTHETIC RUBBER PARTS

After twelve (12) quarters or three (3) years, all installed synthetic rubber parts must be replaced in accordance with MSFC-STD-105. A service life of six (6) years was assumed for this study because the first flight of the Spacelab is scheduled in 1980. The cost impact will be the cost for the replacement of the parts.

4.1.3 FUNGUS-INERT MATERIALS

Fungus-inert materials are listed in MIL-STD-454. Other materials not listed but susceptible to fungi will have to be tested in accordance with MIL-STD-810B. Examples of fungus-susceptible materials are lubricants, synthetic rubber, etc.

4.1.4 MAGNETIC MATERIALS

There are some magnetic materials on the system, such as 400 series CRES, which should be replaced with non or low-magnetic materials. There are some undefined 300 series CRES used. In the annealed condition 329 CRES is magnetic.

4.1.5 CONTAMINATION CONTROL

The carbon from the wear of the brushes on the motors was not a trivial problem in previous operation of the image intensifier system. These carbon particles would degrade the class 100,000 environment. The motors should be replaced by ones with hermetically sealed enclosures.

4.1.6 SPACELAB RESOURCES

With an electrical power requirement of approximately 830 watts, the system was never optimized for minimum power consumption. The Spacelab has available 4.0 kW average power for all the experiments, which means this system alone would consume 20% of the available power. Therefore, design changes should be made to minimize the power consumption.

4.1.7 SAFETY

With 24 kV in the high voltage supply, a caution label is required on an exterior surface.

4.1.8 FACTORS OF SAFETY

The structural integrity of the system has not been computed relative to its ability to meet the Spacelab factors of safety requirements. However, prior to flight aboard the NASA Ames Research Center (ARC) CV-990 aircraft, a stress analysis was performed to assure conformance with the safety and airworthiness requirements of the ARC airborne research program. Additional stress analysis will be required.

4.1.9 ELECTROMAGNETIC CONTROL

The electromagnet surrounding the image tube produces a 400 gauss magnetic flux which may produce undesirable Electromagnetic Interference (EMI). To attenuate the emission, a high permeability magnetic material can be employed to shield the magnetic flux.

4.1.10 EXPLOSIVE ATMOSPHERE

The enclosures for the system should be sealed to prevent gas leakage into the system.

4.1.11 LAUNCH VIBRATION

The system has not been qualified to any vibration levels. A stress analysis, as mentioned in paragraph 4.1.8, would be required, and vibration tests would verify the stress analysis. If there are difficulties in meeting the structural requirements, the system could be shock mounted to attenuate the damaging dynamic inputs.

4.1.12 PRESSURE

A vacuum system is available in the module. Therefore, the vacuum pump in the camera may be eliminated, after a tradeoff study is made on cost and installation/integration.

4.1.13 LANDING ACCELERATION

The 9 g crash landing acceleration should be analyzed for the ultimate condition where the system must not fail in such a way to pose a hazard to the crew. The system does not have to be operational.

4.1.14 THERMAL CONTROL

The allocation for heat rejection of the Spacelab experiments is approximately 13,600 Btu/hr out of a maximum of 21,500 Btu/hr for the total Shuttle Spacelab system. The image intensifier rejects approximately 2776 Btu/hr or 20% of the allocation for the experiments. As stated in paragraph 4.1.6, design changes should be made to minimize the power consumption which in turn will reduce the heat rejection.

4.1.15 WEIGHT

The image intensifier camera system was designed for ground operations. No efforts were made to minimize the weight of the system. Therefore, the system should be investigated to find areas where weight can be reduced without increase in cost.

4.2 PALLET ENVIRONMENT

The inability for the image intensifier camera system on the pallet to meet the design criteria is the same as for the pressurized module, with the additional points listed below.

4.2.1 OUTGASSING

Since the instrument must operate in a vacuum, the outgassing requirements for nonmetallic materials must meet MSFC 50M02442.

4.2.2 THERMAL CONTROL

In space the convective cooling system on the image intensifier system will not work. A design change to a radiation and/or conduction cooling system is required. The system is designed to operate up to 323°K (122°F) by the cooling system. If this temperature is exceeded, the system will be shut down by a thermoswitch.

4.2.3 TEMPERATURE

The temperature environments are:

On-orbit: 200° to 339°K (-100°f to +150°F)

Reentry: 200° to 366°K (-100°f to +200°F)

These temperatures are for the wall of the Shuttle Orbiter payload bay surfaces.

The image intensifier system is designed to survive a nonoperating temperature range from 253° to 343°K (-4.3° to 158°F). There is no information on the camera system as to its temperature limits. Therefore, design changes are required to make the entire system survive the pallet temperature environments.

4.2.4 PRESSURE

The vacuum platen in the film camera, used to stabilize and hold the film stationary and flat, will not work in a vacuum environment. A mechanical device will have to be designed to perform the same function. Probably there are existing cameras, from previous NASA space experiments that can do the job.

The 24 kV high voltage power supply in the image intensifier system may be damaged due to arcing or corona breakdown in a vacuum environment.

4.2.5 RADIATION

The radiation environment of space (including the charged particle fluxes of electrons and protons) is one of the principal concerns to optical materials. The materials may expect their greatest potential damage from this source. Absorption of radiation causes a decrease in transmission by the formation of color centers. The filter in front of the objective lens is exposed to space. No serious damage is anticipated because there will be a lens cover over the filter when the system is not in use. The lens cover would be removed by remote control.

4.2.6 METEOROIDS

The probability of meteoroid damage is very small. The average meteoroid flux for a 300-nautical mile orbit is calculated to be:

Mass = 10^{-6} gm Flux = 7×10^{-8} particle/m^2/sec

Mass = 1 gm Flux = 7×10^{-15} particle/m^2/sec

4.2.7 REMOTE OPERATION

The high optical speed of the objective lens and relay lens used in the image intensifier system results in a very short depth of focus for the lenses. The long length of the system and its internal heat sources make it necessary to focus the instrument after it has reached thermal equilibrium and shortly before its actual use. Each lens must be focused within a tolerance of about $\pm 2.54 \times 10^{-5}$m ($\pm$0.001 inch).

In the pallet environment, the system would have to be remotely focused. Although in principle this could be accomplished by adding a focus drive motor to both the objective lens and the relay lens (or film camera), in practice this would be a cumbersome and expensive approach. A TV camera would have to be added to look at the image being presented to the film, and some type of target projector would be necessary to present a target to the objective lens (unless a star field would be continually available). Extra Vehicular Activity (EVA), although undesirable, is the only presently envisioned means of satisfactorily focusing the lenses in the existing image intensifier system.

SECTION 5

POTENTIAL PROBLEMS OF THE SEC TV CAMERA

The SEC TV camera was evaluated relative to the functional design criteria given in Appendix A. As should be expected, the camera's potential problems are similar to those of the image intensifier camera discussed in Section 4. Thus, some paragraphs within this section of the report will simply refer to appropriate paragraphs in Section 4.

Table V gives the mechanical description and power requirements of the SEC TV camera system.

TABLE V - DESCRIPTION OF WESTINGHOUSE SEC TV CAMERA

Item	Camera Head	Control Unit	Entire System
Size: Length	0.28m (11 in.)	0.38m (15 in.)	Not connected
Width	0.18m (7 in.)	0.31m (12.25 in.)	
Height	0.13m (5 in.)	0.14m (5.5 in.)	
Weight	10.62 Kg (23.41 lb)	9.03 (20.52 lb)	27.41 Kg (60.43 lb)*
Electrical	---	---	115V ac ±10% 60 Hz 1 Amp Max
Heat Rejection (watts)	---	---	92

*Includes connecting cable and synchronizing generator

5.1 PRESSURIZED MODULE ENVIRONMENT

5.1.1 OUTGASSING

Refer to paragraph 4.1.1. A list of materials is not available at the time of this study.

5.1.2 AGE CONTROL FOR SYNTHETIC RUBBER PARTS

Refer to paragraph 4.1.2.

5.1.3 FUNGUS-INERT MATERIALS

Refer to paragraph 4.1.3.

5.1.4 MAGNETIC MATERIALS

A list of materials was not available at the time of this study.

5.1.5 FACTORS OF SAFETY

The structural integrity of the system has not been computed relative to its ability to meet the Spacelab factors of safety requirements. A stress analysis is required.

5.1.6 ELECTROMAGNETIC CONTROL

The 40 gauss magnetic flux around the SEC TV tube and the power transformer in the power supply may produce undesirable electromagnetic interference. The magnetic flux can be shielded by a high-permeability magnetic material.

5.1.7 EXPLOSIVE ATMOSPHERE

Refer to paragraph 4.1.10.

5.1.8 LAUNCH VIBRATION

Refer to paragraph 4.1.11.

5.1.9 LANDING ACCELERATION

Refer to paragraph 4.1.13.

5.2 PALLET ENVIRONMENT

The inability of the SEC TV camera system on the pallet to meet the design criteria is the same as for the pressurized module with the additional points presented below.

5.2.1 OUTGASSING

Refer to paragraph 4.2.1.

5.2.2 THERMAL CONTROL

The camera control unit is convection cooled. A design change to a radiation and/or conduction cooling system is required.

5.2.3 TEMPERATURE

The temperature environments are:

On-orbit: 200° to 339°K (-100° to $+150^{\circ}$F)

Reentry: 200° to 366°K (-100° to $+200^{\circ}$F)

The camera head was designed to operate from 263° to 328°K (14° to 131°F) The control unit was designed to operate from 283° to 313°K (50° to 104°F). Therefore, design changes are required to make the system survive the pallet temperature environments.

5.2.4 PRESSURE

The system is qualified to an elevation of 762 m (2500 feet) with 20% to 90% relative humidity. In a vacuum the electrical system may be damaged by arcing and corona breakdown.

5.2.5 RADIATION

Refer to paragraph 4.2.5.

5.2.6 METEROIDS

Refer to paragraph 4.2.6.

5.2.7 REMOTE OPERATION

In the present equipment the objective lens must be focused manually. Extra Vehicular Activity (EVA) could handle the task, but this is an undesirable solution. A focus drive motor would seem to be a reasonable approach, at some increase in the complexity of the system.

SECTION 6

TRADEOFFS, ANALYSES, AND RECOMMENDED MODIFICATIONS

This section examines in more detail the potential problems outlined in Sections 4 and 5 for the image intensifier and SEC TV systems, respectively. Tradeoffs are discussed and modifications are recommended.

Two different modes of operation for the instruments were considered:

Case I - The instruments are located in a pressurized (14.7 psia) module and will look at space through viewports. The crew will have access to the instruments during the mission.

Case II - The instruments are located on an instrument platform in the unpressurized payload bay and will be operated remotely from the pressurized module. If necessary, the instruments will be wholly or partially enclosed in an environmental shell to maintain the necessary operating environment for the instruments.

A baseline Shuttle sortie mission of 30 to 60 degrees inclination, 100 to 300-nautical miles altitude, and 7-day duration is used for the study.

As previously discussed, a set of design criteria was compiled from the reports provided by NASA and other documents. These design criteria are listed in Appendix A and include the environments for the pressurized module and the pallet. Table VI summarizes the most severe environments. The qualification environments for the two instruments are given in table VII. It is noted from table VII that both instruments are not qualified as-is for a Shuttle sortie mission from a mechanical standpoint. An overall evaluation of the instruments is shown in tables VIII and IX summarizing the work that would be required to meet the design criteria of Appendix A. The columns are not cumulative from left to right.

6.1 MECHANICAL CONSIDERATIONS

From a mechanical standpoint both cameras are not feasible in their as-is condition for the Shuttle sortie mission. These cameras are designed for ground applications. With design modifications they can be made to withstand the space environment.

6.1.1 STRUCTURAL ANALYSIS

The structural analysis consisted of determining the dynamic responses of the camera systems to the launch vibration levels given in Appendix A.

The maximum responses to the instruments under sinusoidal and random vibrations occur at the natural frequencies of the system and components. Without performing a detail structural analysis on the instruments, the acceleration response

TABLE VI - SPACELAB ENVIRONMENTS

(Reference Appendix A)

Environment	Pressurized Module	Pallet
Sinusoidal Vibration	3-8.5 Hz @ 0.80 in. Da Disp. 8-35 Hz @ 3.0g peak 35-50 Hz @ 1.0g peak	Same as pressurized module
Random Vibration	9.1g rms	12.2g rms
Shock	TBD	TBD
Temperature	297^{o} $\pm 3^{o}$K (75^{o} $\pm 5^{o}$F)	On-Orbit: 200^{o} to 339^{o}K (-100^{o} to $+150^{o}$F) Re-Entry: 200^{o} to 366^{o}K (-100 to $+200^{o}$F)
Pressure	1×10^{5} N/m^{2} (14.7 ±0.2 psia)	10^{-5} torr or less
Acoustics	138 dB	145 dB
Acceleration	Booster End Burn: 3g Crash : 9g	Same as pressurized module

TABLE VII - QUALIFICATION ENVIRONMENTS

Environment	EOS Image Intensifier Camera System		Westinghouse SEC TV Camera
	Image Intensifier	Film Camera (GFE)	
Vibration	None	Unknown	Must withstand commercial transportation
Shock	Bench Test	Unknown	
Acceleration	None	Unknown	None
Temperature	None	Unknown	283° to 313°K (50° to 104°F)
Temperature Shock	325° to 253°K (125° to -4°F) in 1800 seconds per MIL-STD-810B	Unknown	None
Pressure	12,192 m (40,000 ft) nonfunctioning and 3,658 m (12,000 ft) functioning per MIL-STD-810B	Unknown	None
Acoustics	None	Unknown	None
Humidity	Functional at 90% RH and 311°K (100°F) per MIL-STD-810B	Unknown	Functional at 90% RH at 762 m (2,500 ft) elevation

TABLE VIII - EVALUATION OF THE EOS IMAGE INTENSIFIER CAMERA SYSTEM FOR THE SHUTTLE SORTIE MISSION

	NO MODIFICATION REQUIRED	ANALYSIS REQUIRED	MINOR DESIGN MODIFICATION REQUIRED	TESTING REQUIRED	MANUFACTURING MODIFICATION REQUIRED	DESIGN MODIFICATION DESIRABLE	MAJOR DESIGN MODIFICATION REQUIRED
DESIGN PHASE							
Combustible Materials				1,2			
Outgassing			1,2				
Age Control For Synthetic Rubber Parts		1,2					
Fungus-Inert Materials				1,2			
Dissimilar Metals	1,2						
Corrosion Resistance	1,2						
Protective Treatment	1,2						
Radioactive Materials	1,2						
Magnetic Materials	1,2						
Finish	1,2						
Contamination Control	1,2						
Maintainability	1,2						
Weight						1,2	
Size	1,2						
Spacelab Resources						1,2	
Thermal Control							1,2
Service Life	1,2						
Operations & Control	1						2
Reliability and Safety	1		2				
Mechanical Interface	1,2						
Factors of Safety		1,2					
TRANSPORTATION PHASE							
Transportation Dynamics		1,2					
Solar Radiation	1,2						
Temperature	1,2						
Humidity	1,2						
Ozone		1,2					
STORAGE PHASE							
Time	1,2						
Temperature	1,2						
Humidity	1,2						
Ozone		1,2					
PRELAUNCH PHASE							
Solar Radiation	1,2						
Pressure	1,2						
Temperature	1,2						
Explosive Atmosphere					1,2		
Electromagnetic Control (EMC)			1,2				
Gas Composition	1,2						
LAUNCH PHASE							
Vibration				1,2			
Acoustic Noise				1,2			
Acceleration				1,2			
Ordnance Shock (Separation Devices)				1,2			
Temperature	1			2			
Pressure	1				2		
Earth Magnetic Field	1,2						
Electromagnetic Control (EMC)			1,2				
ORBIT PHASE							
Shock	1,2						
Acceleration	1,2						
Vibration	1,2						
Radiation	1		2				
Temperature	1			2			
Pressure	1				2		
Magnetic Field	1,2						
Acoustics	1,2						
Charged Particles	1,2						
Meteoroids	1,2						
Electromagnetic Control (EMC)			1,2				
REENTRY AND LANDING PHASE							
Acceleration		1,2					
Temperature	1			2			
Pressure	1		2				

1 - Pressurized Module
2 - Pallet

TABLE IX - EVALUATION OF THE WESTINGHOUSE SEC TV CAMERA SYSTEM FOR THE SHUTTLE SORTIE MISSION

	NO MODIFICATION REQUIRED	ANALYSIS REQUIRED	MINOR DESIGN MODIFICATION REQUIRED	TESTING REQUIRED	MANUFACTURING MODIFICATION REQUIRED	DESIGN MODIFICATION DESIRABLE	MAJOR DESIGN MODIFICATION REQUIRED
DESIGN PHASE							
Combustible Materials				1,2			
Outgassing			1,2				
Age Control For Synthetic Rubber Parts		1,2					
Fungus-Inert Materials				1,2			
Dissimilar Metals		1,2					
Corrosion Resistance		1,2					
Protective Treatment		1,2					
Radioactive Materials	1,2						
Magnetic Materials			1,2				
Finish						1,2	
Contamination Control	1,2						
Maintainability	1,2						
Weight						1,2	
Size						1,2	
Spacelab Resources	1,2						
Thermal Control							1,2
Service Life		1,2					
Operations & Control		1,2					
Reliability and Safety	1,2						
Mechanical Interface						1,2	
Factors of Safety		1,2					
TRANSPORTATION PHASE							
Transportation Dynamics		1,2					
Solar Radiation			1,2				
Temperature	1,2						
Humidity					1,2		
Ozone		1,2					
STORAGE PHASE							
Time		1,2					
Temperature	1,2						
Humidity					1,2		
Ozone		1,2					
PRELAUNCH PHASE							
Solar Radiation			1,2				
Pressure	1,2						
Temperature	1,2						
Explosive Atmosphere			1,2				
Electromagnetic Control (EMC)			1,2				
Gas Composition	1,2						
LAUNCH PHASE							
Vibration							1,2
Acoustic Noise							1,2
Acceleration				1,2			
Ordnance Shock (Separation Devices)				1,2			
Temperature	1,2						
Pressure	1						
Earth Magnetic Field	1,2						
Electromagnetic Control (EMC)			1,2				
ORBIT PHASE							
Shock	1,2						
Acceleration	1,2						
Vibration	1,2						
Radiation	1		2				
Temperature	1			2			
Pressure	1						2
Magnetic Field	1,2						
Acoustics	1,2						
Charged Particles	1,2						
Meteoroids	1,2						
Electromagnetic Control (EMC)			1,2				
REENTRY AND LANDING PHASE							
Acceleration		1,2					
Temperature	1			2			
Pressure	1		2				

1 - Pressurized Module
2 - Pallet

can be plotted over the test spectrum to determine the severity of the responses. This would establish design goals for the structural design to minimize the acceleration responses. Figure 11 shows the acceleration response with an assumed quality factor (Q) of 10 over the entire spectrum for the pallet and pressurized module environments. The quality factor is approximately equal to the transmissibility at resonance for a lightly-damped system, and the assumed value of 10 is typical for a complex system. As shown in figure 11, the minimum expected acceleration is 30 g's over the test spectrum. The pallet environment is more severe than the pressurized module for natural frequencies up to 480 Hz. Above that frequency the pressurized module environment takes over as having the higher responses. The optimum location of the instrument will depend on the natural frequencies of the system and components so that the instrument will experience a minimum of acceleration.

Figure 12 shows the relative displacement of the system and components with Q = 10 for the random vibration. Large displacements create difficulties in the retention of the optical alignment. The depth of focus of the lenses on the image intensifier system is approximately $\pm 2.54 \times 10^{-5}$ m ($\pm$0.001 in.). Therefore, the natural frequencies should be kept as high as possible to reduce the excursions from the desired focal plane caused by launch vibration.

6.1.2 WEIGHTS

A weight breakdown for each instrument is given in tables X and XI. The image intensifier camera system, as shown in table X, is heavy in structural components. The housings, baseplate, and dovetails contribute 66.21 Kg (145.97 lb) of weight or 41.8 percent of the total weight of the system.

Efforts were made to reduce the weight of the image intensifier camera system to make it more suitable for the Shuttle Sortie mission. Table XII shows that a weight reduction of 60.1 Kg (132 lb) can be achieved with modifications to the existing design. This is a 38 percent reduction. The descriptions of the recommended modification are contained in the following sections.

6.1.2.1 Replacement of Focus Coil with Permanent Magnet

The replacement of the focus coil with a permanent magnet would result in a weight reduction and lower the power consumption. Permanent magnets require no power and do not require cooling. When permanent magnet arrays of Alnico-V are used, the magnetic field is constant and is not significantly affected by shock and vibration. The permanent magnet requires shielding from external magnetic disturbances as does the electromagnet. These disturbances can be produced by the presence of iron masses, electric wiring, and the earth's magnetic field. The shielding can be provided by mu-metal. It is necessary to ensure that the shield provides adequate flux carrying capability and does not saturate. The use of a permanent magnet would require the image tube to operate at a fixed gain, compared to the variable gain obtainable with a focusing coil. However, the variable gain feature was never used in the Barium Cloud Experiments, so this is an expendable feature.

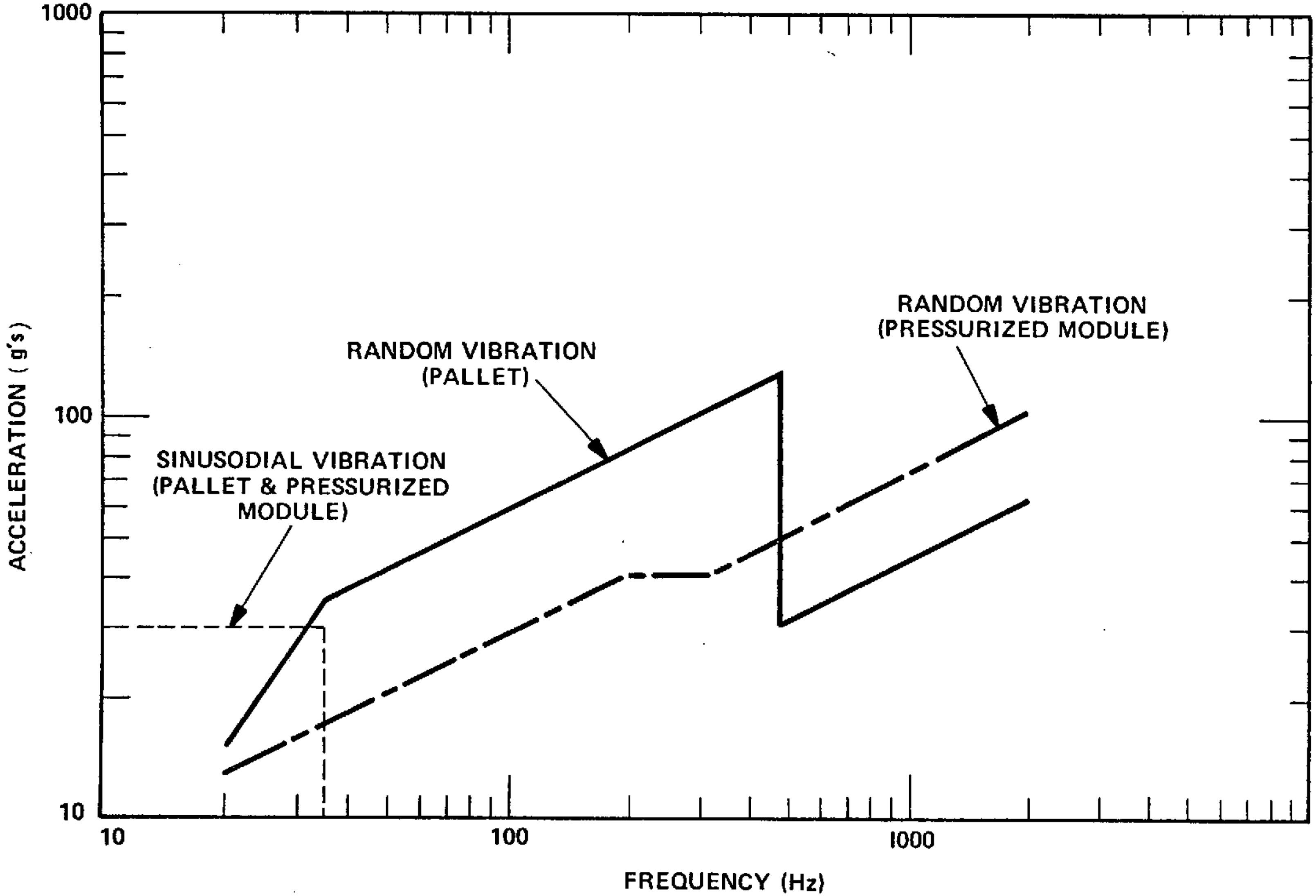

Figure 11. Acceleration Response versus Natural Frequency
(Q = 10)

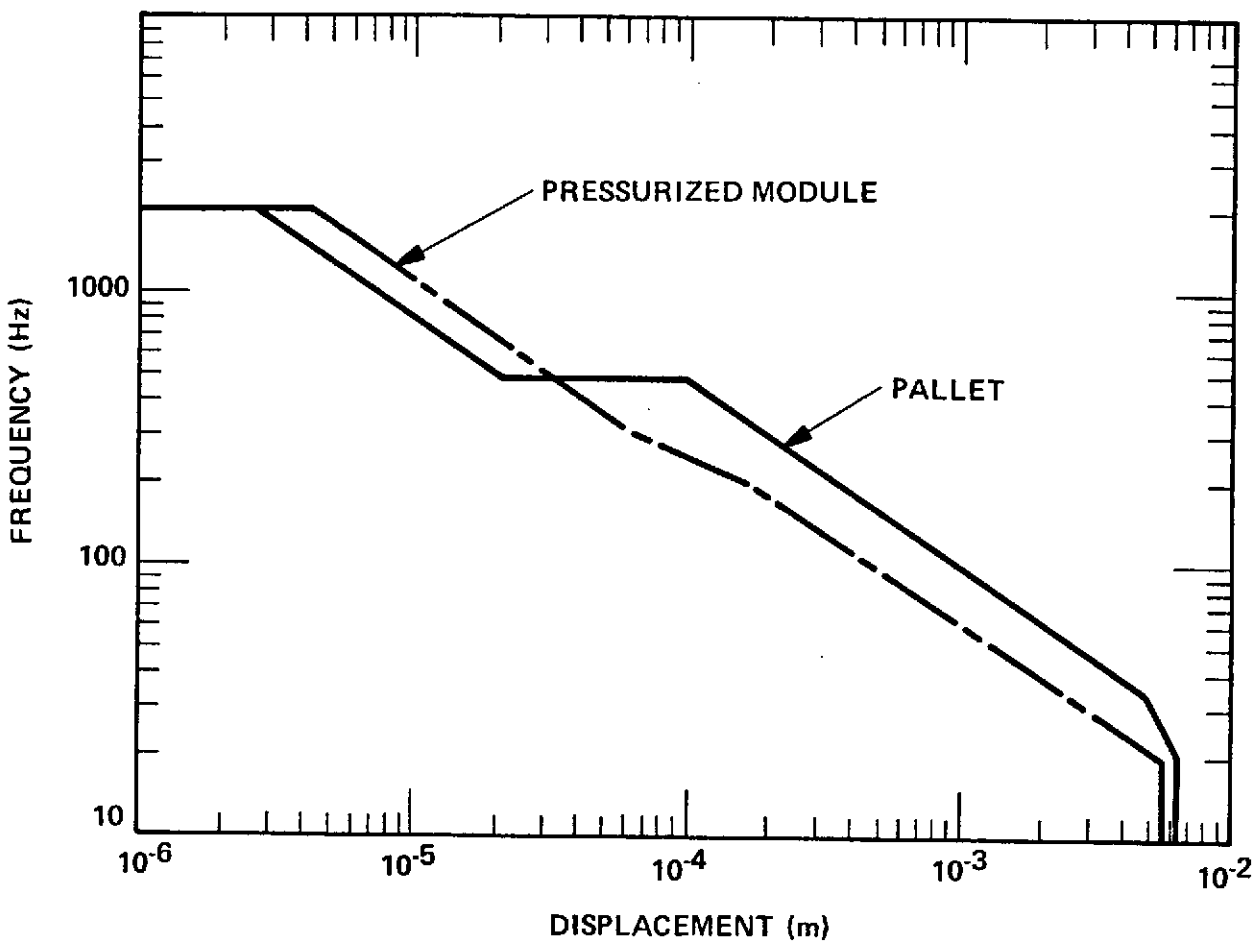

Figure 12. Random Vibration - Relative Displacement versus Natural Frequency (Q = 10)

49288

TABLE X - WEIGHT BREAKDOWN - EOS IMAGE INTENSIFIER CAMERA SYSTEM

Item	Wt (Kg)	Subtotal Wt (Kg)	Total Wt (Kg)
Image Intensifier			
Housing	27.24		
f/1 Objective	8.54		
f/1 Relay	13.39		
Image Tube	1.25		
Low Voltage Power Supply	3.18		
High Voltage Power Supply	2.04		
Coolant Pump	1.36		
Coolant	3.77		
Heat Exchanger	3.63		
Control Panel and Rack	3.68		
Focus Coil	15.89		
Heat Exchanger Cover	2.36		
Filter Tilter	6.81		
Electronic Components	2.04		
Lens Retaining Rings	2.41		
Hoses and Connections	1.59		
Wiring	0.79		
Mechanical Hardware	2.84		
Miscellaneous	5.24		
		108.05	
Film Camera			
Housing	11.27		
Baseplate Assembly	3.38		
Printed Circuit Board Assy	0.07		
Coding Post Assembly	0.34		
Vacuum Bracket Assembly	0.15		
Transport Plates Assembly	6.51		
Wiring	0.11		
Mechanical Hardware	0.30		
Miscellaneous	0.58		
		22.71	
Baseplate		20.90	
Dovetails		6.80	
			158.46 (349 lb)

TABLE XI - WEIGHT BREAKDOWN - WESTINGHOUSE SEC TV CAMERA

Item	Wt (Kg)	Subtotal Wt (Kg)	Total Wt (Kg)
Camera Head			
Cover	4.24		
Printed Circuit Boards	1.07		
Image Tube	3.62		
High Voltage Power Supply	0.39		
Rail	0.55		
Image Tube Mount	0.24		
Connector	0.05		
Wiring	0.16		
Mechanical Hardware	0.30		
		10.62	
Control Unit			
Housing	2.49		
Chassis	0.43		
Printed Circuit Boards	1.28		
Transformer	0.43		
Card Cage	0.54		
Capacitors	0.39		
Plug-In Cord	0.18		
Connectors	0.11		
Wiring	0.66		
Mechanical Hardware	1.25		
Miscellaneous	1.27		
		9.03	
Connecting Cable		4.47	
Synchronizing Generator		3.29	
			27.41 (60.43 lb)

TABLE XII - WEIGHT REDUCTION FOR IMAGE INTENSIFIER CAMERA SYSTEM

Item	Modification	Old Wt (Kg)	New Wt (Kg)
Magnetic Field for Electron Focus	Use permanent magnet in place of coil (solenoid)	31	7.3
Housing	Use magnesium alloy in place of aluminum alloy	27.2	9.5
Dovetails	Use magnesium alloy in place of aluminum alloy	6.8	4.4
Baseplate	Use honeycomb sandwich structure in place of aluminum alloy plate	20.9	4.6
	Total	85.9 (189.38 lb)	25.8 (56.88 lb)

Table XIII shows the estimated weight breakdown for the two focusing approaches. With a permanent magnet a weight reduction of 23.7 Kg (52 lb) could be achieved. Note also the components that can be deleted.

6.1.2.2 Redesign of Intensifier Housing and Dovetails of Film Camera

The housing is a brazed structure fabricated from 6061-T6 aluminum alloy which has a weight of 27.2 Kg (60 lb). A weight savings of 17.7 Kg (39.0 lb) could be obtained by changing the material to magnesium. The MIA alloy is the only magnesium alloy that can be brazed satisfactorily.

Figure 13 shows the stress levels of housing at the mounting webs. Since the housing is a stiffness design, the stresses are extremely low compared to the yield strength of the 6061-T6 aluminum alloy. M1A magnesium alloy, which is proposed for the new housing material, has a lower yield strength of 12.4×10^7 N/m^2 (18,000 psi). This strength is much higher than the stress levels shown in figure 13.

The dovetails used for mounting the film camera to the baseplate weigh 6.8 Kg (15 lb). A weight reduction of 2.4 Kg (5.3 lb) can be achieved by changing the material to a magnesium alloy from the aluminum alloy that is currently used.

6.1.2.3 Use of Lightweight Baseplace

The existing aluminum alloy baseplate, on which the image intensifier and film camera are mounted, weighs 20.9 Kg (46 lb). A significant weight reduction can be achieved by using an aluminum honeycomb sandwich construction. The existing 0.019 m (0.75 in.) thick plate could be substituted with a honeycomb sandwich with the same bending stiffness. Figure 14 shows the sandwich thickness and overall weight as a function of facing thickness with the same stiffness as the 0.019 m (0.75 in.) thick plate. As shown, the minimum weight is achieved with a facing thickness of approximately 0.508×10^{-3} meter (0.020 in.) which will have a corresponding sandwich thickness of 0.046 meter (1.8 in.). A weight savings of approximately 16.3 to 18.2 Kg (36 to 40 lb) could be achieved, depending on the core density used. Aluminum pads are bonded on the facing sheet and machined to achieve the proper plate flatness for the mounting of the instrument.

6.1.3 PACKAGING

6.1.3.1 Image Intensifier Camera System

The mounting techniques of electronic components in the image intensifier system would produce difficulties in surviving the dynamic launch environment. The time delay relay is mounted by only its connecting pins. Its looseness is quite noticeable. There are four relays secured by friction clips. During vibration, the friction could not hold the relays. The two large meters are cantilevered off the instrument panel. Additional supports would reduce the

TABLE XIII - ESTIMATED WEIGHT OF ELECTROMAGNETIC FOCUSING APPROACHES FOR THE IMAGE INTENSIFIER CAMERA

Item	Coil (Solenoid) (Kg)	Permanent Magnet (Kg)
Basic Element	15.89	7.3
Low Voltage Power Supply	3.18	-
Coolant Pump	1.36	-
Coolant	3.77	-
Heat Exchanger	3.63	-
DC Ammeter	0.7	-
Heat Exchanger Cover	2.36	-
Total	30.19 (66.56 lb)	7.3 (16.09 lb)

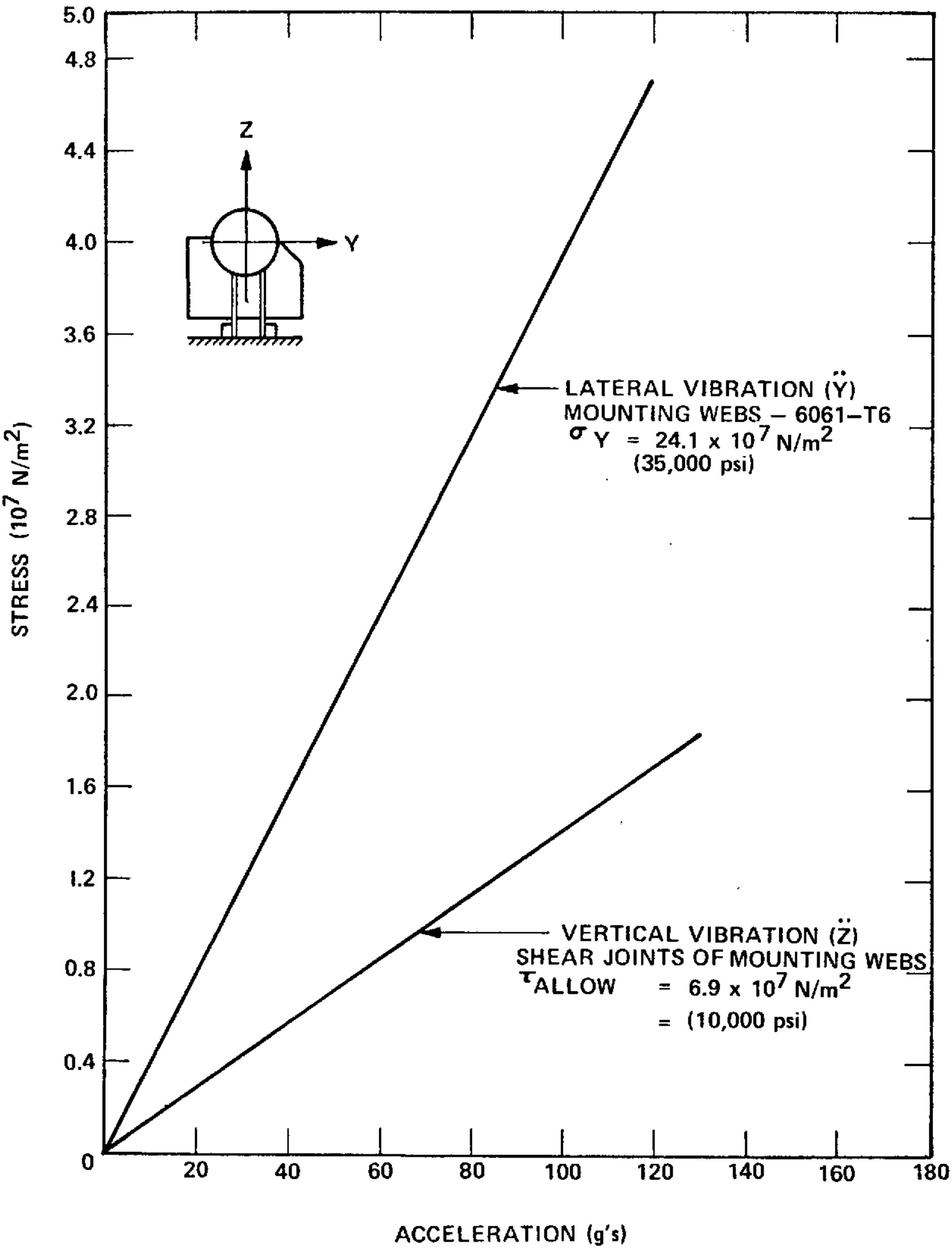

Figure 13. Image Intensifier System - Stress versus Response Acceleration to Vibration

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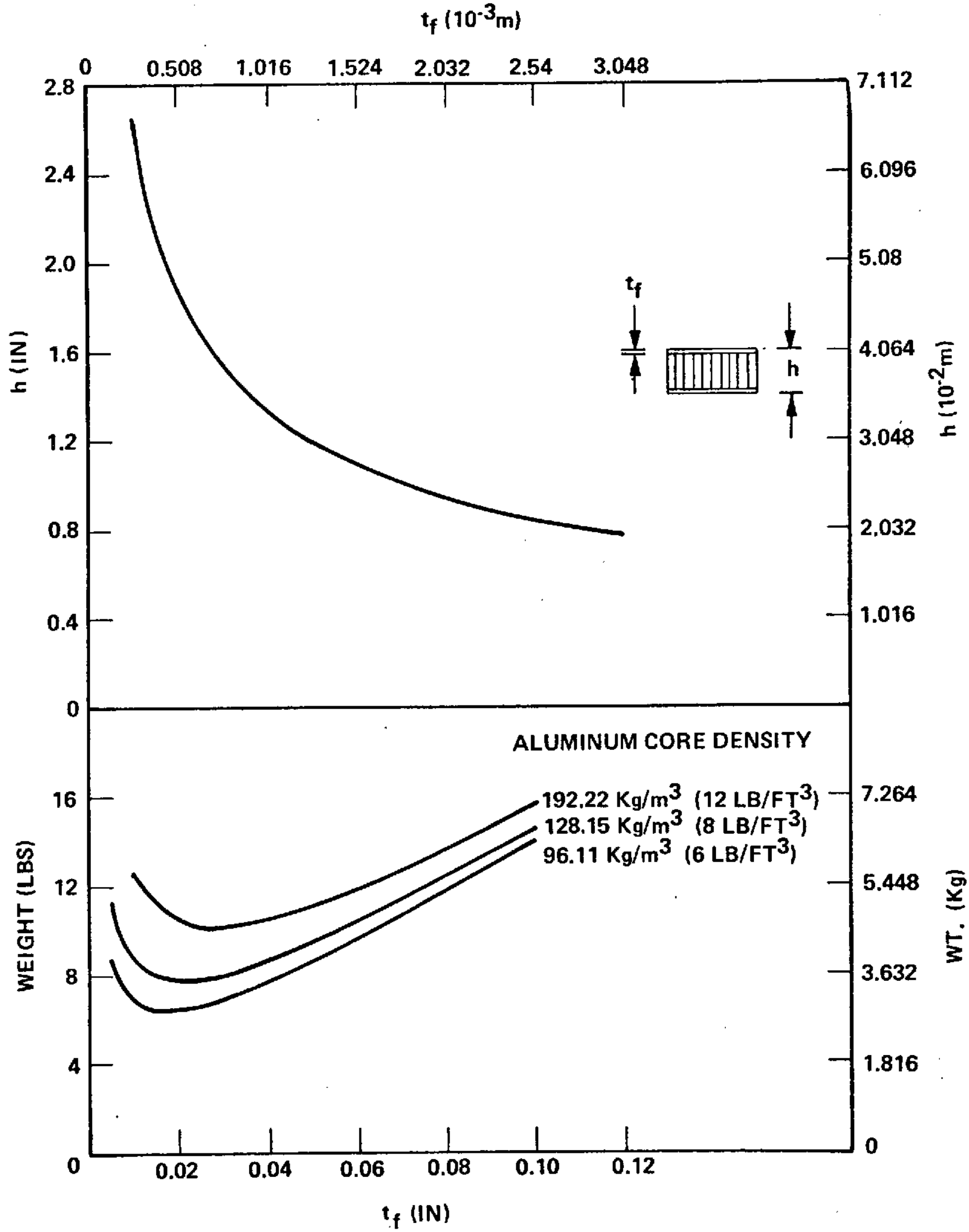


Figure 14. Image Intensifier System - Honeycomb Sandwich Baseplate

49290

deflections and stresses from the plastic mounting face. The sheet metal shelf behind the instrument panel, which holds the five relays and the transformer, needs to be stiffened to raise the resonant frequency. This would reduce the excursions at the resonant frequency during the launch vibration.

6.1.3.2 SEC TV Camera System

The electronic components are packaged to commercial packaging practices. The printed circuit boards in the camera head have large unsupported areas. Large capacitors are mounted on printed circuit boards with no outside support, which will produce stress and fatigue problems. These large capacitors will have to be potted to the circuit boards. The printed circuit boards in the card cage of the control unit are held in place by "plug-in" pins on the cage. The boards are so loosely supported that they rattle. A design modification is required to lock the boards in place and to provide rigid supports on all edges of the boards. All printed circuit boards in the camera head and control unit should be conformal coated to prevent arcing and shorting.

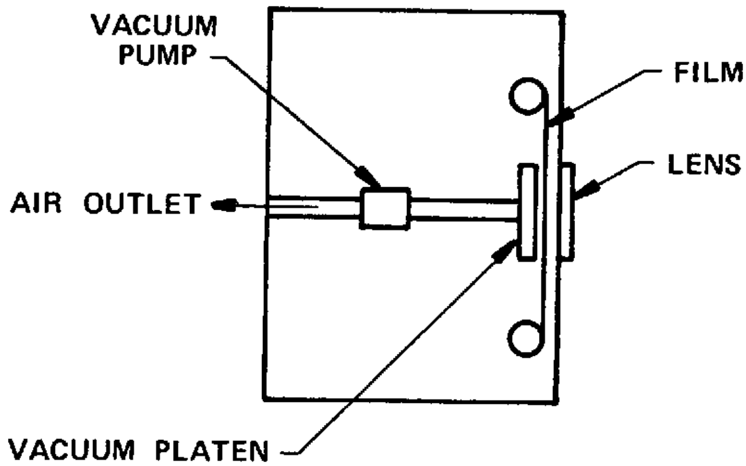
The high voltage supply in the camera head is cantilevered off four standoffs which are 0.038 m (1.5 in.) long. The responses to the launch vibration could be greatly reduced by chassis mounting the supply.

The image tube in the camera head rides on a rail with two rolls of bearings for the focusing. There is no preload on the bearings, which produces slack in the bearing races. If the camera head was mounted on the pallet, the launch vibration can throw the camera out-of-focus and out-of-alignment. Therefore, the bearings of the rails should be spring loaded. Fortunately, the camera tube itself is rugged enough to withstand the most severe vibration levels (curve IV) of MIL-E-5400J. However, care must be taken in the design of the camera head so that resonances, which could produce microphonics, are avoided.

6.1.4 FILM PLATEN, IMAGE INTENSIFIER CAMERA SYSTEM

Although the film camera was not part of the EOS built system, and therefore not an item for study, a small amount of time was devoted to considerations of hold-down mechanisms for the 70 mm film. EOS also feels this technology exists from NASA space experiments. As noted before, due to the short depth of focus of the relay lens, the frame-to-frame film position (flatness) must be repeatable to about $\pm 1.3 \times 10^{-5}$ m ($\pm$0.0005 in.).

A vacuum platen in the film camera of the image intensifier camera system is currently used to stabilize and hold the film stationary and flat after the film has been pulled down. A simplified schematic of the system is shown in figure 15.



49291

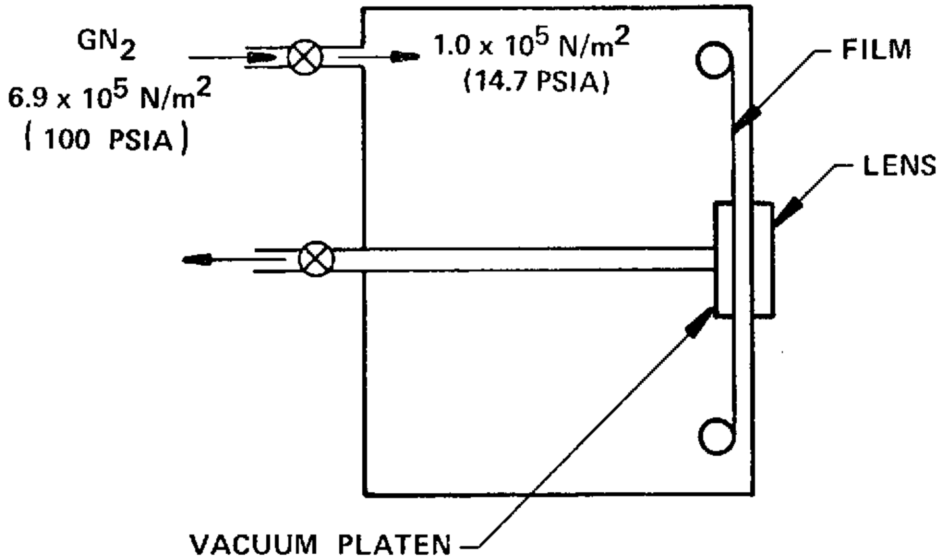
Figure 15. Current Film-Hold Design

The shutter is located 0.00635 m (0.25 in.) from the film plane. This design produces good results for a camera with variable framing rates.

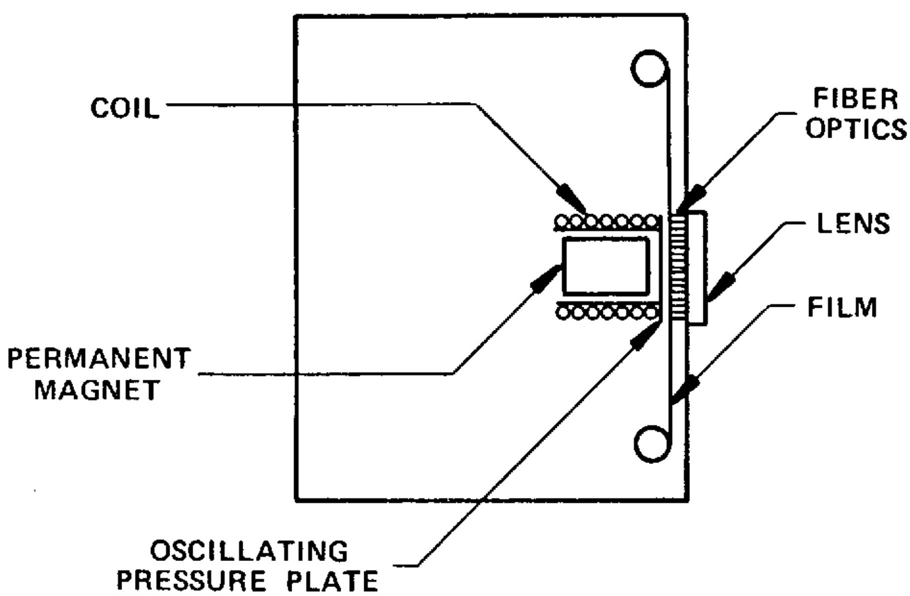
In the hard vacuum of the pallet environment, the existing design would not work. Figure 16 shows two alternate methods of performing the function with minimum modifications to the current camera configuration. The following are descriptions of the concepts.

DESIGN #1. This design utilizes the vacuum environment in place of the vacuum pump. Gaseous nitrogen (GN_2) is used to pressurize the inside of the camera. The pressurizing gas leaks around the sealing surface, which is formed by the film, and escapes out to space through a valve. Figure 17 shows the usage rate of GN_2 versus the outlet diameter of the valve. The feasibility of the design concept would depend on the available quantity of GN_2 for this experiment and the duration of the experiment per mission, which is approximately 1.5 to 2.0 hours. As shown a quantity of approximately 0.454 Kg (1.0 lb) would be sufficient to perform the experiment.

DESIGN #2. This design would use an oscillating pressure plate to hold the film against a fiber optics surface. The plate would oscillate so that each frame of the film would be held against the fiber optics. The fiber optics would be approximately 0.00635 m (0.25 in.) thick. The existing vacuum platen system would



DESIGN NO. 1



DESIGN NO. 2

Figure 16. Design Concepts of Camera Film Hold-down

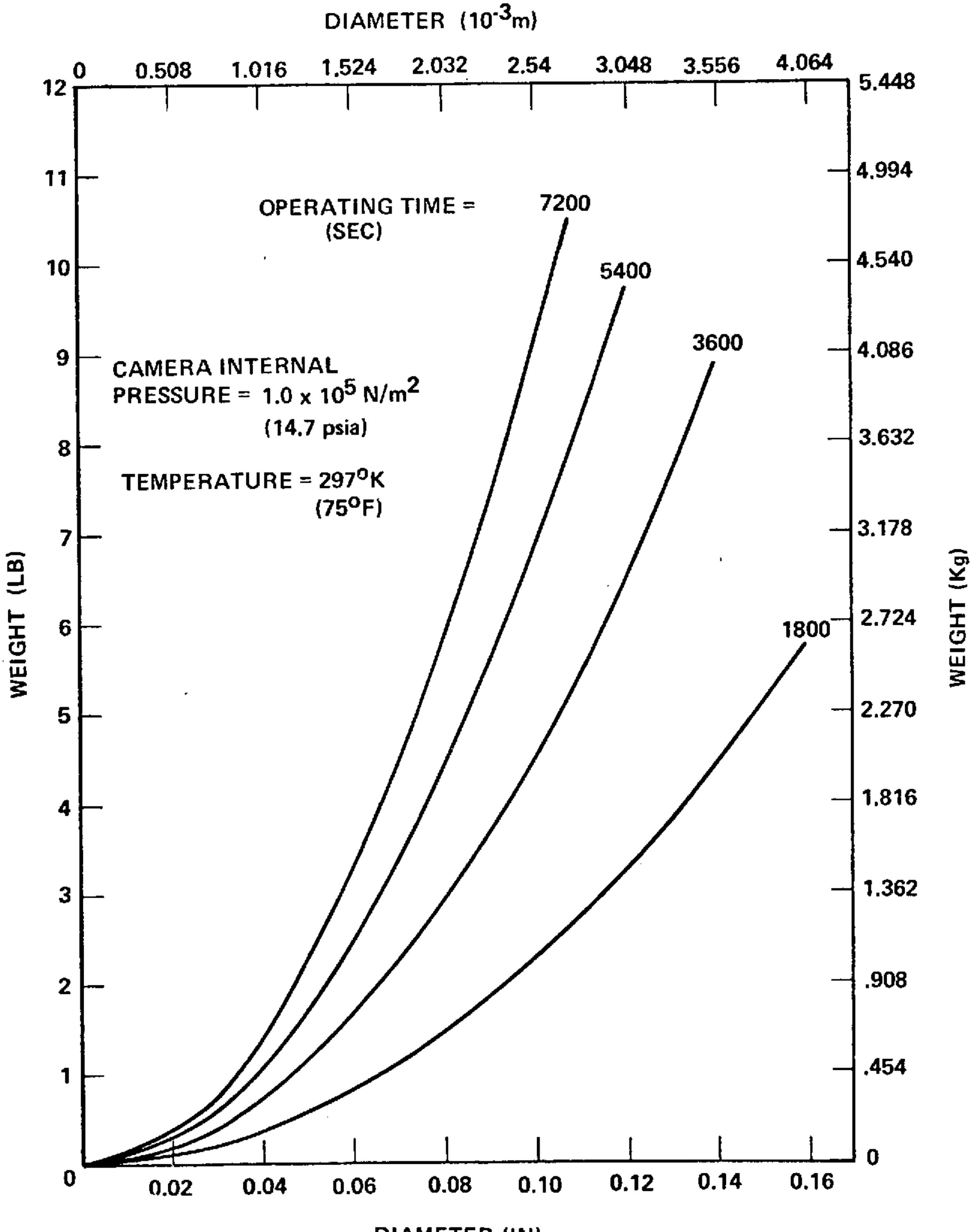


Figure 17. Camera Film Hold-down - GN_2 Weight versus Outlet Diameter

49293

be replaced by the pressure plate, coil, and permanent magnet. This design would also produce a minimum change to the existing camera configuration.

6.2 THERMAL CONSIDERATIONS

Thermal evaluation studies were conducted on the two instruments for the pressurized module and pallet environments (Cases I and II respectively). The thermal environment for each of these two cases is:

	Environment	
	Temperature	Pressure
Case I - Pressurized Module	$297^{\circ} \pm 3^{\circ}K$ ($75^{\circ} \pm 5^{\circ}F$)	1 atm
Case II - Pallet	200° to $339^{\circ}K$ (-100° to $200^{\circ}F$)	Space vacuum

The thermal environment that the equipment will be exposed to in the pressurized module is quite benign and comparable to ground laboratory operation, with one notable exception: the absence of gravity. Thus, the thermal design must accommodate operation under zero "g" conditions. This infers that cooling effected by natural convective means on Earth must be modified to accept forced convection.

The thermal environment associated with pallet operation is much more severe. The equipment will be exposed to solar radiation, Earth heating (albedo and thermal radiation) and periods of solar occultation. The equipment must operate in vacuum as well as zero "g" conditions. The thermal design must provide acceptable component temperatures under the wide range of heating conditions described above. Typical Earth heat inputs for a 200 nautical mile orbit are shown in figure 18 to provide an indication of the nature of some of the varying environmental heat inputs.

Recommended thermal design concepts for Cases I and II follow.

Westinghouse SEC TV Camera - Case I

The TV camera system has been designed to operate in still air on the ground. The total heat dissipation is not large (92 watts, see table V) and high heat dissipating elements are mounted on heat sinks that are amenable to cooling by natural convection, as shown in figure 19a.

For successful TV control unit operation in the zero "g" environment in the module the natural convective portion of the thermal design must be replaced by forced convection. The forced convection cooling may be done with air as shown in figure 19b or liquid as shown in figure 19c.

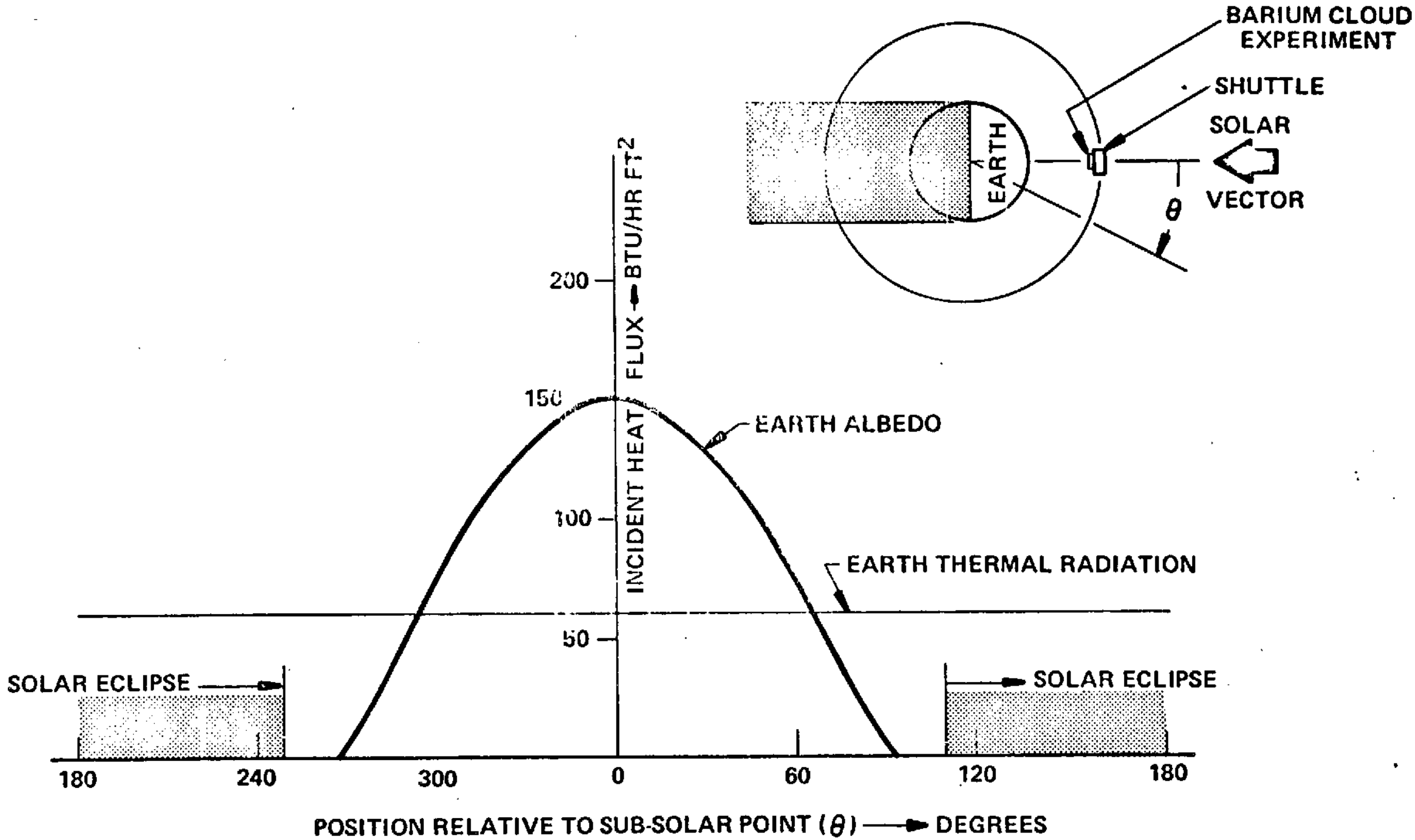
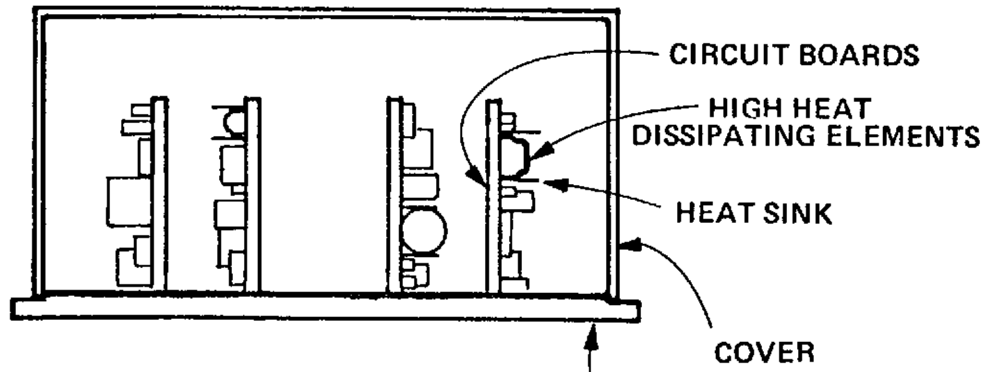
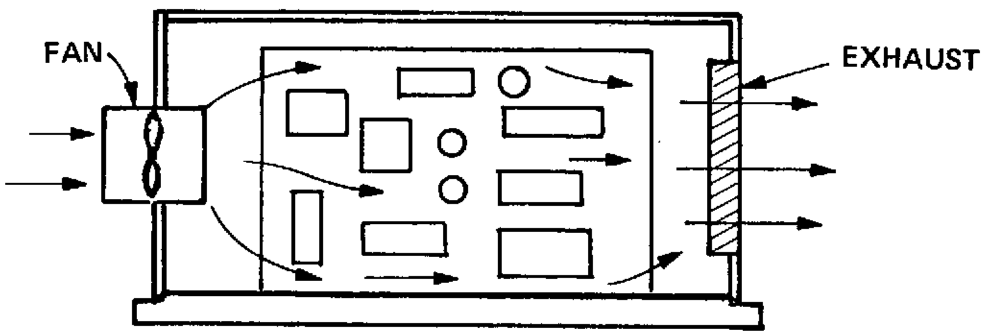


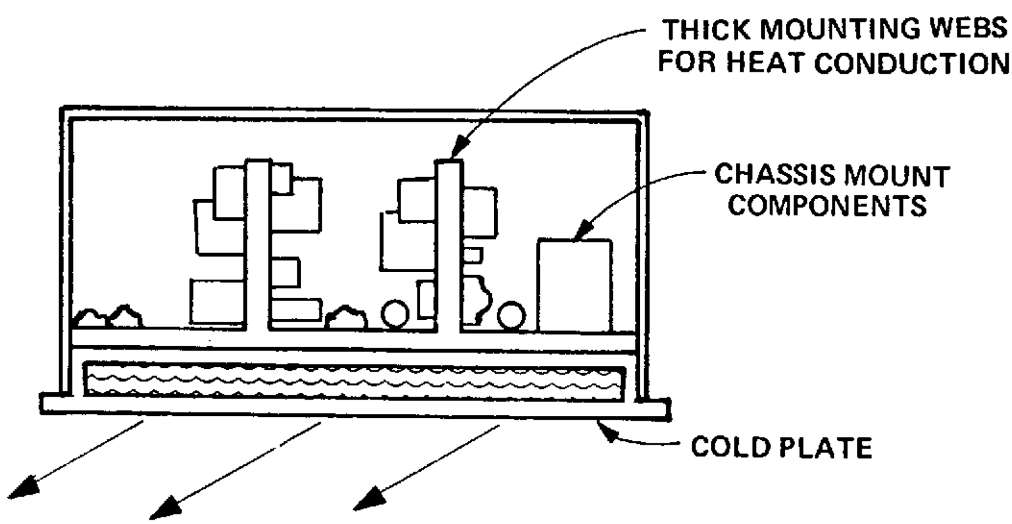
Figure 18. Typical Earth Heat Input 200 Nautical Mile Orbit



19a. GROUND COOLING (NATURAL CONVECTION)



19b. FORCED AIR COOLING



19c. LIQUID COOLING

Figure 19. TV Camera Control Unit

49295

The design concept shown in figure 19b incorporates the following features:

1. Relocate circuit boards to permit adequate air flow and add a fan.
2. Chassis mount high heat dissipating components.

The fan required would be rather small, on the order of 50 cfm. Chassis mounting will spread the heat dissipation over a larger area, which will facilitate the rejection process.

One method of liquid cooling the TV control unit is shown in figure 19c. Heat dissipating elements are mounted on a chassis that incorporates an integral cold plate. Liquid is obtained from the Spacelab cooling system.

Liquid cooling is more efficient than air cooling and generally leads to a smaller packaged volume. As a result, the liquid cooled system is preferred.

The TV camera dissipates a low level of heat (approximately 5 watts). This heat is conducted to the camera case and radiated away.

TV Camera - Case II

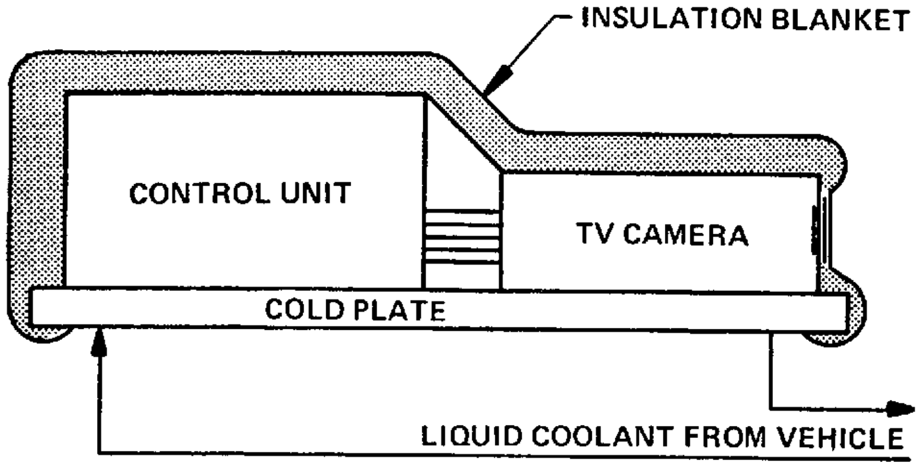
The preferred thermal design for pallet operation is similar to the liquid cooled scheme described above except that an insulation blanket is required (see figure 20a). The purpose of the insulation blanket is to isolate the TV camera system from the radically changing external environment.

An alternate approach is to air cool the TV camera system with pressurized gas from the pressurized module, as shown in figure 20b. The pressurized gas would be provided by a fan or compressor, forcing air through a duct to the TV camera system. The liquid cooled approach is preferred for two reasons; (1) liquid is a more efficient heat transfer medium, and (2) liquid is easier to circulate than air, i.e., the pump power would be less than fan or compressor power required for the same amount of cooling.

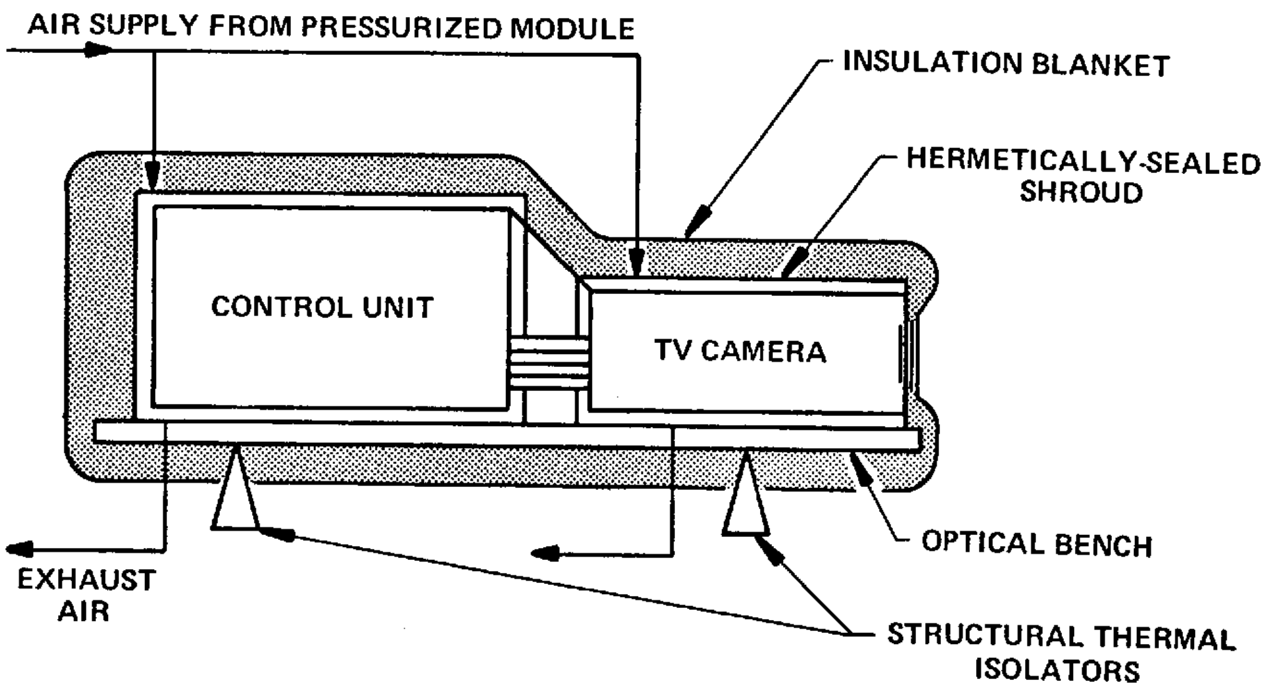
EOS Image Intensifier Camera System - Case I

The existing image intensifier camera system heat load and cooling breakdown is shown below:

Image Intensifier	Watts	Cooling
High voltage supply	45	Air cooled natural convection
Image intensifier tube	15	Air cooled natural convection
Low voltage supply	150	Air cooled forced convection
Focus coil	160	Liquid cooled
Pump	200	Liquid cooled
Heat exchanger fan	20	Air cooled
Digital meters	30	Air cooled
Miscellaneous	25	Air cooled
	645	
Film Camera		
Motor	180	Air cooled
Clutch	5	Air cooled
Total	830 watts	



20a. LIQUID COOLED



20b, GAS COOLED

Figure 20. TV Camera System Pallet Operation

The system is shown schematically in figure 21. Note that natural and forced air convective cooling is employed in addition to pumped liquid cooling.

Those portions of the design that currently rely on natural convection cooling will have to be modified prior to operation in the zero "g" environment in the pressurized module. High heat dissipating elements will have to be chassis mounted and packaged so that they can be cooled by the fan. It is also likely that a second fan will be required.

A preferred cooling approach is to completely repackage the electronics on a chassis so that it can be liquid cooled. This scheme would employ liquid coolant from the space vehicle, as shown in figure 22.

The camera drive motor and clutch may require either a separate fan or mounting on a liquid cooled cold plate.

It has been suggested in another part of this report that the focus coil be replaced by a permanent magnet. This concept would greatly reduce the system heat load as shown below:

Image Intensifier System	Watts
High voltage supply	45
Image intensifier tube	15
Digital meter	15
Miscellaneous	20
Film Camera	
Motor	180
Clutch	5
Total	280 watts

The permanent magnet is insensitive to temperature changes in the range of interest as shown in figure 23 (Ref. 1). Propoer focusing of the electrons in the image intensifier tube requires that the magnetic field be stable to within one percent.

Again, cooling could be effected through the use of fans or a liquid cooled cold plate.

Image Intensifier System - Case II

The thermal control configuration recommended for pallet operation is shown in figure 24. The image intensifier and camera are mounted on a liquid cooled cold plate. Liquid for this purpose is assumed to be available from the vehicle. A bypass line is inserted in the cooling loop to permit circulation in those instances when vehicle coolant may not be required or desired.

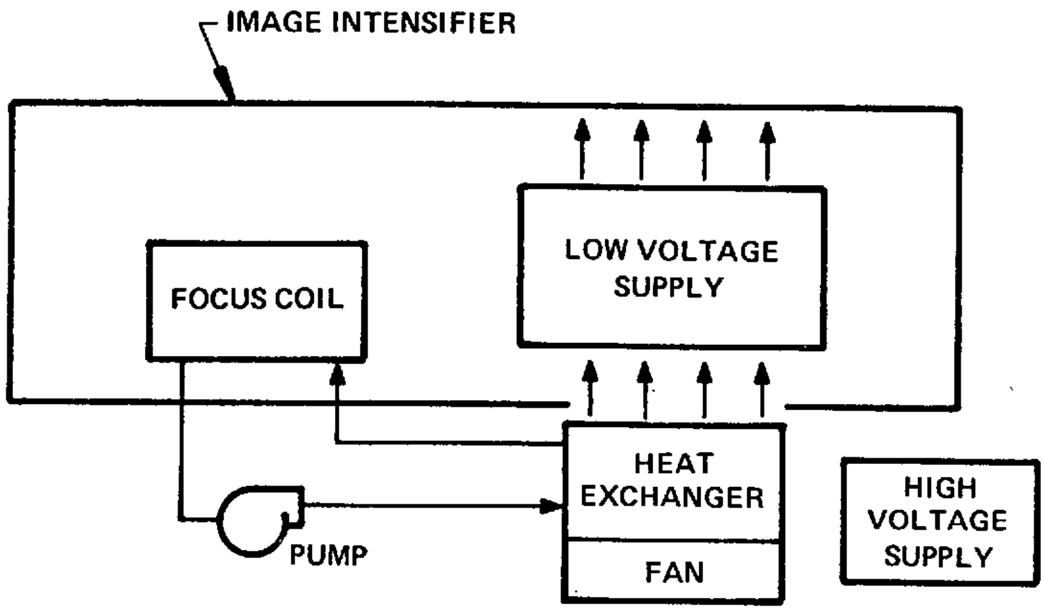


Figure 21. EOS Image Intensifier Ground Cooling

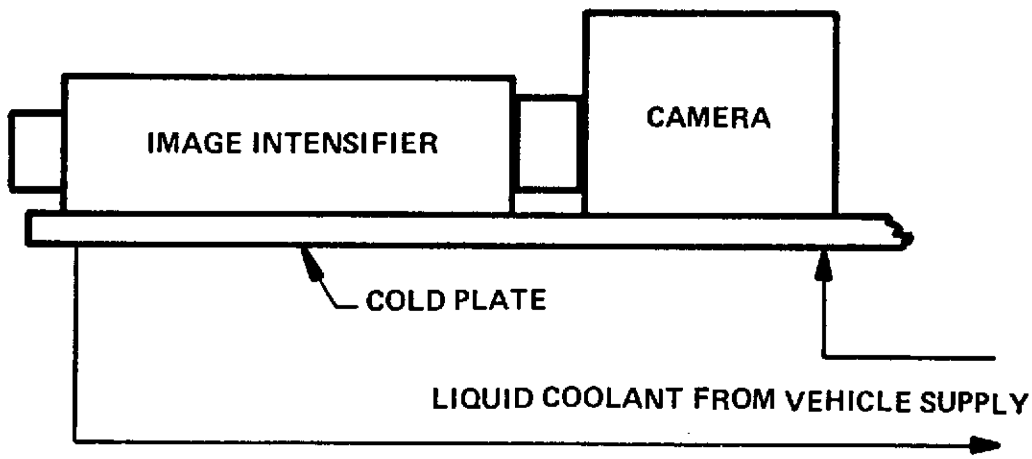


Figure 22. Image Intensifier System Recommended Configuration for Module Operation

49298

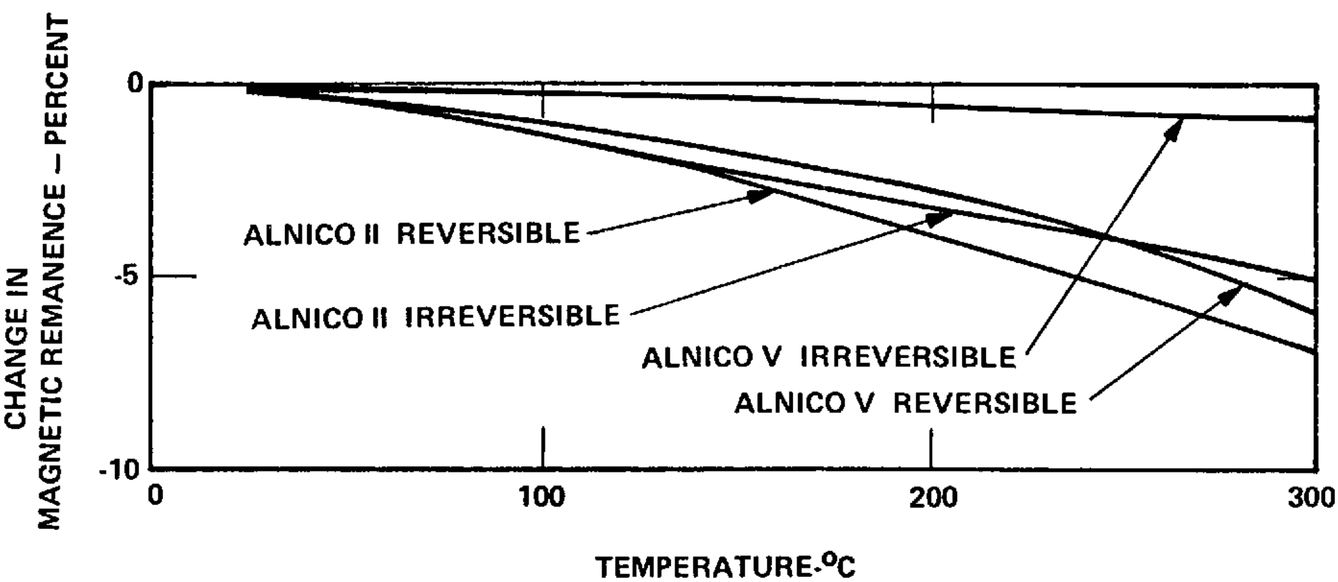


Figure 23. Effect of Temperature on Magnetic Remanence

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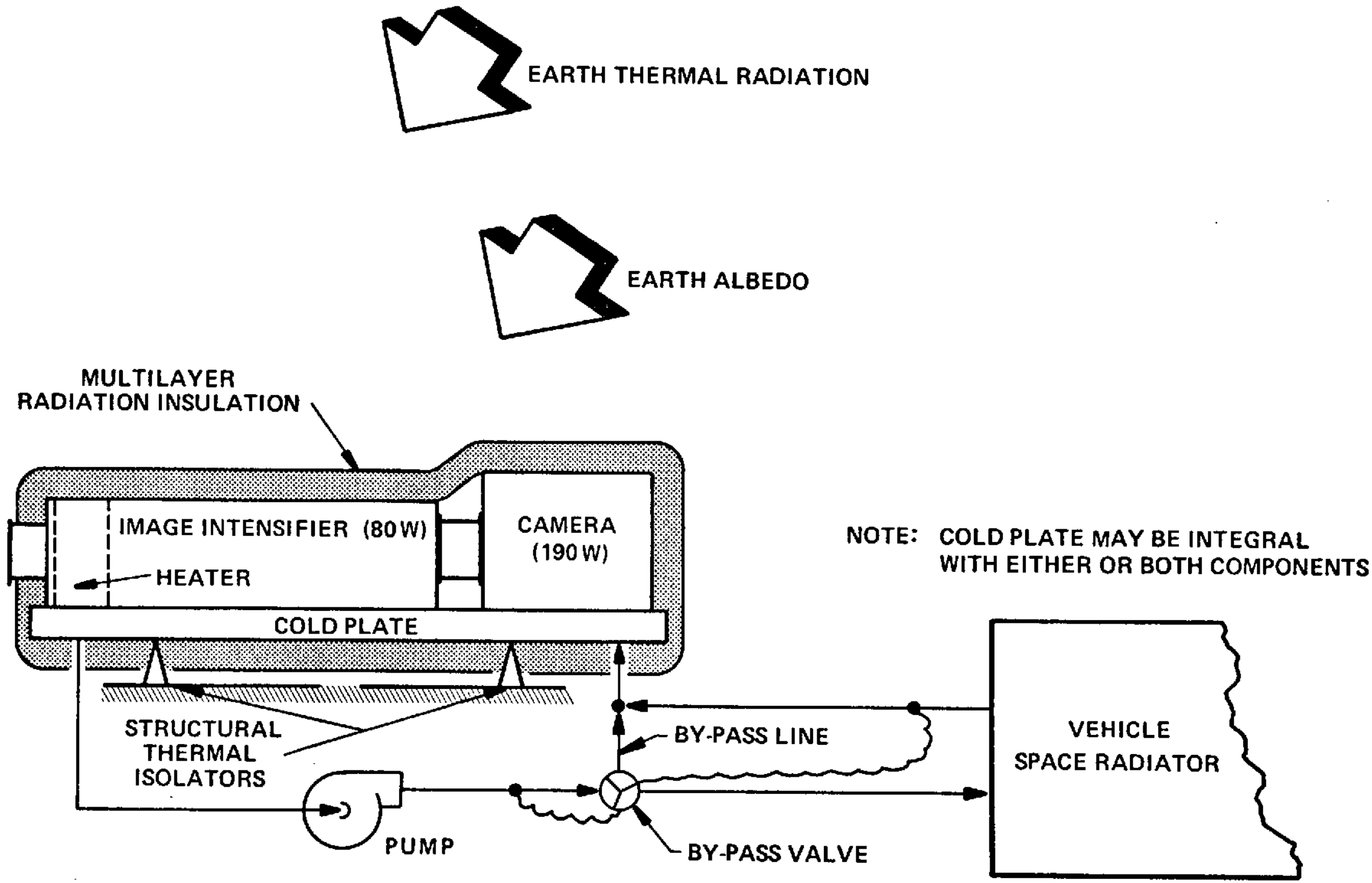

Figure 24. Recommended Temperature Control Configuration for Pallet Operation

The system is isolated from the environmental extremes by a multilayer-radiation insulation blanket. A thermostatically controlled heater is placed at the aperture end of the intensifier to counter balance the heat loss to space when the aperture is open. This technique will minimize axial temperature gradients and is commonly used in space applications (Mariner '73 TV narrow angle optics).

The unit is mounted on the pallet by structural thermal isolators to minimize extraneous heat conduction from the pallet structure. In addition the camera motor must be vacuum rated.

The recommended temperature control concept will maintain the system at a uniform temperature with minimal gradients over the anticipated range of orbital extremes.

6.3 ELECTRONIC CONSIDERATIONS

6.3.1 IMAGE INTENSIFIER CAMERA

As discussed before, it is recommended that the focusing coil (solenoid) in the present equipment be replaced with a permanent magnet. This change eliminates the need for the low voltage power supply and its associated cooling subsystem. This change not only saves significant weight and power but improves considerably the reliability of the instrument.

The high voltage power supply operates at about 24 kV and will be subject to arcing problems in a vacuum. The solution to this problem is straightforward, and the discussion on TV arcing in paragraph 6.3.2 also is applicable here.

No changes are recommended in the image tube itself. However, RCA no longer manufactures the exact image tube used in the original equipment, but an improved version is available. The improved version has higher resolution and sensitivity and is about 6 cm longer. The old tube is RCA's C33011; the new tube is C33063.

During the study, the use of electrostatically focused (ES) image tubes for the modified system was briefly considered, instead of the present electromagnetically focused (EM) tube. The ES tube would decrease the system weight since it requires no magnet. However, it requires both fiber optics input and output, which lowers the tube's resolution and sensitivity. The ES tube also has an order of magnitude more distortion than the EM type. Thus, an easy tradeoff was made to retain the EM tube.

Both of these tubes are of the so-called first generation type. Since the instrument was designed (1969), second generation tubes have become available which could radically change the approach to a new instrument. This possibility is discussed in Section 8.

6.3.2 SEC TV CAMERA

There are three methods of mounting the TV camera which are considered in making recommendations regarding modifications to the equipment. The first method is to mount all three units in the pressurized module; the second method is to mount the sensor head only in the pressurized module; and the third is to mount all units on the pallet. Each mounting configuration requires different modifications.

Minimum Modification - Pressurized Module Location

To accommodate the least number of changes to the camera equipment it would be necessary to mount all units in the pressurized area. The units need only to be adaptable to the temperature and vibration environment.

As a minimum, the camera control unit should be repackaged in order to improve mechanical ruggedness and to provide better heat transfer from heat dissipating components. As part of this repackaging effort, the synchronizing generator should be built into the control unit. In addition, the camera sensor head should be repackaged in order to provide substantial support to the image tube subassembly and to provide acceptable mounting for the circuit boards.

There is one potential problem that could make the camera inoperative. The image tube voltages necessary for their operation can be as high as -23 kV. At sea-level pressure the insulation provided is just capable of standing off these potentials. At lower pressures, the air, which is used as an insulator, could break down causing corona and arcing.

There is also questionable insulation provided for the 800V and 400V generated within the control unit, and sent to the camera head via the camera control to camera head interconnecting cable. At or near the corona critical pressure there may be arcing at various points within the control unit, connectors, and the camera head.

The recommended solution to the potential image tube arcing problem is to provide adequate insulation at critical points. This means that the image intensifier and image section of the SEC should be encapsulated in appropriate RTV material with an electrically conducting optical window located at the intensifier photocathode. The outside of the window should be grounded to an electrically conductive case housing the image tubes. If the high voltage supply cables are also shielded and connected to the tube case and to the high voltage power supply case, all voltage stresses will be placed across known and adequate insulating material. The insulation properties would then be independent of the ambient pressure.

The 800V and 400V within the various units should also be adequately insulated. This means that the power transformer, rectifiers, filters, and regulator diodes should be encapsulated in an appropriate insulating material. In regard to the zener diodes, the electrical insulating material might improve thermal conditions if the material is also a good thermal conductor. All connectors should be encapsulated and all circuit boards containing high voltages should be conformally coated or encapsulated.

Modifications Necessary for Units Located on Pallet

In addition to those modifications listed for the pressurized module, changes should be made to improve heat dissipation. There are some electrical components, power transistors, power resistors, power transformer, and image tubes that should be mounted to facilitate thermal conductivity to the mounting surface. It should be noted that the image tube assembly dissipates several watts. The temperature may therefore rise above the 328°K (131°K) limit unless adequate consideration is given to the thermal conductivity of the image tube mounting structure.

A summary of all these recommended modifications is shown in table XIV.

Image Tube Changes

The SEC image tube has, as the basic storage element, a sensitive target made of a porous potassium chloride material deposited on a substrate. Under high illumination conditions, this target is bombarded by high energy electrons which are absorbed in the porous material. It is possible that sufficient energy is collected to cause the temperature of the target to rise to a point where irreversible damage is caused to this element.

Westinghouse developed a special target structure which is capable of dissipating the energy in the target during high illumination conditions. This burn resistant tube should be used to replace the standard SEC device. Through this modification a greater chance for successful operation will be secured. A modification to the high voltage power supply is required with the burn resistant target SEC because the image section operates on less applied voltage.

6.4 OPTICAL CONSIDERATIONS

No particular modifications are recommended for the objective and relay lenses used in the image intensifier camera system. The mechanical design of the lens mounts (glass-to-metal contact with screw-in retaining rings) is a common approach that has successfully passed stringent testing on past military programs. Thus, no particular problems are foreseen in this area. The lenses are sealed by O-rings and are purged with dry nitrogen gas. About 15 percent overpressure (compared to atmospheric) is maintained in the lens cell.

The optical design of the lenses has not been reconsidered and would be an appropriate topic only if the field of view, resolution, etc., of the lenses need to be modified. This topic, although not a part of this study, must be addressed when firm instrumentation requirements are generated.

The remainder of this section discusses some particular points relating to optical system performance.

TABLE XIV - SUMMARY OF RECOMMENDED MODIFICATIONS
TELEVISION CAMERA

Camera Components	Pressurized Module	Pallet
CAMERA HEAD		
Image Tube Assembly	• Encapsulate in RTV • Provide ridged mount	• Encapsulate in RTV • Provide ridged mount • Encapsulate SEC connector
H.V. Power Supply	• Encapsulate in RTV • Replace H.V. heads and connectors	• Encapsulate in RTV • Provide heat sink for power components • Replace H.V. heads and connectors
Circuit Boards	• Conformal coat • Replace commercial components	• Conformal coat • Replace commercial quality components • Provide heat sink for power components
CAMERA CONTROL		
Video Processor Cards	• Repackage for improved mechanical mounting	• Repackage for improved mechanical mounting
Power Supply	• Repackage for improved mechanical mounting • Heat sink power components • Encapsulate H.V. section	• Repackage for improved mechanical mounting • Heat sink power components • Encapsulate H.V. section
G-5 Control	• Automatic shorting during warm-up	• Automatic shorting during warm-up
CABLES	• All connectors encapsulated	• All connectors encapsulated
SYNC GENERATOR	• Repackage into camera control unit	• Repackage into camera control unit

6.4.1 DEPTH OF FOCUS ANALYSIS FOR THE IMAGE INTENSIFIER CAMERA SYSTEM

The purpose of the image intensifier camera system is to take photographs of low-contrast objects at low light levels. In the design of the instrument, every attempt was made to make use of all the photons available to the camera, which requires that all the optics involved have a large aperture (low f/number). Thus, both the objective lens and the relay lens have maximum apertures of f/1 and are relatively efficient in their light gathering ability. However, this fast optical speed makes them sensitive to small focus changes, and the lens image quality begins to suffer rapidly as the lenses are moved out of focus. EOS was of course aware of this property in the initial design of the image intensifier system and recommended that the instruments be warmed up for approximately 1 hour and focused before use. The long overall length of the instruments and the large amount of internal heat generated by the electromagnetic focusing coil made it almost impossible to set the focus of the objective lens and relay lens and have the lenses remain in focus for a long period of time.

One of the major recommended changes, as discussed previously, is the replacement of the focusing coil with a permanent magnet. This will do away with the internal heat source and, with the simplified mechanical mounting of the permanent magnet/image tube, we can now reasonably expect the mechanical design to hold the optics within their allowable depths of focus during the total Shuttle flight. This will do away with any refocusing which is a nuisance in the pressurized module and essentially an impossibility on the pallet. For pallet operation it would be possible to mount a small, closed circuit TV camera which would view the image at the same plane as the film in the film camera. However, we consider this an awkward and expensive approach and prefer instead to redesign the mechanical structure of the image intensifier to maintain optical focus.

We have stated before that the depth of focus is approximately $\pm 2.54 \times 10^{-5}$ meters (± 0.001 inch) for each of the f/1 optics. The purpose of this section is to present the background for this estimate. It should be noted that the depth of focus applicable to the TV camera is much larger for two reasons: 1) the objective lens is slower, approximately f/4 or larger, and 2) there is no relay lens.

To determine the allowable depth of focus of the image intensifier camera optics, we will evaluate the resolution in lp/mm that can be obtained on the photographic film used in the camera. This film resolution desired is naturally "as high as possible," but some number is needed at least for estimating purposes. Towards this end, we might consider the cloud features observed during the September 1971 Barium Cloud Experiment. In that experiment, the cloud was at a range of approximately 31,000 km and details or lines about 10 km wide were desired to be resolved. As an approximation, we can take this size as being equivalent to the "bar" in a typical resolution target. Thus, a bar and a space of the target would correspond to about 20 km at the 31,000 km range, or an angular resolution of approximately 6.45×10^{-4} radians. The objective lens of the image intensifier system has a focal length of 150 mm and, since the relay lens works at unity magnification, the equivalent spot size on the photographic film would be

$$150 \text{ mm} \times 6.45 \times 10^{-4} \text{ radians} = 0.0967 \text{ mm}$$

The reciprocal of the spot size is assumed to be approximately equal to the final resolution, so that the desired minimum resolution on film is approximately 10 lp/mm. We note that if the cloud is very dim then photon noise statistics will set the ultimate resolution limit, which could be considerably lower than this value. However, we will ignore that consideration.

The final resolution limit on film that the image intensifier system can deliver can be estimated by considering two factors:

a. The Modulation Transfer Function (MTF) that can be delivered to the film by the objective lens, image tube, and relay lens.

b. The MTF or contrast required by the film to resolve a certain resolution level.

Both of these factors are not fixed numbers but functions of spatial frequency (i.e., resolution in lp/mm). We will examine each of the separate factors in turn to derive an approximation for the limiting film resolution.

6.4.1.1 MTF for Objective Lens and Relay Lens

Neither the objective lens nor the relay lens in the image intensifier system is diffraction limited (i.e., geometrically perfect) but they are of very high quality and we can assume that, when the lenses are out of focus, their MTF is essentially that of a defocused, diffraction-limited lens. As Levi shows (Ref. 2), the defocused MTF can be written as

$$\mathrm{MTF}\ (\nu_r, d) = \frac{4}{\pi} \int_{\nu_r}^{1} \sqrt{1-X^2} \cos \left[2\pi\nu_r d \ (X-\nu_r) \right] dX \qquad (1)$$

where ν_r = relative spatial frequency = $\lambda\nu F$

ν = spatial frequency

$d = b/2\lambda F^2$

b = actual defocus distance

λ = wavelength of light used

F = lens f/number at the focal plane

X = variable of integration, corresponding to the normalized radius in the exit pupil.

The defocused parameter, d, is the defocusing in terms of "Rayleigh units," where a Rayleigh unit is equal to $2\lambda F^2$. One Rayleigh unit is typically the "depth of focus" quoted for an optical system, but it is better for our case to actually examine the MTF degradation due to defocusing.

Levi gives tables of the defocused MTF in terms of the number of Rayleigh units of defocusing. However, EOS had previously written a computer program to calculate defocused MTF and this was used for the analysis.

6.4.1.2 Image Tube MTF

A simple general mathematical function has been found (Ref. 3) which closely approximates the MTFs of most image intensifiers. For a single-stage magnetically-focused image tube, the expression is

$$MTF = e^{-\left(\frac{\nu}{40}\right)^{1.5}} \quad \text{(Single Stage)} \qquad (2)$$

where ν is the spatial frequency in lp/mm. For a 2-stage image tube, appropriate to the image intensifier system, we take the square of this function so that

$$MTF = e^{-2\left(\frac{\nu}{40}\right)^{1.5}} \quad \text{(Two Stages)} \qquad (3)$$

The experimental data on image tubes that EOS has had at its disposal correlates quite well with this approximation.

6.4.1.3 Photographic Film Requirements

Photographic film has a varying contrast requirement, or "threshold," as a function of the resolution desired from the film. This relationship is generally assumed to be of the form

$$C = a\nu^{b} \qquad (4)$$

where C is the threshold contrast of the impressed target, ν is the resolution of the target in lp/mm, and a and b are constants which are characteristic of the particular photographic film used, including its processing. As used here, contrast is defined as (H - L) / (H + L) where H and L are the highlight illuminance and low light illuminance, respectively, in the impressed target. The film characteristics are determined by contact printing bar chart targets of various spatial frequencies and various contrasts onto the film and determining the resultant resolution. These constants are not exact but are averages determined from many such experiments.

Since there are two constants in the contrast equation, it is necessary to know the film resolution at two different contrast values. Kodak usually rates its film at 1000: 1 contrast and 1.6: 1 contrast, or at contrasts of 1.0 and 0.23 by our definition. The film's resolving capability is then given for these two different contrasts.

For the purposes of this analysis, the total system resolution will be analyzed using two different Kodak films, Type 2485 and Type 3400. Type 2485 film is the fastest instrumentation film available from Kodak and has been used for previous Barium Cloud Experiments. It has a resolution of 50 lp/mm at 1.0 contrast and 20 lp/mm at 0.23 contrast. Thus, the film has relatively low resolution. The second Kodak film to be considered, Type 3400, has higher resolution but lower sensitivity which would probably exclude it from an actual experiment. However, its use is considered here primarily to show system capability. Type 3400 film requires about 0.6 ergs/sq. cm exposure to achieve a net density of 1.0, compared to an exposure of about 0.12 ergs/sq. cm for Type 2485 film. Type 3400 film resolves 160 lp/mm and 63 lp/mm at 1.0 and 0.23 contrast, respectively.

6.4.1.4 Limiting Resolution on Film

We can combine the preceding equations and discussions into one overall requirement:

$$M_o M_t M_{ol} M_{rl} = C \tag{5}$$

where M_o is the inherent contrast of the object we wish to photograph

M_t is the MTF of the image tube

M_{ol} is the MTF of the objective lens

M_{rl} is the MTF of the relay lens

and C is the threshold contrast of the film.

The left side of this equation is simply the contrast (at a particular spatial frequency) of the image presented to the film, and the right hand side is simply the contrast required by the film to resolve that particular spatial frequency.

Since both the objective lens and the relay lens are f/1, and since they both work at approximately the same wavelength, they will then have approximately the same MTF characteristics with defocus. Therefore if we let $M_1 \doteq M_{rl} \doteq M_{ol}$ be the MTF of either of these lenses, and then put the various factors into the equation, we have

$$M_o \, e^{-2\left(\frac{\nu}{40}\right)^{1.5}} \, M_1^{\,2} = a\nu^b . \tag{6}$$

Solving for M_1 gives

$$M_1 = \sqrt{\frac{a}{M_o}} \quad \nu^{b/2} \; e^{(\nu/40)^{1.5}} \tag{7}$$

We use this equation numerically in a two step procedure:

a. A particular value of ν, in lp/mm, is substituted into the right hand side of the equation to arrive at the necessary lens MTF, M_1.

b. The defocus distance which yields this MTF is found by trial and error using the previously-mentioned computer program for defocused MTF.

A wavelength of 0.4934 microns was used for the analysis. The calculated MTF values are fairly insensitive to wavelength.

The results of this calculation are summarized in figure 25 which is a plot of system resolution, on film, as a function of focus error in both the objective lens and the relay lens. In other words, both lenses are out of focus by the shown amount. These results do not include practical problems such as atmospheric scatter, mount vibration, relative cloud motion during the exposure time, etc.

From figure 25, we can see that the system resolution is down to 10 lp/mm, the desired minimum for 2485 film, when the lenses are out of focus by approximately 50 microns (0.002 inch). In a practical design approach, we would not allow the total error budget to be used up by focus errors, and a focus tolerance of about 25 microns (0.001 inch) would be a likely goal.

With the higher resolution Type 3400 film, the limiting resolution is about 29 lp/mm and the depth of focus for 10 lp/mm resolution would be about 90 microns. Note that figure 25 plots depth of focus in terms of deviation from the desired focal plane, which can be either positive or negative, so that the total deviation is twice the value shown.

We can increase the allowable defocus by increasing the lens f/number, but this of course decreases its photometric efficiency. A useful rule of thumb states that, for a given MTF value, the allowable depth of focus is proportional to the f/number of the lens. Thus, at f/2 the depth of focus would be twice as large as at f/1. But, of course, doubling the f/number reduces the light throughput by a factor of 4.

6.4.2 TRACKING REQUIREMENTS

During any Barium Cloud Experiment conducted from the Space Shuttle, there will be relative motion between the cloud and the Shuttle and a tracking capability may be required to achieve the desired resolution. A 2-hour experiment is anticipated. Tracking requirements do not impact the instruments per se, but we have given some thought to the topic as an aid to those who must analyze the payload resources necessary to implement the tracking. If the instruments are mounted on

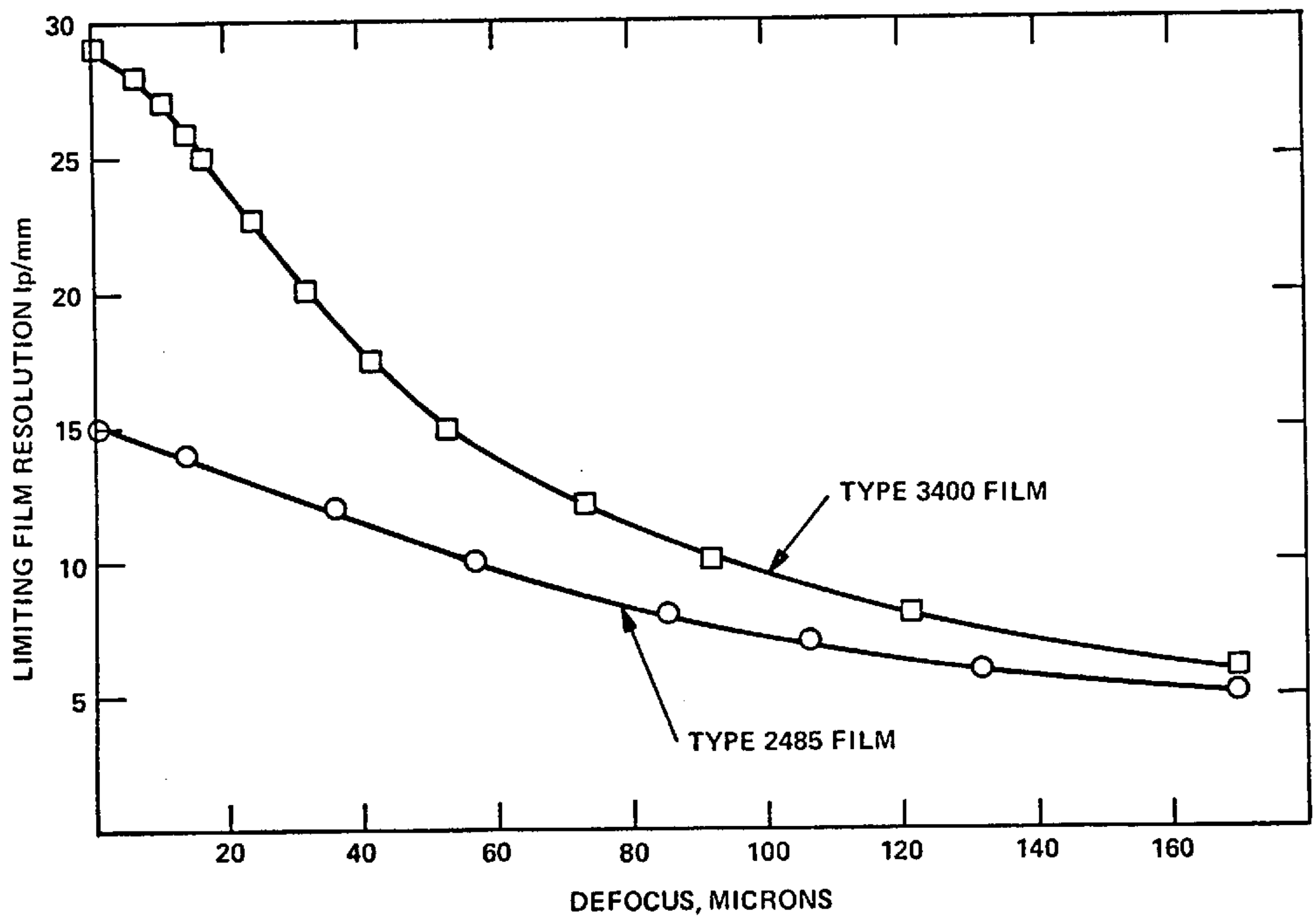

Figure 25. Limiting Film Resolution as a Function of Focus Error for the Objective and Relay Lens - EOS Image Intensifier Camera

the pallet, then a separate tracking platform can be used. If the instruments are in the pressurized module then the Shuttle itself will have to be positioned. Not addressed here is the method by which the tracking signals are derived. An automatic tracking capability might, for example, be added to the TV system.

To estimate the tracking requirements, we will determine the detrimental effects of tracking errors upon the resolution of the image intensifier camera. As discussed in paragraph 6.4.1, a resolution of about 10 lp/mm is the minimum desired. The depth of focus calculations were based on this value. It might be reasonable to allow, say, 20 percent MTF reduction due to tracking errors.

A tracking error, constant during the frame exposure time, will cause a (mathematically) thin line in the image plane to be smeared into a bar of width W along the direction of smear. This is the "spread function" due to tracking error, and the MTF associated with this spread function is

$$\text{MTF} = \frac{\text{Sin}X}{X}$$

where $X = \pi W \nu$

and ν = spatial frequency.

Arbitrarily requiring this MTF to be 80 percent at 10 lp/mm, we have

$$\frac{\text{Sin}X}{X} = 0.8$$

or $X = 1.13$

and $W = 0.036$ mm (allowable image smear).

The objective lens has an effective focal length of 150 mm. Thus, the allowable angular smear is $(0.036)/150 = 2.4 \times 10^{-4}$ radians or 0.014 degrees.

The exposure times, during the September 1971 Barium Cloud Experiment, varied from about 0.2 second at the start of the Experiment to about 2.0 seconds at the end, 2 hours later. Thus, a reasonable tolerance on tracking error would be 0.007 degree/second. Longer exposure times, or longer focal length objective lenses, would reduce this value proportionately.

6.5 RELIABILITY CONSIDERATION

A brief, preliminary analysis was made of the reliability of each of the two instruments in their present configurations. This analysis consisted of the summation of the generic failure rates of the parts (or subassemblies) of each instrument. This summation is shown in tables XV and XVI. Electronic, electromechanical, and mechanical parts were considered. No consideration was given to design or assembly defects, such as overstress or misalignment.

TABLE XV - ESTIMATED FAILURE RATES - IMAGE INTENSIFIER SYSTEM

Part Name	Quantity	*λ	Total
Objective Lens and Relay Lens	1	N/A	---
Filter Tilter and Iris Assembly	1	N/A	---
Image Intensifier Tube and Focus Coil	1	10.000	10.000
Relay Lens Assembly	1	N/A	---
Power Supply	2	13.979	27.958
Cooling System	1	2.466	2.466
Line Cord	1	N/A	---
Control Console			
Meters	2	2.816	5.632
Relays	5	0.500	2.500
Transformer	1	2.000	2.000
Circuit Breaker	1	3.250	3.250
Pump	1	134.032	134.032
Potentiometers	6	1.400	8.400
Switches	3	3.600	10.800
Lamps	3	6.500	19.500
Main Housing and Camera Focus Mechanisms	1	17.402	17.402
Film Camera	1	48.000	48.000
			291.940

*Failure rates per 10^6 hours from MIL-HDBK-217, FARADA, and AVCO Reliability Handbook

TABLE XVI - ESTIMATED FAILURE RATES - SEC TV CAMERA

Part Name	Quantity	* λ	Total
Camera Head	1	33.000	33.000
Camera Control Unit			
Resistor, Carbon	277	0.048	13.296
Resistor, M.F.	4	0.360	1.440
Potentiometer	24	1.400	33.600
Capacitor, Tant	104	0.174	18.096
Capacitor, Mica	15	0.081	1.215
Capacitor, Al	12	0.288	3.456
Capacitor, Paper	11	0.660	7.260
Diodes	30	0.350	10.500
Zener Diodes	22	0.300	6.600
Transistors	72	2.400	172.800
IC	23	3.200	73.600
Switches	10	3.600	36.000
Inductors	6	1.720	10.320
Camera Cable	1	N/A	------
Power Cable	1	N/A	------
Lens Adapter	1	N/A	------
Housing	2	2.048	4.096
			425.279

*Failure rates per 10^6 hours from MIL-HDBK-217, FARADA, and AVCO Reliability HDBK.

The predicted reliability, R, is given by

$$R = \exp(-\tau\Sigma\lambda)$$

where τ is the experiment time and in hours and $\Sigma\lambda$ is the summation of the generic failure rates on a per hour basis.

This analysis resulted in the following estimated reliability for 150 hours of operation:

System	Reliability
EOS Image Intensifier	0.95715
Westinghouse SEC TV Camera	0.93820

It should be noted that this analysis applies only to the present design of the two instruments. However, the reliability of any modified design should be even higher. The calculated reliability of the two instruments is high and considered to be within the range of space hardware.

SECTION 7

ESTIMATED COSTS

An engineering estimate has been made of the costs associated with the various equipment modifications discussed in the preceding sections. It should be emphasized that these estimates are based on many factors that are yet to be resolved such as environmental requirements, technical performance, reliability, number of units, and schedule, just to name a few.

In addition, these estimates are not of the "ground-up" variety in which a complete baseline design is established with vendor estimates obtained for materials and subcontracts, documentation requirements established, etc. Instead, we have keyed our estimates to the summaries shown in tables VIII and IX, which itemized the various aspects of the instruments that need attention to meet the design criteria in Appendix A. This table listed six levels of activity:

1. Analysis Required
2. Minor Design Modifications Required
3. Testing Required
4. Manufacturing Modification Required
5. Design Modification Desirable
6. Major Design Modification Required

To derive a cost figure, we estimated the increase in unit cost associated with each level of activity (where one was required) for both the pallet and pressurized module. These cost increases were then combined into the following four categories:

1. Minor Modifications - Minimum design changes required to meet the design criteria for a sortie mission.
2. Full Recommended Modification - Tasks included in (1) plus all the design changes needed to make the instruments more compatible with the Spacelab. This includes minimizing weight, power consumption and heat rejection, plus ruggedizing the instruments.
3. New Design - Minimum Documentation - Implement all design changes in (2) and completely redesign all parts, as appropriate, to maximize compatibility with the Space Shuttle Spacelab. Consideration will be given to changes in the instruments' basic characteristics. Qualification testing, acceptance testing, and 100 percent parts inspection will be performed.

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4. New Design - Complete Documentation - Tasks included in (3) plus a complete and documented structural analysis, thermal analysis, reliability analysis, Quality Assurance coverage, etc., with a complete screening of all components.

The results of the above efforts are summarized in table XVII, which shows the unit cost estimate assigned to the four different categories for each instrument for both the pressurized module and the pallet.

The first column shows the original 1970 purchase price. For the image intensifier system, the $38K unit price ($46K minus $8K for the film camera) represents the unit price for the design, development, and delivery of 10 systems.

The second column shows the 1970 price converted to 1974 dollars, using an escalation factor of 6 percent per year for 4 years. We have assumed this factor based on a labor increase of 5 percent per year and an overall material increase of 7 percent per year. These factors are probably conservative. For example, the price of aluminum has risen 45 percent over the past 12 months. The remainder of the table is also in terms of 1974 dollars.

Columns three and four are the estimates derived from Categories (1) and (2) defined above. Note that the estimate for the image intensifier system is not much higher for the Full Recommended Modification category than it is for the Minor Modifications category. One of the reasons is that the use of a permanent magnet instead of a focusing coil has allowed the deletion of several major components, which helps offset the costs of the redesign efforts.

To go from the category of Full Recommended Modification to that of New Design will require an increase of about 50 percent for the image intensifier camera and about 40 percent for the TV camera. This latter increase is smaller because relatively more changes would have to be made in the TV camera to bring it up to the Full Recommended Modifications category and thus it would be easier to move to the New Design category.

The last column and category, New Design With Complete Documentation, is the toughest to estimate. Included here are the costs of NASA-type program controls for space qualified hardware: full Quality Assurance and Quality Control; extensive testing, analysis, and reporting; interface and coordination with numerous outside activities; full drawing packages; screening and traceability of all parts and components; and many other expensive tasks. Just the cost for components alone can rise sharply due to screening requirements. This increase can vary from perhaps a factor of 10 for mechanical parts to a factor of 30 for electronic parts. If we assume a median increase factor of 20 for parts and components, and also assume that 1/3 of the instrument's cost is due to parts and components, then this factor contributes an overall increase factor of 22/3 or 7.33 to the system's cost.

Additional documentation, testing, etc., could easily contribute an additional 30 percent to overall program costs. Thus, this rationale implies approximately a 10 times increase in cost for a "complete documentation" program over a "minimum documentation" program. This final estimate is shown in the last column of table XVII. Since a prime goal of the Space Shuttle is to reduce the cost of space experiments, hardware that is fully "space qualified" may not be required and the cost for a new design would probably lie somewhere between the estimates shown in the last two columns of table XVII.

TABLE XVII - ESTIMATED UNIT COST (IN $K) FOR VARIOUS LEVELS OF MODIFICATION

Instrument	Original purchase price 1970	Purchase price in 1974 dollars based on 6%/year escalation	Minor Modifications		Full Recommended Modifications		New design, minimum documentation		New design, complete documentation	
			(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Image Intensifier Camera	46 (a)	58	65	74	67	79	100	118	1000	1180
TV Camera	30 (b)	38	48	56	59	70	83	98	830	980

Key: (1) Pressurized module

(2) Pallet

Notes: (a) Cost includes approximately $8K for film camera purchased by NASA under a separate contract with Geotel Corporation

(b) Cost includes 17-inch monitor

SECTION 8

CONSIDERATIONS OF ADVANCED TECHNOLOGY

The instruments studied during this contract were designed prior to 1970. New technology has developed since that time which can improve the performance of low light level equipment. It is apparently too early in the Space Shuttle program to firm up the sortie missions and therefore the instrumentation required. However, applicable new technology should be considered before any hardware is modified or redesigned. This section briefly discusses some of these technological advances.

8.1 IMAGE INTENSIFIER CAMERA

8.1.1 ELIMINATION OF THE RELAY LENS

The 1:1 relay lens in the image intensifier camera was a state-of-the-art design in 1970 and probably still is today. The lens is a true f/1 (0.5 numerical aperture) at the input and output focal planes, and it was designed at this high speed for good photometric efficiency in transferring the phosphor image to the photographic film. This transfer efficiency is given approximately by

$$\frac{T}{4F^2}$$

where T is the lens transmission and F is the lens f/number. For the f/1 relay lens and 0.6 transmission, the transfer efficiency is 15 percent. Thus, even for this very high speed relay lens, there is a loss of about 85 percent of the available energy to expose the film.

A more modern approach to the image transfer problem is to discard the relay lens and place the film in intimate contact with the image tube, which will have the output phosphor deposited on a fiber optics face plate. Energy transfer is then essentially 100 percent efficient, minus the small transmission loss caused by the fiber optics. The resolution loss due to the fiber optics is more than offset by the resolution gain due to deleting the relay lens.

To avoid scratching the film emulsion, the film must be pulled back away from the face plate before the next film frame is moved into position. This extra motion and mechanism limits the frame rate that can be obtained. However, 70 mm cameras have been built which are capable of 20 fps, which is about four times faster than the maximum frame rate used during the September 1971 Barium Cloud Experiment.

This type of camera has to be specially designed to work with a particular image tube (and focusing coil or permanent magnet, in the case of an electromagnetically-focused tube), but this appears to be a reasonable compromise compared to the approximately six-fold gain in energy available for film exposure.

8.1.2 SECOND GENERATION IMAGE TUBES

In the last few years, the so-called "second generation" intensifier tubes have been developed and are replacing the electrostatic "first generation" devices. The newer tubes derive their electron gain by the use of small channels, similar to hollow fiber optics. An electron traveling down this channel releases additional electrons every time it collides with the channel wall, so large gains can be generated in short distances. Focusing is by "proximity," i.e., an electron generated at the photocathode is captured immediately by a channel and forced to impinge on a corresponding point on the phosphor. This newer tube is to be contrasted with the first generation type, which uses electrostatic fields to focus, onto the phosphor, the electrons generated at a point on the photocathode. These newer tubes are sometimes termed Microchannel Plates (MCPs). Presently, they are made in diameters up to 75 mm.

The MCP will have less than 1 percent distortion, compared to perhaps 10 percent or higher in a first generation, electrostatically-focused tube. They are much shorter than first generation tubes but have less resolution. However, if system resolution is limited by photon noise (and new Barium Cloud Experiments will probably be in this category), then MCPs can offer a much more compact system than the present image intensifier camera. An MCP approach, with direct film contact to the fiber optics output, could offer a very attractive package.

Table XVIII summarizes some pertinent comparisons between the present magnetically focused tube and a possible MCP replacement. If additional gain is needed (considered unlikely), a diode stage can be added to the MCP as shown in the last column of table XVIII.

8.2 TV CAMERA

An image tube was introduced 4 to 5 years ago after the SEC was developed, which has some advantage over the SEC. This is the Silicon-Intensifier Target (SIT) camera tube manufactured by RCA or the Electron Bombarded Silicon (EBS) device made by Westinghouse. These two tubes, the SIT and the EBS, operate on the same principle which is to utilize a silicon diode array target. The target exhibits higher gain than the SEC target and is much more rugged both electrically and mechanically.

As a result, it is possible to replace the SEC with a tube which is better adapted to the space environment. The target is not troubled by over-exposure as is the SEC tube and the gain may be at a sufficient level to delete the requirement for integration. The SIT target gain is 2500 under normal operating potentials compared to 100 with the SEC. The comparative results of resolution for various focal plane illumination conditions is shown in figure 26.

The replacement of the SEC tube with an EBS device would require only minor mechanical changes and some high voltage power supply changes. Table XIX gives further details.

TABLE XVIII - IMAGE TUBE COMPARISONS FOR IMAGE INTENSIFIER

Parameter	2-Stage Magnetic Tube	Microchannel Plate (MCP) Tube	MCP/Diode Combination Tube
Limiting resolution	55 lp/mm	25-28 lp/mm	20 lp/mm
Radiant power gain (S-20, P11, 2870°K)	~ 5,000	~ 5,200	~ 165,000
Maximum output steady-state brightness	25 ft-L	5 ft-L	5 ft-L
Overall length	18 cm (7.09 in.)	~1.2 cm (0.47 in.)	~2.5 cm (0.98 in.)
Magnetic field for focusing	Solenoid or permanent magnet	Not required	Not required
Gating	Difficult	Easy	Easy
High voltage required	~ 25 kV	~ 10 kV	~ 10 kV
Useful life	Adequate	Questionable	Questionable
Phosphor persistance problem	Not fully determined, probably significant	Little or none	Little or none

TABLE XIX - COMPARISON OF SEC AND EBS CAMERA TUBES FOR SEC TV

Parameter	Burn Resistant SEC	EBS
Target gain	100	2500
Limiting resolution	550	600
Dark current	Negligible	35 nA
Peak signal current	400 nA	1000 nA
Lag	5%	8%
Image diagonal	25 mm (0.98 in.)	25 mm (0.98 in.)
Length	0.216 m (8.5 in.)	0.216 m (8.5 in.)
Gun diameter	0.026 m (1.03 in.)	0.026 m (1.03 in.)

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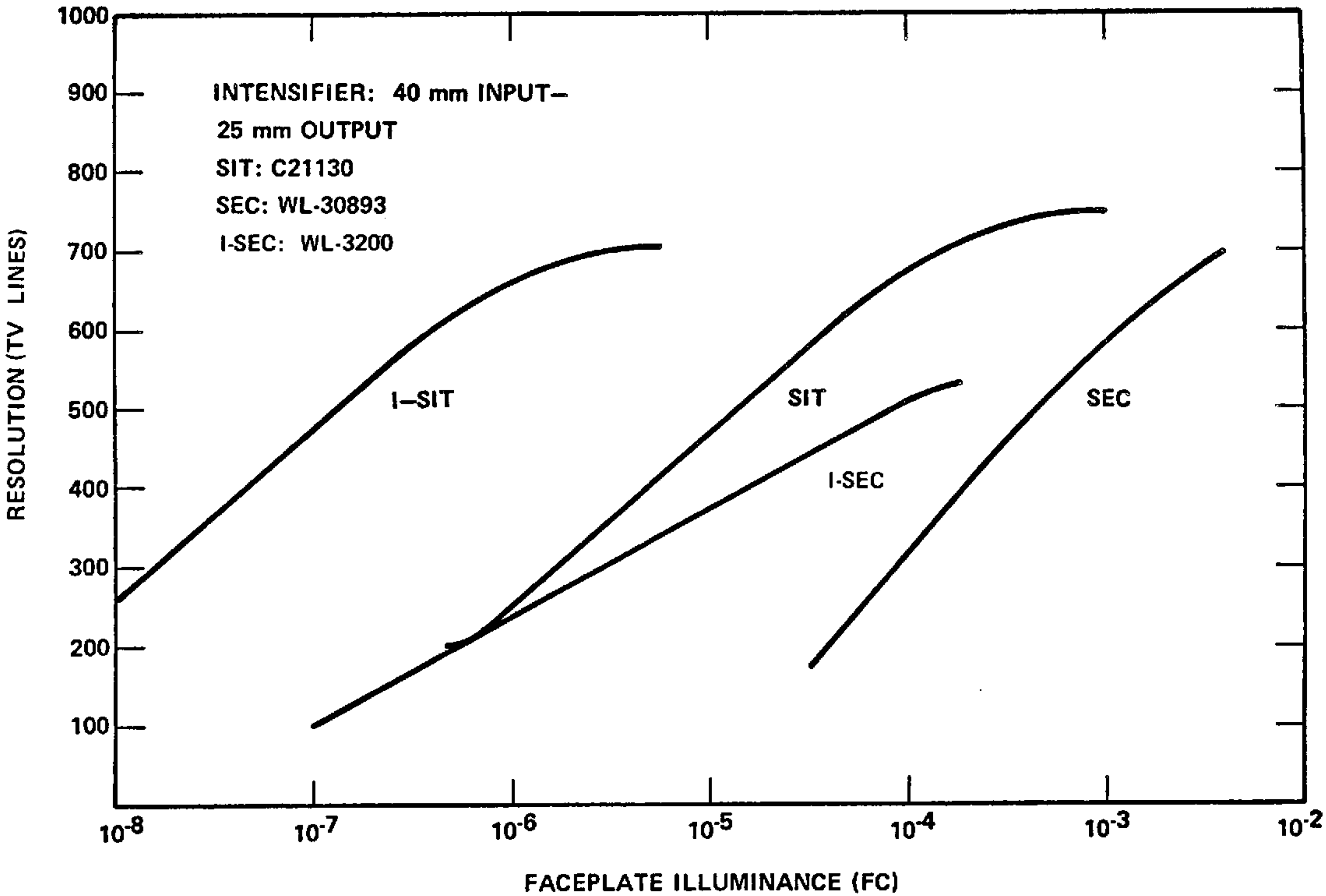

Figure 26. Comparison of SEC and SIT Television Camera Tubes

An investigation should be conducted with the SIT/EBS to determine if the additional gain will suffice for the application. If the detection of the image is limited by photon noise and the integration mode of the SEC is necessary to improve the signal-to-noise, then the added gain of the SIT is not important. In the case that the SEC simply is lacking in gain and the image detection is not photon noise limited, then it may be possible that the EBS would simplify the camera electronics and also increase reliability through improved target characteristics.

SECTION 9

BIBLIOGRAPHY

This section contains all the material reviewed or consulted during the study efforts. There is no significance to the order in which they are listed. (Refer to table XX.)

TABLE XX - BIBLIOGRAPHY

No.	Document	Title/Number	Date	Author/NASA Location	Notes
1	Book	Proceedings of the Space Shuttle Sortie Workshop, Vol. 1 Policy and System Characteristics	July 31-August 4, 1972	Dr. Rodney W. Johnson, Headquarters, General Chairman Dr. Leslie Meredith, Goddard Space Flight Center, Greenbelt, Maryland, Cochairman	Sponsored by Office of Space Science and Office of Applications
2	Drawing	Barium Ion Cloud Experiment (Pallet Mount) PH-2, Phase II	October 30, 1973	Received from C. Tynan NASA-Langley Research Center, Hampton, Virginia	Conceptual Approach for Instrument Mounting
3	Manual	Sortie Laboratory User's Guide George C.Marshall Space Flight Center (Memorandum dated May 7, 1973 Cover Sheet)	April 1973	Sortie Laboratory Task Team Program Development	Interim Issue based on U.S. Option
4	Report	Space Shuttle and Spacelab Discussions, Vol. A-Structures, Thermal, and Mechanical Systems-JSC08500	October 11, 12, 1973	Lyndon B. Johnson Space Center Houston, Texas	LP10103-E180
5	Report	Space Shuttle and Spacelab Discussions-Rockwell Presentations, Space Shuttle Overview and Current Status-SSV73-58	October 11, 12, 1973	North American Aerospace Group (NAS9-14000)	
6	Report	Space Shuttle and Spacelab Discussions, Vol. B Environmental Thermal Control and Life Support System-JSC08500	October 11, 12, 1973	Lyndon B. Johnson Space Center Houston, Texas	LP10103-B44

TABLE XX - BIBLIOGRAPHY (Contd)

No.	Document	Title/Number	Date	Author/NASA Location	Notes
7	Letter/Draft of Test Requirements	Test Requirements for the Commercial Hardware Evaluation Program - Ref. No. S&E-ASTR-MT-73-098	June 7, 1973	S&E-ASTR-MTC/H.M. Feather George C. Marshall Space Flight Center, Huntsville, Alabama	
8	Report	Payload-Shuttle Interface Data Book-MSFC-PD-73-1, Revision A	July 27, 1973	Program Management George C. Marshall Space Flight Center, Huntsville, Alabama	
9	Report	Space Shuttle Program-Space Shuttle System Payload Accommodations, Level II Program Definition and Requirements, Vol. XIV JSC 07700, Revision A	July 16, 1973	Lyndon B. Johnson Space Center, Houston, Texas	
10	Manual	NASA Technical Memorandum NASA TM X-64627 - Space and Planetary Environment Criteria Guidelines for Use in Space Vehicle Development 1971 Revision	November 15, 1971	Robert E. Smith, Editor George C. Marshall Space Flight Center, Huntsville, Alabama Aero-Astrodynamics Laboratory	
11	Report	A High Resolution Image Intensifier System for the Proposed Shaped Charge Barium Ion Cloud Release	June 1973	Paul K. Clemens Computer Sciences Corporation (Under Contract No: NAS6-1847-Task 71-39)	Prepared for: NASA Wallops Station Wallops Island, Virginia

TABLE XX - BIBLIOGRAPHY (Contd)

No.	Document	Title/Number	Date	Author/NASA Location	Notes
12	Report	Issue 3 of Spacelab System Requirements, Level II (Contract Document 8) Draft	August 1, 1973	European Space Research Organization, European Space Research and Technology Centre	
13	Report	Terrestrial Environment (Climatic) Criteria Guidelines for Use in Space Vehicle Development, 1971 Revision (NASA TM X-64589)-NASA Technical Memorandum	May 10, 1971	Glenn E. Daniels, Aero-Astrodynamics Laboratory George C. Marshall Space Flight Center, Huntsville, Alabama	
14	Report	Addendum to above document Paragraph 18.5 W Water Entry and Recovery Conditions	January 20, 1972	S. Clark Brown/George H.Fichtl Aerospace Environment Division Aero-Astrodynamics Laboratory NASA-George C. Marshall Space Flight Center	
15	Report	NASA Technical Memorandum Study of Shuttle-Compatible Advanced Technology Laboratory (ATL) NASA TM X-2813	September, 1973	Staff of Shuttle Experiments Office, Langley Research Center Hampton, Virginia	
16	Specification Report	Two Piece SEC Camera Model STV-614 DB 95-155	May, 1969	Westinghouse Electric Corporation	
17	Report	NASA Technical Memorandum Natural Environment Design Requirements for the Sortie Module-NASA TM X-64668	June 2, 1972	George S. West, Jr., Aero-Astrodynamics Laboratory George C. Marshall Space Flight Center, Alabama	Attachment C SEO 1/26/73

C-2

TABLE XX - BIBLIOGRAPHY (Contd)

No.	Document	Title/Number	Date	Author/NASA Location	Notes
18	Test Specification	Revised Vibration, Acoustic, and Shock Design and Test Criteria for Components Located on the Sortie Laboratory (Spec. dated 8/24/72) S&E-ASTN-AA(72-89)-Letter; Spec-S&E-ASTN-ADV(72-91)	September 7, 1972	Harry J. Bandgren, Chief Vibration and Acoustics Section George C. Marshall Space Flight Center, Huntsville, Alabama	Supersedes Criteria in Memorandum S&E-ASTN-ADV-(72-80)
19	Manual	Spacelab Guidelines and Constraints for Program Definition, Level 1 ESRO-SL-73-1, NASA MF-73-1, Revision 1	September 21, 1973	NASA-Douglas R. Lord	
20	Design Specification	Spacelab Design Requirements Document	September 7, 1973	George C. Marshall Space Flight Center, Huntsville, Alabama	
21	Equipment Specification	General Equipment Specification Part 1, Performance, Design and Verification Requirements for Equipment and General Laboratory Equipment to be Selected for Project Sortie Laboratory EC 006M00000 A	January 8, 1973	George C. Marshall Space Flight Center, Huntsville, Alabama	

TABLE XX - BIBLIOGRAPHY (Contd)

No.	Document	Title/Number	Date	Author/NASA Location	Notes
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23	Statement of Work	Analysis of Commercial Equipment and Instrumentation for Shuttle Sortie Laboratory Payloads.	September, 1973	Program Development George C. Marshall Space Flight Center	
24	Specification	Specification for Image Intensifier System	June 23, 1969	NASA/Wallops Island Wallops Island, Virginia	This is the Contractual Specification for the EOS Image Intensifier Camera System.
25	Specification	Specification for Intensified Image S.E.C. Data Acquisition System Specification No. L55-1026	April 17, 1970	NASA/Langley Research Center, Hampton, Virginia	
26	Handbook	Concept Verification Testing Experiment/Technology Users' Handbook MSFC-HDBK-511	July 31, 1973	W.A. Brooksbank, Jr. Manager, CVT Task Team George C. Marshall Space Flight Center Huntsville, Alabama	

TABLE XX - BIBLIOGRAPHY (Contd)

No.	Document	Title/Number	Date	Author/NASA Location	Notes
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		NOTICE 1 - MIL-STD-454C	May 19,1971		
		NOTICE 2 - MIL-STD-454C	December 1, 1971		
		NOTICE 3 - MIL-STD-454C	May 1, 1972		
28	Military Standard	Environmental Test Methods MIL-STD-810B	June 15, 1967		Supersedes MIL-STD-810A (USAF) dated June 23, 1964
		NOTICE 1 - MIL-STD-810B	October 20, 1969		
		NOTICE 2 - MIL-STD-810B	September 29, 1969		
		NOTICE 3 - MIL-STD-810B	September 18, 1970		
		NOTICE 4 - MIL-STD-810B	September 21, 1970		
29	Military Specification	Environmental Testing, Aeronautical and Associated Equipment, General Specification USAF-NOTICE 1 to MIL-E-5272C(ASG)	January 22, 1971		

TABLE XX - BIBLIOGRAPHY (Contd)

No.	Document	Title/Number	Date	Author/NASA Location	Notes
30	Military Specification	Electromagnetic Compatibility Requirements, System Interim Amendment MIL-E-6051D, Amendment 1 (USAF)	July 5, 1968		
31	Military Specification	Propellant Pressurizing Agent, Nitrogen MIL-P-27401B	September 19, 1962		Superseding MIL-P-27401A (USAF) 7 November 1960
32	Report	Shuttle Payload, Data Acquisition and Control for the User - Summary	Late 1973-Early 1974	NASA	Extracted from larger document
33	Report	Space Shuttle System Payload Accommodations Level II Program Definition and Requirements, Vol. XIV JSC 07700, Revision B	December 21, 1973	NASA, Lyndon B. Johnson Space Center, Houston, Texas	
34	Report	Analysis of Multipurpose Equipment for Space Application	December 10, 1973	Beckman Instruments Advance Technology Operations Anaheim, California	Final Report for Study Contract-NAS8-29776 Prepared for George C. Marshall, Space Flight Center, Huntsville, Alabama

TABLE XX - BIBLIOGRAPHY (Concluded)

No.	Document	Title/Number	Date	Author/NASA Location	Notes
35	Report	Payload-Shuttle Interface Data Book-MSFC-PD-73-1 (Revision B)	January 18, 1974	NASA, Program Development George C. Marshall Space Flight Center, Huntsville, Alabama	
36	Report	Off-the-Shelf Equipment Utilization in Shuttle Payloads-Plan	January, 1974	Concept Verification Test George C. Marshall Space Flight Center Huntsville, Alabama	
37	Charts	RIDS Status; ESRO/NASA Planning Schedule (NASA-S-73-3686B)	Late 1973 or Early 1974		Extracted from larger document
38	Charts	Orbiter Payload Cabling Concept; Electrical Interfaces	Late 1973 or Early 1974	North American Aerospace Group (14SSV14128)	Extracted from larger document
39	Charts	Analytical Prediction of the Orbiter Payload Bay Environment; NASA-S-73	Late 1973 or Early 1974		Extracted from larger document
40	Manual	Technical Manual Operating and Maintenance Instructions Wallops Island Image Intensifier System	February, 1971	Xerox Corporation/Electro-Optical Systems, Pasadena, California	
41	Standards	Standard Nuclear Instrument Modules TID-20893 (Revision 3)	December 1969	U.S.Atomic Energy Commission	Applicable to interface standardization for electronic instrumentation

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1. Alagany Ludman Steel Corporation, "Electrical Materials Handbook," Document No. 43, 1961.

2. Leo Levi, Applied Optics, A Guide to Optical System Design, John Wiley and Sons, 1968.

3. C. B. Johnson, "MTFs, A Simplified Approach," Electro-Optical Systems Design, November 1972, p. 22.

APPENDIX A

SHUTTLE SORTIE MISSION -

BARIUM CLOUD EXPERIMENT

FUNCTIONAL DESIGN CRITERIA

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Concluded)

1.0 SCOPE

This document establishes the functional design criteria for the feasibility study of adapting existing electro-optical instruments for a barium cloud experiment to be used on-board a Shuttle Spacelab. Two different modes of operation for the instruments are to be considered:

Case I - The instruments will be located in a pressurized (14.7 psia) module and will look at space through viewports. The crew will have access to the instruments during the mission.

Case II - The instruments will be located on an instrument platform in the unpressurized payload bay and will be operated remotely from the pressurized module. If necessary, the instruments will be wholly or partially enclosed in an environmental shell to maintain the necessary operating environment for the instruments.

A baseline Shuttle sortie mission of 30 to 60 degrees inclination, 100 to 300 nautical miles altitude, and 7-day duration will be used for the study.

2.0 APPLICABLE DOCUMENTS

The following documents form a part of this functional requirement:

FEDERAL

FED-STD-209	Clean Room and Work Station Requirements, Controlled Environment

MILITARY

MIL-STD-810B	Environmental Test Methods
MIL-E-6051D	Electromagnetic Compatibility Requirements, Systems
MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-E-5272	Environmental Testing, Aeronautical & Associated Equipment, General Specification for
MIL-P-27401	Propellant Pressurizing Agent, Nitrogen
MIL-STD-889	Dissimilar Metals

NASA

MSFC 10M33222	Man/Systems Design Requirements for Sortie Lab
MSFC 50M02442	ATM Material Control for Contamination Due to Outgassing
MSFC-STD-105	Synthetic Rubber, Age Control of
NASA TMX-64627	Space and Planetary Environment Criteria Guidelines for Use in Space Vehicle Development

3.0 DESIGN CRITERIA

3.1 DESIGN PHASE

The design of the barium cloud experiment shall conform to applicable specifications as specified herein.

3.1.1 Combustible Materials

Combustible materials shall not be used unless a suitable non-combustible or self-extinguishing material is not available for the design application. When it is imperative to use a combustible material in the specified environment, the functionally acceptable material with the lowest flame propagation rate shall be used.

3.1.2 Outgassing (Ref. 1)

All non-metallic materials to be used in the pallet environment shall meet the outgassing requirements of the NASA specification, MSFC 50M02442.

3.1.3 Age Control for Synthetic Rubber Parts (Ref. 1)

Age control for synthetic rubber parts shall be in accordance with MSFC-STD-105.

3.1.4 Fungus-Inert Materials (Ref. 1)

The requirements for fungus-inert materials shall be in accordance with MIL-STD-454, Requirement 4. Nutrient materials, if used, shall be treated by a method that will render the resulting exposed surface fungus-resistant as demonstrated by the ability to successfully pass the fungus test specified in MIL-E-5272.

3.1.5 Dissimilar Metals (Ref. 1)

Dissimilar metals shall not be used in intimate contact unless suitably protected against electrolytic corrosion. If dissimilar metals are used, as defined in MIL-STD-889, an interposing material, compatible to each, shall be used.

3.1.6 Corrosion Resistance

Materials shall be of corrosion-resistance types, or shall be suitably processed to resist corrosion in all environments specified herein. Stress corrosion resistance shall be considered where appropriate.

3.1.7 Protective Treatment

Materials that are subject to deterioration when exposed to the environmental conditions specified herein, shall be protected in a manner that will, in no way, prevent compliance with the requirements of this specification.

3.1.8 Radioactive Materials

No radioactive materials shall be used.

3.1.9 Magnetic Materials

No or low magnetic materials shall be used wherever possible.

3.1.10 Finish

When no specific finish requirements are specified herein, selection of proper surface treatments, finish materials and application methods shall be governed by the type of material used, environmental and functional design requirements, and handling and storage requirements as imposed by this specification.

3.1.11 Contamination Control (Refs. 2 and 3)

Equipment material or equipment finish shall not flake-off, generate dust or contain releasable particles that could degrade the FED-STD-209, class 100,000 spacecraft environment. All surfaces shall be capable of being cleaned with suitable solvents to maintain surfaces visibly clean. Contamination protection devices such as aperature doors, window covers, electrical heaters, and dust free storage containers shall be used as necessary.

3.1.12 Maintainability (Ref. 4)

The barium cloud experiment will be designed to offer accessibility and repairability. Field maintenance shall be limited to checkout, removal, and replacement of parts.

3.1.13 Weight

The weight of the barium cloud experiment shall not exceed TBD pounds.

3.1.14 Size

The envelope dimensions shall not exceed TBD x TBD x TBD inches.

3.1.15 Electrical Power (Refs. 3 and 5)

The power available for all the experiments in the lab are given as follows:

Average: 4 KW

Peak: 9 KW

The power available for the barium cloud experiment has not been defined.

3.1.16 Thermal Control (Ref. 6)

The on-orbit peak payload heat rejection will be 21,500 BTU/HR. The allocation for the experiment will be TBD BTU/HR.

3.1.17 Service Life (Ref. 4)

After shipment from the EOS facility, and after five years storage, the barium cloud experiment shall have remaining a useful life of not less than one year while subjected to the environments specified herein, without compromise of its reliability or structural integrity.

3.1.18 Operations and Control (Ref. 3)

Human performance/human engineering requirements shall be as specified in MSFC 10M33222, "Man/Systems Design Requirements for Sortie Lab".

3.1.19 Reliability and Safety (Ref. 4)

The operating requirements for a manned research facility dictate special requirements for safety and reliability of each laboratory experiment. The experiment must operate reliably throughout the mission or be repairable without jeopardizing the crew and mission. Because of the length of the mission, major repairs will not be normally allowed. Other demands on the crew time in orbit will make it important that repair time requirement be minimal.

Design considerations for the experiment shall aim at eliminating, minimizing or controlling possible hazards by:

Design for Minimum Hazard - Through provision of appropriate design features and safety factors. Damage control, containment and isolation of potential hazards are to be included in design considerations.

Safety Devices - Known hazards which cannot be eliminated by design shall be reduced to an acceptable level by use of appropriate safety devices as part of the system, subsystem, or equipment.

Warning Devices - Where it is not possible to preclude the existence or occurrence of a known hazard, warning devices shall be employed for the timely detection of hazardous conditions, the generation of adequate warning signals and the control of the hazard. Warning signals and their application shall be designed to minimize the probability of erroneous signals or of improper personnel reaction to the signal.

Special Procedures - Where it is not possible to reduce the magnitude of an existing or potential hazard by design, or by use of safety and warning devices, special procedures shall be developed to counter hazardous conditions for enhancement of ground and flight crew safety.

3.1.20 Mechanical Interface

TBD

3.1.21 Factors of Safety (Ref. 3)

Package integrity and structural mounting provisions load carrying capability shall be based on the following minimum factors of safety in lieu of performing static load structural testing:

Yield Factor of Safety = 2.0

Ultimate Factor of Safety = 3.0

Hydraulic and pneumatic systems, where used, shall meet the following minimum requirements:

(1) Lines and Fittings, less than 1.5 inch diameter

Proof Pressure = 2.0 x limit pressure

Ultimate Pressure = 4.0 x limit pressure

(2) Lines and Fittings, 1.5 inch diameter or greater

Proof Pressure = 1.2 x limit pressure

Ultimate Pressure = 1.5 x limit pressure

(3) Hydraulic and Pneumatic Tanks & High Pressure Vessels

Proof Pressure	= 1.5 x limit pressure
Ultimate Pressure	= 2.0 x limit pressure

(4) Actuating Cylinder, Valves, Filters, Switches

Proof Pressure	= 1.5 x limit pressure
Ultimate Pressure	= 2.0 x limit pressure

3.2 TRANSPORTATION PHASE

The barium cloud experiment shall withstand the following environments encountered during transit, and as packaged for shipment.

3.2.1 Transportation Dynamics

Dynamic inputs to the barium cloud experiment during all handling, transportation and hoisting operations shall be constrained to not exceed the launch phase conditions of paragraph 3.5.

3.2.2 Solar Radiation (Ref. 7)

Direct and diffused sky radiation will not exceed the equivalent of 128 mW/cm^2 of normally incident radiation.

3.2.3 Temperature (Ref. 4)

Temperature will range from 4° to $55^{\circ}C$ (32° to $130^{\circ}F$).

3.2.4 Humidity (Ref. 4)

Humidity will range from 20 to 90 percent RH.

3.2.5 Ozone (Ref. 7)

The atmospheric ozone range will be:

0.5 ppm	72 hours
0.25 ppm	3 months
0.05 ppm	3 years

3.3 STORAGE PHASE

The barium cloud experiment will withstand the following environments, encountered as packaged for shipping, during storage.

3.3.1 Time (Ref. 4)

The storage time will not exceed five (5) years.

3.3.2 Temperature

Refer to paragraph 3.2.3.

3.3.3 Humidity

Refer to paragraph 3.2.4.

3.3.4 Ozone

Refer to paragraph 3.2.5.

3.4 PRELAUNCH PHASE

The barium cloud experiment will withstand the following environments encountered during prelaunch operations.

3.4.1 Solar Radiation

Refer to paragraph 3.2.2.

3.4.2 Pressure

The pressure will be 14.7 psia.

3.4.3 Temperature (Ref. 2)

Temperature will range from 4° to $27^{\circ}C$ (40° to $80^{\circ}F$)

3.4.4 Explosive Atmosphere (Ref. 7)

Explosive atmosphere is arbitrarily defined as any atmosphere possessing characteristics that fall within the boundary conditions defined in table 1.

Table 1. Explosive Atmosphere Characteristics and Limiting Bounds

Atmospheric Environment Characteristics	Range
Pressure	100 to 800 torr
Temperature	15^{o} to $55^{o}C$
Auto Ignition Temperature	Greater than $350^{o}C$
Chemical Constituents	Hydrogen (fuel) and air (oxidizer) combined in any potentially explosive mixture ratio.*

*For purposes of design evaluation through testing, gasoline (fuel) and air (oxidizer) may be substituted for hydrogen and air, using Test Method 511.1, Procedure I, of MIL-STD-810B.

3.4.5 Electromagnetic Control (EMC) (Ref. 2)

Payload electromagnetic interference requirements shall be specified in accordance with specification MIL-E-6051D as modified for payload use, to assure that radiated and conducted interference problems do not occur upon integration of payloads into the Orbiter payload bay. EMC verification of the integrated Shuttle/payload shall be required.

The Orbiter shall provide the capability to equalize electrical potential existing between it and the payloads without damage to payload or Orbiter systems. Lighting protection shall be provided.

3.5 LAUNCH PHASE

The barium cloud experiment shall withstand the following environments encountered during the launch phase.

3.5.1 Vibration (Ref. 8)

The barium cloud experiment shall withstand the flight random vibration and vehicle dynamics. The criteria for random vibration were derived by using the acoustic criteria. The criteria for the vehicle dynamics were based on the transient vibration analyses of the shuttle launch configuration.

3.5.1.1 Pressurized Module

Input to Instruments Mounted to Spacelab Walls Or Floor. Total Weight of Instruments Greater Than 60 Pounds.

1. Flight Random Vibration Criteria (3 min/axis)

20 - 200 Hz	@ 0.060 g^2/Hz
200 - 320 Hz	@ -3 dB/oct
320 - 2000 Hz	@ 0.038 g^2/Hz

Composite = 9.1 grms

2. Vehicle Criteria

Flight Axis (3-50 Hz @ 3 oct/min)

3 - 8.5 Hz	@ 0.80 inches D. A. Disp.
8.5 - 35 Hz	@ 3.0 G's peak
35 - 50 Hz	@ 1.0 G's peak

Lateral Axes (3-35 Hz @ 3 oct/min)

3 - 7 Hz	@ 0.80 inches D. A. Disp.
7 - 35 Hz	@ 2.0 G's peak

3.5.1.2 Pallet

Input to Instruments Mounted on Stiffened Skin Honeycomb Structure. Total Weight of Instruments Greater Than 200 Pounds but Less Than 500 Pounds.

1. Flight Random Vibration Criteria (3 min/axis)

20	Hz @ 0.081 g^2/Hz
20 - 35	Hz @ +6 dB/oct
35 - 480	Hz @ 0.25 g^2/Hz
480 - 2000	Hz @ 0.014 g^2/Hz

Composite = 12.2 grms

2. Vehicle Dynamics Criteria

Flight Axis (3-50 Hz @ 3 oct/min)

3 - 8.5	Hz @ 0.80 inches D. A. Disp.
8.5 - 35	Hz @ 3.0 G's peak
35 - 50	Hz @ 1.0 G's peak

Lateral Axes (3-35 Hz @ 3 oct/min)

3 - 7	Hz @ 0.80 inches D. A. Disp.
7 - 35	Hz @ 2.0 G's peak

3.5.2 Acoustic Noise (Ref. 8)

The barium cloud experiment shall be designed to survive an acoustical noise environment with a spectrum as defined in Table 2.

3.5.3 Acceleration (Ref. 6)

The acceleration levels will be as follows:

CONDITION	X	Y	Z
Liftoff	2.2 g	+ 0.2 g	0.0 g
High-Q Boost	1.9	± 0.2	+ .5
Booster End Burn	3.0 ± .3	± .2	+ .3
Orbiter End Burn	3.0 ± .3	± .2	+ .4

TABLE 2. PREDICTED ACOUSTICS CRITERIA FOR SPACELAB

(One Third Octave Band Acoustic Criteria in dB re 2 x 10^{-5} N/m^2)

Frequency (Hz)	External to Spacelab Lift-off (dB)	External to Spacelab Boost (dB)	Internal to Spacelab Lift-off (dB)	Internal to Spacelab Boost (dB)
5.0	119.0	118.5	107.0	106.5
6.3	121.0	120.5	110.0	109.5
8.0	122.5	122.0	112.0	111.5
10.0	124.0	123.5	114.0	113.5
12.5	126.0	125.5	116.5	116.0
16.0	127.5	127.0	118.5	118.0
20.0	129.0	128.5	120.5	120.0
25.0	130.5	129.5	122.5	121.5
32.0	131.5	130.5	124.0	123.0
40.0	132.5	131.0	125.5	124.0
50.0	133.0	131.5	126.0	124.5
63.0	133.5	131.5	126.5	124.5
80.0	134.0	131.5	127.0	124.5
100.0	134.0	131.0	127.0	124.0
125.0	134.0	130.0	127.0	123.0
160.0	134.0	129.0	127.0	122.0
200.0	134.0	128.0	127.0	121.0
250.0	133.5	126.0	126.5	119.0
320.0	133.0	124.5	126.0	117.5
400.0	132.5	123.5	124.5	115.5
500.0	131.5	121.5	123.0	113.0
630.0	130.5	120.0	121.5	111.0
800.0	129.5	118.5	119.5	108.5
1000.0	128.0	116.5	117.5	106.0
1250.0	127.0	114.5	116.0	103.5
1600.0	126.0	112.5	114.0	100.5
2000.0	125.0	111.0	112.5	98.5
2500.0	123.5	109.0	110.5	96.0
3200.0	122.5	107.5	108.5	93.5
4000.0	121.5	106.0	107.0	91.5
5000.0	120.0	104.5	105.0	89.5
6300.0	119.0	103.5	103.0	87.5
8000.0	118.0	102.5	101.5	86.0
10000.0	117.0	102.0	100.0	85.0
Overall SPL	145.0	141.5	138.0	134.5
Duration	60 sec	120 sec	60 sec	120 sec

3.5.4 Ordnance Shock (Separation Devices)

TBD

3.5.5 Temperature (Ref. 2)

3.5.5.1 Pressurized Module

The temperature will range from 50° to 135°F.

3.5.6 Pressure (Ref. 6)

3.5.6.1 Pressurized Module

The pressure will be 14.7 ± .2 psia. All components to be located inside the modules will, in normal operations, not be exposed to vacuum. However, the possibility of accidental depressurization of the module must be taken into account; therefore, all subsystems or components must be capable of sustaining depressurization as well as repressurization without posing any hazard to the crew or Orbiter operations.

3.5.6.2 Pallet

The launch pressure profile is shown in figure 1.

3.5.7 Earth Magnetic Field (Ref. 7)

The strength of the Earth's magnetic field varies over the surface of the Earth from 0.65 to 0.70 gauss near the magnetic poles; it is weakest toward the equatorial region where its value is 0.30 to 0.35 gauss. At some distance from the Earth, the intensity variation may be taken to be inversely proportional to the cube of the distance from the center of the dipole outward to the magnetopause at approximately 10 earth radii (in the sunward direction). The average total magnetic field is given below.

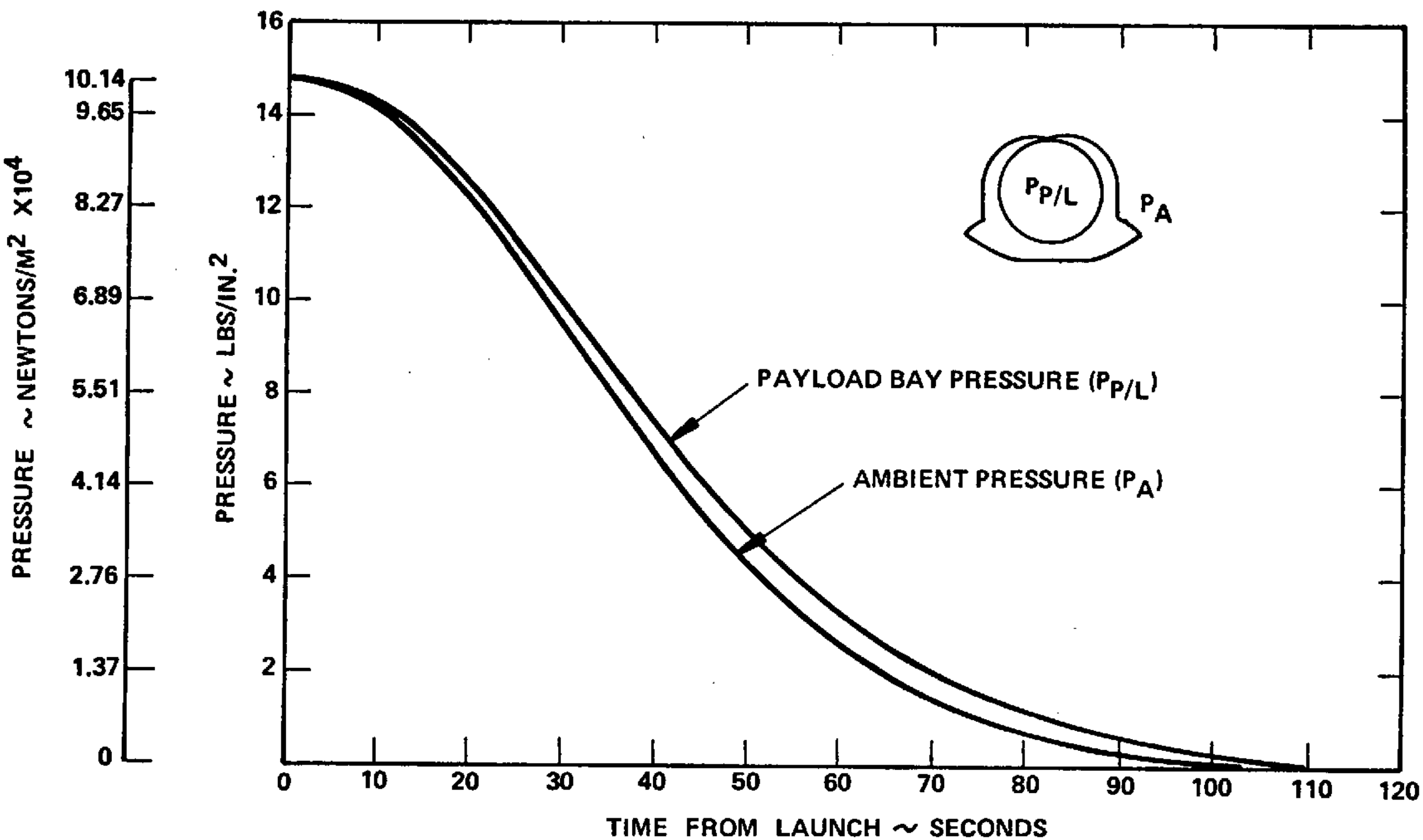

Figure 1. Payload Bay Ascent Pressure History

Average Total Magnetic Field In Gauss

Altitude (km)	Geodetic Colatitude in Degrees			
	0	30	60	90
200	0.52243	0.50782	0.40338	0.31406
400	0.48121	0.46403	0.36670	0.28630
1000	0.37978	0.35841	0.28088	0.21778
2000	0.26428	0.24682	0.18904	0.14629
3000	0.19052	0.17608	0.13343	0.10330
4000	0.14158	0.129988	0.09773	0.07571

3.5.8 Electromagnetic Control (EMC)

Refer to paragraph 3.4.5.

3.6 ORBIT PHASE

The barium cloud experiment will withstand the following environments encountered during the orbit phase.

3.6.1 Shock

The shock inputs during the orbit phase will not exceed the shock level during the launch phase given in T.B.D.

3.6.2 Acceleration (Ref. 6)

The acceleration level during the space operations is as follows

X	0.2 g
Y	.1 g
Z	.1 g

3.6.3 Vibration

The vibration inputs during the orbit phase will not exceed the vibration levels during the launch phase given in paragraph 3.5.1.

3.6.4 Radiation (Ref. 9)

The experiments shall be designed to provide necessary proctection to insure that the safe dosage limits of the equipment are not exceeded.

3.6.4.1 <u>Galactic Cosmic Radiation</u>

Galactic cosmic radiation consists of low intensity, extremely high energy charged particles. These particles, about 85 percent protons, 13 percent alphas, and the remainder heavier nuclei, bombard the solar system from all directions. They have energies from 10^8 to 10^{19} electron volts (ev) per particle and are encountered essentially everywhere in space. The intensity of this environment in "free-space," e.g., outside the influence of the Earth's magnetic field, is relatively constant (0.2 to 0.4 particles per square centimeter per steradian per second) except during periods of enhanced solar activity when the fluxes of cosmic rays have been observed to decrease due to an increase in the strength of the interplanetary magnetic field which acts as a shield to incoming particles. Near the Earth, cosmic rays are similarly influenced by the Earth's magnetic field resulting in a spatial variation in their intensity. The extreme of the galactic cosmic ray environment is at sunspot minimum. The environment is constant and may be scaled down to 24 hours. See Section 2.4.1 of NASA TMX-64627 for additional data on this subject. Estimates of the daily cosmic ray dose for the various orbits are shown in table 3. These should be considered in the Shuttle Spacelab design studies.

Table 3. Galactic Cosmic Ray Dose Rates (REM/DAY)

Event \ Orbit	255 n.mi. 55° Incl.	200 n.mi. Polar	Geo-synchronous
Solar Maximum	0.005	0.008	0.024
Solar Minimum	0.008	0.013	0.036

3.6.4.2 Trapped Radiation

The trapped radiation environment will be taken from most recent data of NASA SP-3024 (currently in six volumes) or from the TRECO computer code available from the National Space Science Data Center, NASA/Goddard Space Flight Center, and merged with trajectory information to find particle fluxes and spectra. The fluxes and spectra will be converted to dose by data and/or computer codes provided by MSFC/S&E-SSL-NR (see Section 2.4.2 of NASA TMX-64627).

Near-Earth Environment - The radiation belts trapped near the Earth are approximately azimuthally symmetric, with the exception of the South Atlantic anomaly where the radiation belts reach their lowest altitude. The naturally occurring trapped radiation environment in the anomaly region remains fairly constant with time although it does fluctuate with solar activity. Electrons will be encountered at low altitudes in the anomaly region as well as in the auroral zones.

Synchronous Orbit Altitude Environment - The trapped proton environment at synchronous orbit altitude is of no direct biological significance, but may cause deterioration of material surfaces over long exposure times. The proton flux at this altitude is composed of only low energy protons (less than 4 Mev) and is on the order of

10^5 protons/cm^2-sec. The trapped electron environment at synchronous altitude is characterized by variations in particle intensity of several orders of magnitude over periods as short as a few hours. However, for extended synchronous altitude missions, a local time averaged environment can be used. See Section 2.4.2.2 of NASA TMX-64627 for additional data.

Solar Particle Events - Solar particle events are the emission of charged particles from disturbed regions on the sun during solar flares. They are composed of energetic protons and alpha particles that occur sporadically and last for several dys. The free-space particle event model to be used for Shuttle Spacelab orbital studies is given in Section 2.4.3.1 of NASA TMX-64627.

Radiation Dose Limits - Table 4 lists the allowable radiation limits for the flight crews to be used for all applicable program considerations. These values are based on information contained in "Radiation Protection Guides and Constraints for Space - Mission and Vehicle - Design Studies Involving Nuclear Systems", a report of the Radiobiological Advisory Panel of the Committee on Space Medicine, Space Science Board, National Academy of Sciences. The Radiobiological Advisory Panel's concept of a primary reference risk is adopted and a unit reference risk is considered acceptable for the subject manned space flight programs.

Table 4. Radiation Exposure Limits and Exposure Rate Constraints for Unit Reference Risk

Constraints in REM	(REM) Bone Marrow (5 cm)	Skin (0.1 mm)	Eye (3 mm)	Testes (3 cm)
1 yr. avg. daily rate	0.2	0.6	0.3	0.1
30-day maximum	25	75	37	13
Quarterly maximum	35	105	52	18
Yearly Maximum	75	225	112	38
Career limit	400	1200	600	200

NOTE: These exposure limits and exposure rate constraints apply to all sources of radiation exposure. In making trade-offs between man-made and natural sources of radiation, adequate allowance must be made for the contingency of unexpected exposure.

3.6.5 Temperature (Ref. 2)

3.6.5.1 Pressurized Module

The temperature will be maintained at 75 $\pm$ 5^{o}F.

3.6.5.2 Pallet

The temperature will range from -100^{o} to + 200^{o}F for both P/L bay doors open and closed.

3.6.6 Pressure (Ref. 2)

3.6.6.1 Pressurized Module

The pressure will be 14.7 ±0.2 psia. All components to be located inside the module will, in normal operations, not be exposed to vacuum. However, the possibility of accidental depressurization of the module must be taken into account; therefore, all subsystems or components must be capable of sustaining depressurization as well as repressurization without posing any hazard to the crew or Orbiter operations.

3.6.6.2 Pallet

The pressure will be 10^{-5} torr or less.

3.6.7 Magnetic Field

TBD

3.6.8 Acoustics (Ref. 10)

3.6.8.1 Pressurized Module

The maximum overall sound pressure level will be 55 db.

3.6.8.2 Pallet

The maximum overall sound pressure level will be 145 dB.

3.6.9 Charged Particles (Ref. 9)

The electron density values and data in Section 2.3 of NASA TMX-64627 shall be used.

3.6.10 Meteoroids (Ref. 9)

The experiments shall provide protection against loss of functional capability of selected critical items when subjected to the meteoroid flux model as defined in NASA TMX-64627.

3.6.11 Electromagnetic Control (EMC)

Refer to paragraph 3.4.5.

3.7 REENTRY AND LANDING PHASE

The barium cloud experiment will withstand the following environments encountered during the reentry and landing phase.

3.7.1 Acceleration (Ref. 6)

The acceleration levels will be as follows:

CONDITION	X	Y	Z
Entry & Descent	±0.25 g	±0.5 g	- 2.5 g
Landing & Braking	+0.8	±0.5	- 2.5
Crash (Ultimate)	-9.0	±1.5	- 4.5

3.7.2 Temperature (Ref. 2)

3.7.2.1 <u>Pressurized Module</u>

The temperature will be maintained at 75 $\pm$ 5^{o}F.

3.7.2.2 <u>Pallet</u>

The temperature will range from -100^{c} to +200^{o}F.

3.7.3 Pressure (Ref. 6)

3.7.3.1 <u>Pressurized Module</u>

Refer to paragraph 3.5.6.1.

3.7.3.2 <u>Pallet</u>

The reentry pressure profile is shown in figure 2.

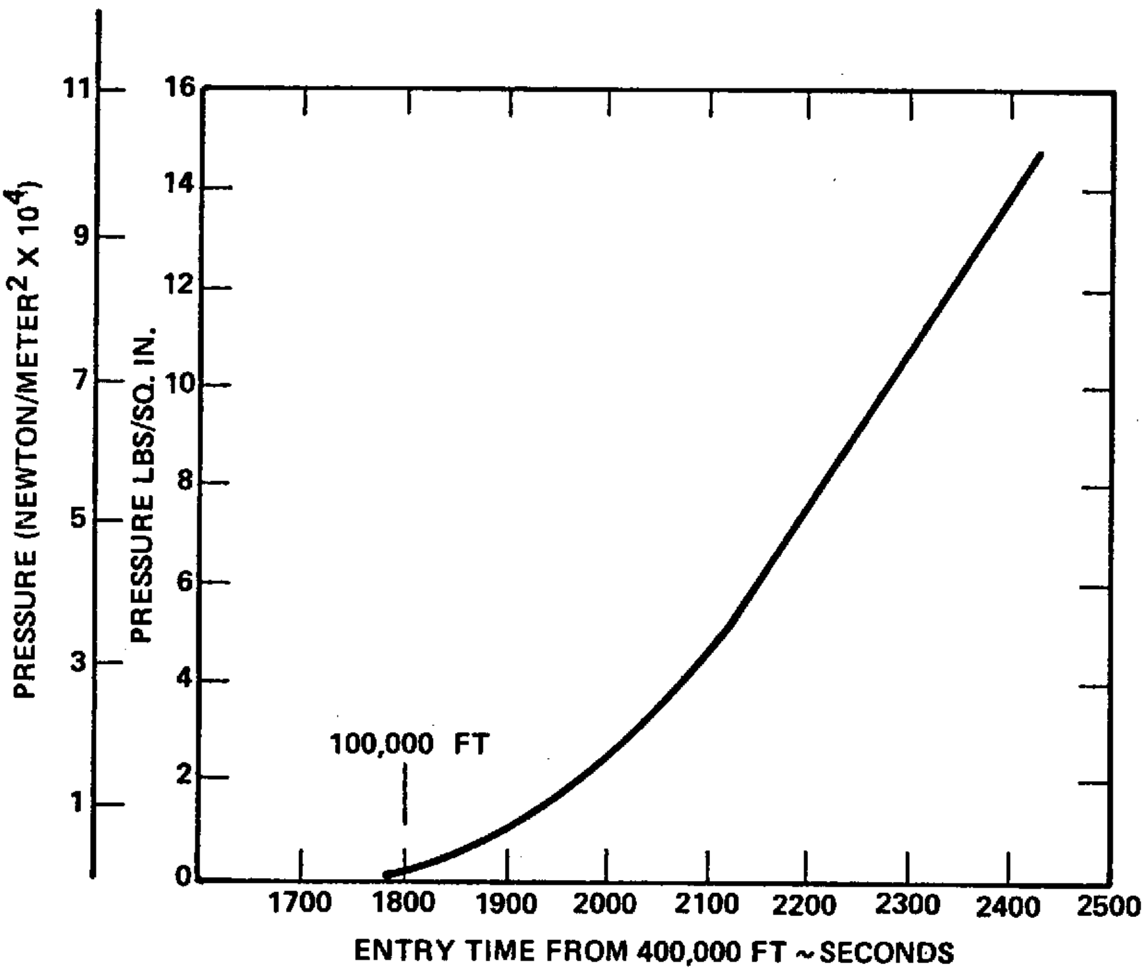

Figure 2. Entry Ambient Pressure Profile

49516

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