FINAL REPORT
CONTRACT NAS 8-36721

MATERIALS COMPATIBILITY WITH OXIDIZER-RICH GASES AT ELEVATED TEMPERATURES AND PRESSURE

November 1987-1989

Perpared For George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

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ACUREX Corporation

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Approved By: Marvin J. Rieb

Date: 4-13-89

PREFACE

The objective of this program was to investigate oxygen compatibility and resistance to ignition of candidate materials for use in a liquid rocket engine designed to incorporate an oxidizer rich preburner-LOX turbopump configuration. The program was a continuation of the work initiated under NASA Contract NAS 8-36713.

This program was divided into two basic tasks.

This first task was to develop a preliminary design of an oxidizer turbopump preburner section complete with thermal and MS Parameter analyses and to develop a conceptual design of the main injector with a preliminary engine specification as the final product.

The second task was directed totally at testing materials in oxygen-rich environmemts. The task included the installation and checkout of the Drop Weight Tester that was furnished under the previous contract. The task included conducting tests with the DWT and supporting testing in a Propagation Rate Tester and Friction Rub Tester.

This report describes the work accomplished under the program and is submitted as fullfillment of the work to be accomplished under the terms of this contract.

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1. INTRODUCTION

Of the many cycle options available to the liquid rocket engine design, the Full Flow Topping Cycle is one of the better choices because the full flow of both propellants is available to drive the turbomachinery. Such an arrangement offers the maximum available turbine drive power thereby permitting the lowest possible turbine inlet temperature, other factors being equal.

Mission analyses by accepted NASA, Air Force and industry mission models of vehicles based on Full Flow Cycle engines and the external tank (ET) of the Space Transportation System have shown that significant payload gains can be realized by increasing the thrust-to-weight ratios of the engines. A "Booster" version of the full flow, staged combustion cycle engine study utilized dual oxidizer-rich and fuel-rich preburner-turbopump assemblies to provide double flow rates and corresponding "double" engine thrust rates of over 1,000,000 lb without significant changes in overall engine size envelope.

One of the concerns regarding the Full Flow Dual Preburner Cycle is that it uses an oxidizer-rich preburner on the LOX side. Experience with the oxidizer-rich preburner has been mixed. Attempts with LOX/RP encountered hard starts, instability, streaking, etc. Attempts to run LOX/LH_2 preburners by starting fuel-rich and transitioning through stoichiometric to oxidizer-rich mixture ratios have also been unsatisfactory. However, LOX/LH_2 tests, at NASA-MSFC in the mid-1960's, starting oxidizer-rich were very successful. LOX/LH_2 preburners have run well with both gaseous and liquid injection of the propellants over mixture ratios of from approximately 20:1 to 150:1 which indicates the oxidizer-rich LOX/LH_2 preburner is quite feasible.

There is general acknowledgement (1,2) that when concerns regarding material compatibility with oxygen-rich environments are resolved, major improvements in rocket reliability and performance will be possible. These advancements will reflect directly in launch systems safety and economy. Among generic improvements are: lower operating temperatures in turbopump turbines and turbine exhaust ducts: LOX turbopump shaft sealing simplicity; single stage turbine for oxidizer pump drive; simplified main injector; improved combustion stability; smaller, lighter, lower cost combustion chamber; reduced pogo tendency; increased Isp; high thrust-to-weight; propellant commonality and component commonality in launch vehicle stages and propellant GSE.

In the development of a Full-Flow Cycle Rocket engines, development of material technology to support the design of components associated with oxidizer-rich gases, i.e. the oxidizer-rich preburner, oxygen turbopump and gas main injector, is essential. A beginning of this material development was initiated under NASA Contract NASA 8-36713 and continued during this contract as indicated by the program objectives summarized in Table 1.

(1) W.R. Marshall ltr to Ivan Bekey, Nasa HQ dated 11/26/85
(2) J. Redus memo of L.Worlund, NASA MSFC, dated 1/7/87

Table 1: Program Objectives

- o Develop preliminary design of an oxidizer turbopump preburner section including stress/thermal and MS Parameter Analyses
- o Develop conceptual design of main injector
- o Prepare engine specification
- o Install new dropweight tester (DWT)
- o Conduct DWT tests in oxygen-rich environment at elevated temperature and pressures
- o Support material test program for Friction Rub Tester
- o Support material test program for Propagation Rate Tester

II PROGRAM SUMMARY

The efforts of this contract produced a preliminary design of an oxidizer-rich preburner in sufficient detail as to identify material types and thickness. A thermal analysis and the MS Parameter analysis was a part of this preliminary design effort. Further a conceptual design of a gas-gas main injector and an engine specification was prepared.

The new DWT, furnished under NASA Contract NAS 8-36713, was installed in a test cell at the Materials Compatibility Test Facility at MSFC. The control system for this DWT was defined, procured, and installed to operate the DWT. The system was checked out and demonstrated the capability to test samples at 1000°F and 10,000 psig. Correlation test were conducted using materials tested in other DWT's at MSFC and WSTF. Test operations were then started in support of the NASA materials test program.

The accomplishments of this contact are summarized in Table 2.

Table 2: Program Accomplishments

- Prepared preliminary design drawings of the oxygen-rich preburner
- Conducted thermal analyses of the preburner
- Conducted MS Parameter analysis for the preburner
- Prepared conceptual design drawings of the main injector
- Refined the engine specification
- Refurbished test cell 3 in Bld 4623 for DWT
- Installed DWT in test cell
- Designed, procured and installed the DWT control and data acquisition system
- Procured and installed high pressure oxygen compresser
- Demonstrated DWT operation at 1000°F and 10,000 psig
- Conducted tests with DWT

- Recommemded materials and test conditions for Propagation Rate tests and Friction Rub tests.

III. PROGRAM TASKS

The program schedule, Figure 1, reflects the final status of the tasks described in the following paragraphs.

A. Task 1 - System Design Definition

The objectives of this task were to develop the preliminary design of the oxidizer-rich preburner for the oxidizer turbopump defined for the baseline engine concepted under NASA Contract NAS8-36713, to prepare the conceptual design of the main injector for the baseline engine, and to refine the baseline engine specification.

During preliminary design of the preburner, condsideration was given to reduction of residual propellant volumes, eliminating zones of excessive material, reduction of flange sizes, and streamlining section transitions to improve thermal and structural characteristics.

One of the major concerns in oxygen-rich environments is material ignition and burning. Therefore in the analyses conducted during this preliminary design emphasis was placed on thermal analysis and the MS Parameter analysis. Of primary concern in the preburner was the deflector inside the preburner chamber that would see the highest temperature so all the analyses were performed for two candidate materials (copper 102 and Inconel 718) for this deflector in the oxidizer-rich preburner environment. The thermal analyses provide the heat rate data for calculating the MS Parameter.

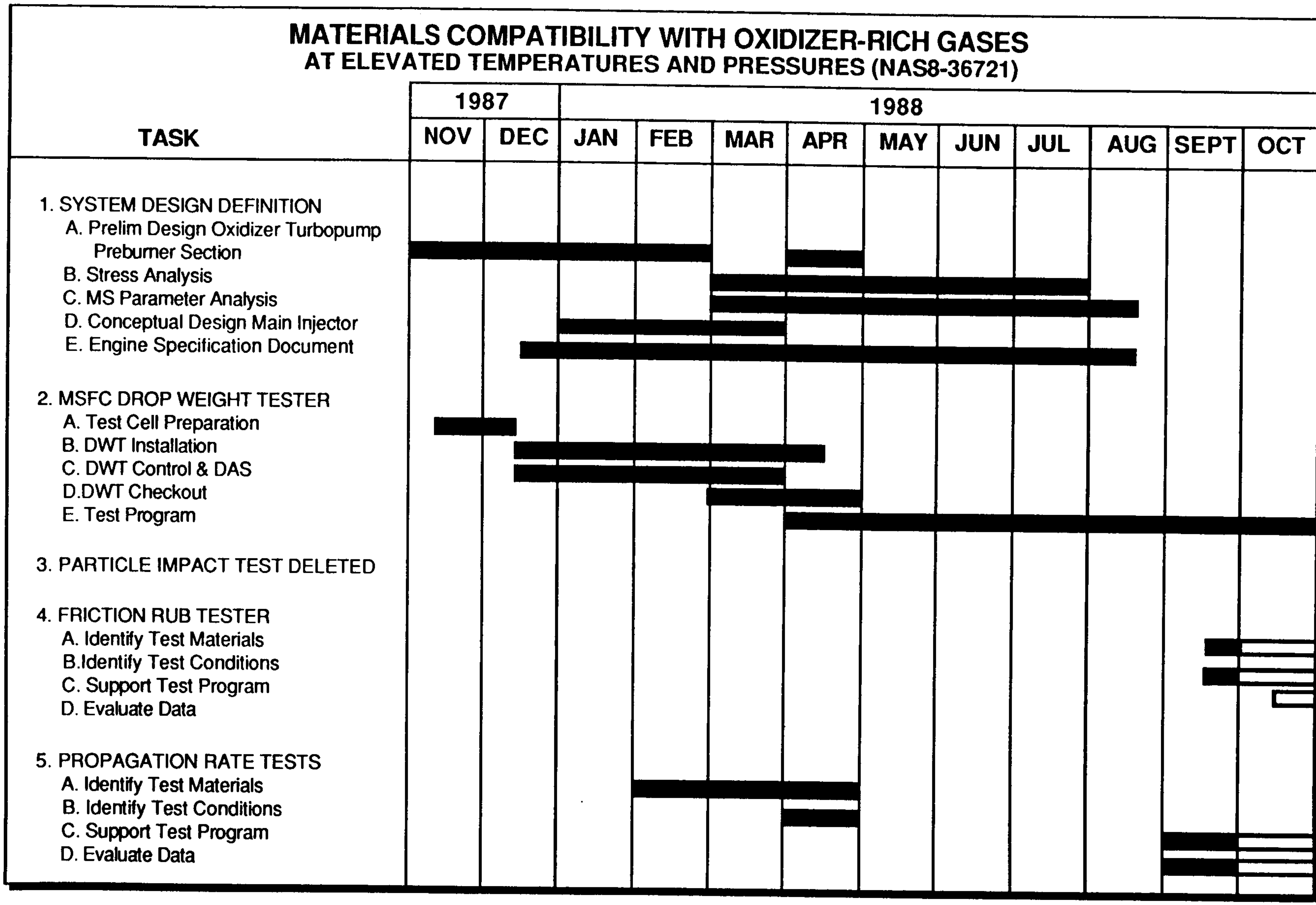

Figure 1: Final Status Program Schedule

Full Navier Stokes calculations were done to determine the mixing and heat transfer to the inner surfaces of the preburner using a three dimensional code KIVA. This code is a finite volume technique which is capable of modeling the complex geometry of the preburner as well as the injection and mixing of the oxygen and hydrogen and subsequent combustion. ACE (Aerotherm Chemical Equilibrium) and MEIT (Momentum and Energy Intergal Technique) computer codes were also used to obtain the final data needed to calculate the MS Parameter. Appendix A contains the details of the analyses.

The conceptual design of the gas-gas injector was completed. The design included fuel injection tubes for injection of the gaseous fuel and a rigimesh injector face for low velocity injection of the gaseous oxidizer. Material selection, Table 3, was made based on the hydrogen and oxygen compatible materials requirements as well as other considerations, i.e., structural, fabrication, etc.

Table 3: Injector Materials

ITEMS	MATERIAL
o Oxygen Manifold	o Monel 400 (alternate Hayres 214)
o Hydrogen Manifolds	o 316 SS
o Injector Elements	o 316 SS
o Injector Face	o Rigidized nickle feltmetal

The oxygen manifold material, Monel 400, was chosen for compatibility with oxygen, formability and machinability. It also has good weldability and the resulting weld zones are also expected to retain compatibility with the oxygen-rich environments. Strenght is moderate at 1200^{o}R, 60,000 psi yield, but is still expected to permit reasonable wall thickness without excessive weight. Haynes 214 is an alternate in the event that a higher strength material is needed. Haynes 214 is expected to be more expensive to fabricate.

The Hydrogen manifold and the injector elements material, 316 SS, was chosen as a compromise between oxygen compatibility and resistance to hydrogen embrittlements. This material is used in the SSME autogenous gas heat exchanger with oxygen on one side and hydrogen on the other at higher temperatures, about 1650^{o}R, sharper thermal gradients and higher pressures than in the proposed gas-gas injectors.

The injector face material serves to smooth out the velocity profile of the in-flowing oxygen. The material is exposed to the radiant heat of the chamber, and cooled by the throughflow of oxygen-rich gas. It is not expected to exceed a temperature of 1400^{o}R. Rigidized nickel feltmetal was selected because it has good oxidation resistance, and provides the desired flow distribution properties.

The specification for the baseline engine concepted under contract NAS 8-36713 was revised and is presented in Appendix B.

The drawings associated with Task 1 are listed in Appendix C. One reproducible and two blue line copies of each drawing has been supplied to the COR with this report.

B. Task-2 Support, MSFC Drop Weight Tester(DWT)

The primary objectives of this task were to install the DWT provided under NAS8-36713, demonstrate the operability of the system, and conduct a materials test program.

Test bay number 3 in Bld 4623 was assigned for this DWT. The test bay had been inactive for quite some time requiring considerable refurbishment. All the old gas lines and electrical cabling were removed from the test bay and the test bay was painted. The control room was also stripped of all old lines and wiring and painted. An existing GN_2 supply panel in the control room was refurbished and used as the GN_2 distribution panel. The panel is supplied by the facility 3000 psig GN_2 source. The panel contains three manually operated regulators that step down the GN_2 supply pressure for GN_2 cooling pressure (100 psig), GN_2 actuation pressure (150 psig), and GN_2 balance pressure (1200 psig). Each of these step-down systems contain a manual shut off valve upstream of the regulator and a relief valve downstream of the regulator. New gas lines were installed from the panel into the test bay to the DWT. Solenoid valves were installed, as necessary, to supply GN_2 for the required operations at the DWT. The GOX high pressure lines were installed using high pressure tubing and fittings. The shut off valves in the high pressure lines are all dome load high pressure valves. The GOX high pressure compressor procured for this system is nitrogen driven requiring no electrical power. For 10,000 psig operation, the compressor requires a 1000 to 2500 psig inlet pressure which allowed the use of the existing GOX supply system in BLD 4623. The control system was identified and the missing components were purchased. The control system is fully automated beginning with input of test conditions and setting of key perimeters to monitor and control the test ready-safety "GO" gates. The operator is required to increase pressure until the striker moves into test position, then actuates the plummet drop sequence. The shutdown and data recording functions are automatic. The control system does have two shut down overrides that provide a normal shutdown or an emergency shutdown. Figures 2 and 3 show the installed DWT and control console respectively.

Upon completion of installation, the system was tested to demonstrate operability capabilities. The first tests conducted were to demonstrate the systems' ability to heat test samples to 1000^{o}F. Since these test could be conducted without pressure in the chamber, a miniature thermocouple was inserted through the chamber discharge line, into the sample cup and positioned under a test sample. The thermocoulpes to be used during actual testing is located on the outer surface of the pressure barrel. Test were then conducted heating the sample to 1000^{o}F in increments of 200 degrees and comparing the data of the two thermalcouples. The tests were conducted several times to verify the data. The final results revealed that the sample temperatures lagged the barrel temperature by ten seconds. The control system was programmmed to provide heat an extra ten seconds after the barrel temperature reached the set temperature. The system is reapeatable and the time to reach 1000^{o}F from ambient is eight minutes with post-test cooldown time requiring six minutes. The system was also pressurized to 10,000 psig to demonstrate the operability of the compressor. The time required to reach 10,000 psig starting at 1000 psig was seventy seconds.

Upon completion of the checkout test operations, tests were conducted using materials supplied by NASA. These test were run to compare the results in this DWT with the results obtained on the same materials at the same test conditions in other DWT's.

Appendix F contains a complete description of the system, the equipment that makes up the system, recommended maintenance and a list of recommended spare parts. Appendix G is a list of all drawings associated with the DWT system. One reproducible and two blue line copies of each drawing has been supplied to the COR with this report. Appendix H is the DAS Operating Manual for the DWT.

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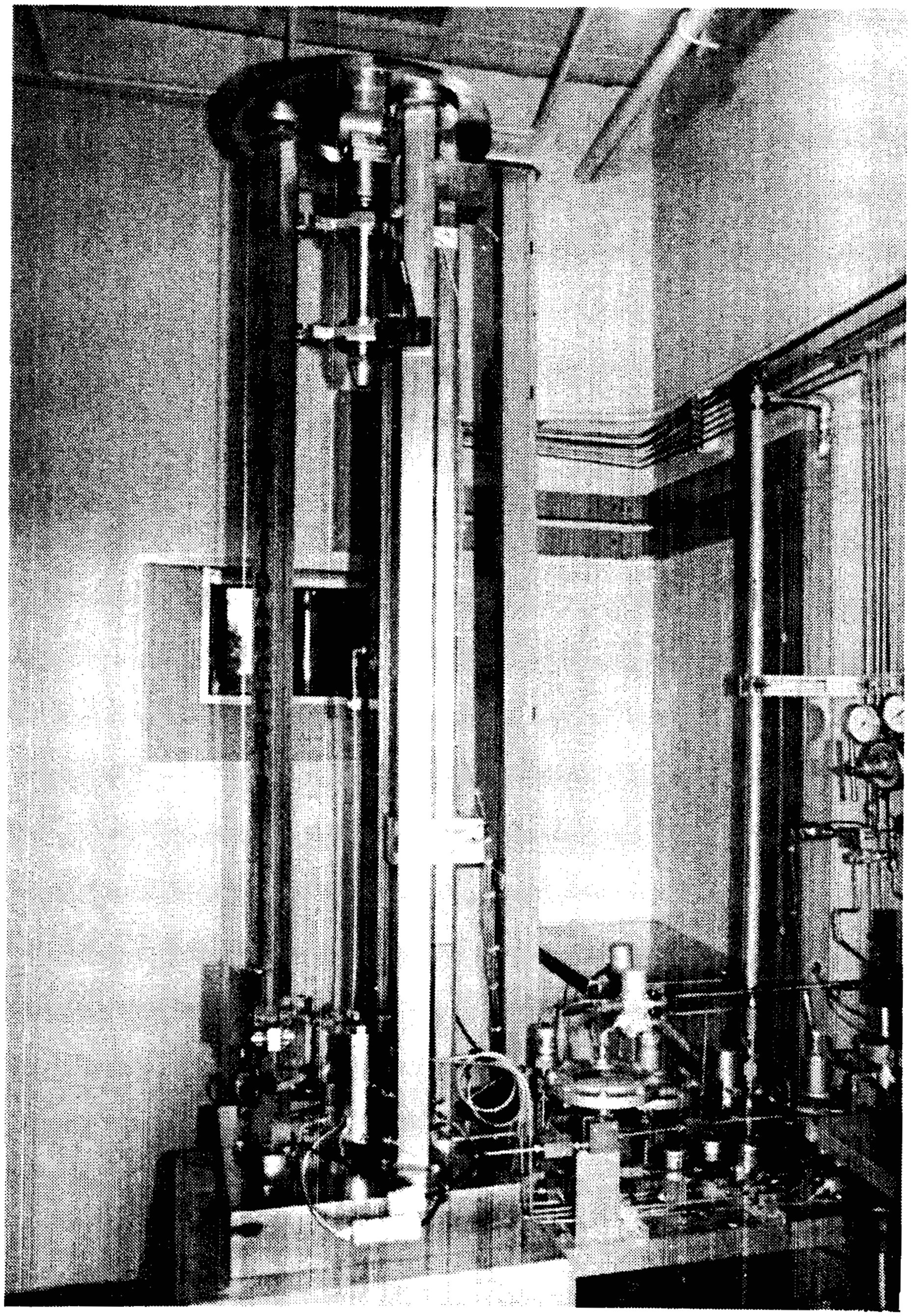

Figure 2: DWT Installation

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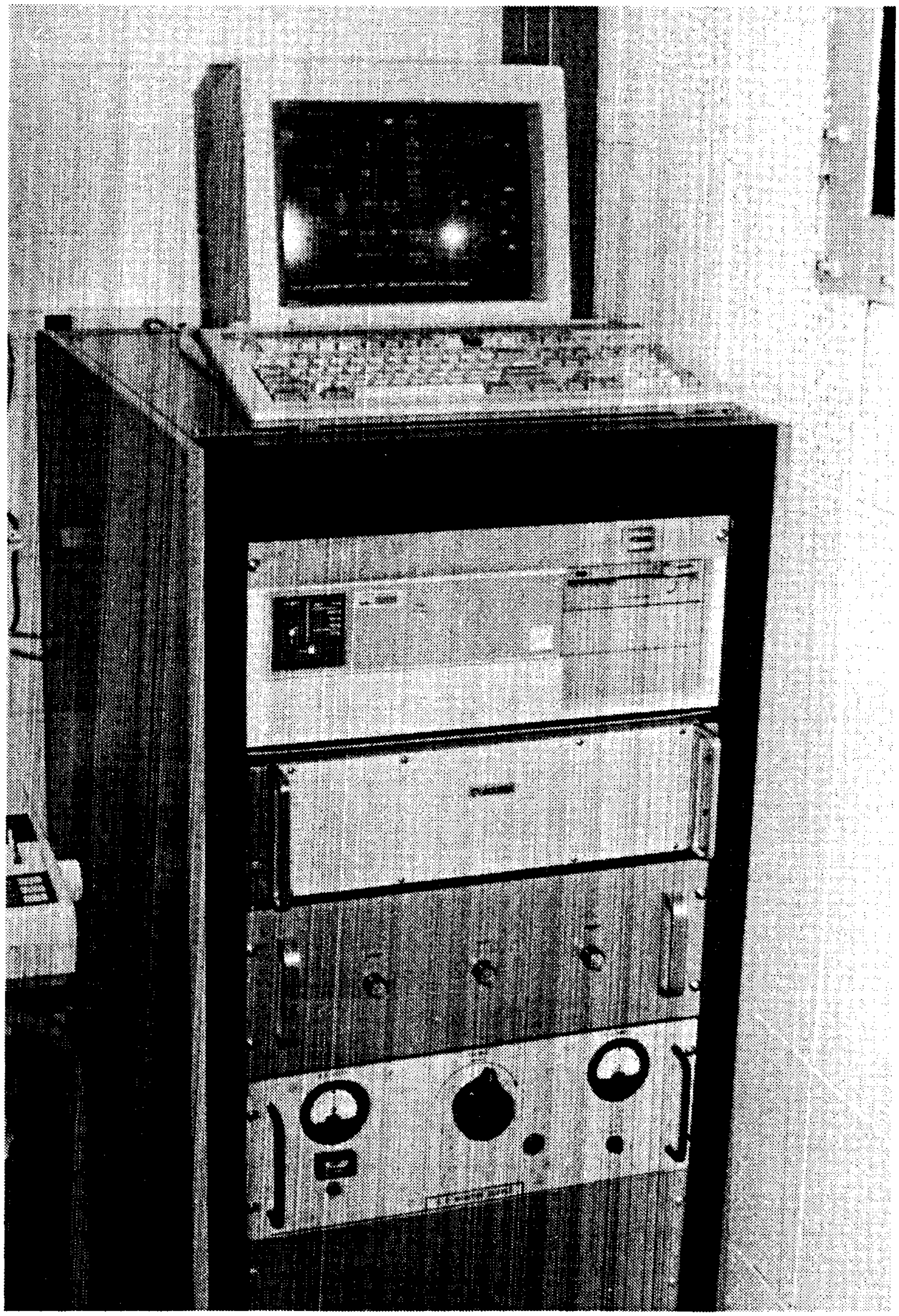


Figure 3: DWT Control Console

C. Task 3 - Support Friction - Rub Tester

The primary objectives of this task were to recommend materials for testing identify test conditions, and support analytical and data evaluation.

A list of materials for testing and test conditions were supplied, however the test equipment was never received by NASA-MSFC and no testing was conducted.

D. Task 4 - Support Propagation Rate Tests

The primary objectives of this task were to recommend materials for testing, identify test conditions, and support analytical and data evaluation.

A list of materials for testing and test conditions were supplied. Assistance was provided to make the propagation rate tests operational and to conduct the checkout test of the system.

APPENDIX A

MS PARAMETER/THERMAL ANALYSES

The MS Parameter is a new engineering tool. It may be used to help evaluate how close a material in a specific situation (material and its environment) is to ignition. The MS Parameter is in essence " how fast a material must burn to liberate sufficient heat for it to continue to burn". Comparision of the calculated MS Parameter with a measured MS Parameter, for the same material in a similiar but more difficult(higher temperature) environment gives a quantitative measure of the materials margin from ignition. Thus the approach is similiar to the approach used in strength of materials where a calculated stress is compared with the measured material strength. Unfortunately at this time there is no data base on measured MS Parameter values whereas for many engineering materials there is a wealth of data for the measured strength of materials. It is useful to calculate operating MS Parameter values because the results give relative values among various materials for a specific situation.

A study was performed to determine the MS Parameter (Ref. 1) for two candidate materials for a deflector in an oxidizer-rich preburner environment.

The equation for the MS parameter is

$$MS = \frac{\text{rate of heat conduction}}{f x d x HC} + \frac{\text{rate of heat convection}}{d x HC} \qquad (1)$$

where d is the density (lb/iu^3.cn.), HC is the heat of combustion (BTU/lb) and f is a function of oxide layer thickness. The first term (conduction) is a time dependent term and the second term is a steady state term.

For each of candidate materials the MS Parameter was calculated for two intial deflector material temperatures, two thicknesses and two locations along the length of the deflector. The two materials considered for this analysis were copper 102 and Inconel 718. Thicknesses of the deflector were assumed to be 0.5 inches and 0.25 inches. The initial temperatures through the thickness of the material were 530 R and 1076 R. Locations along the length of the deflector were chosen at points of maximum and minimum convective transfer rates determined from a boundary layer calculation. In this analysis it was assumed that no oxide layer existed therefore "f" was set equal to unity Values of "d" and "HC" for Inconel and copper are shown in Table 1.

Table 1: Material Constants

Material	Heat of Combustion (BTU/lb)	Density (lb/in^3)	Ignition/Melt Temperature (°R)
Inconel 718	2000	.297	3000
Copper 102	1083	.323	2440

PROP890411-1.0

To determine the convection ra s along the length of the deflector a series of calculations we: made with the KIVA, ACE (Aerotherm Chemical Equilibrium), and IEIT (Momentum and Energy Integal Technique) computer codes. IVA (Ref. 2) is a Navier-Stokes code for calculating two and three dimensional fluid flows with chemical reactions and fuel sprays. ACE (Ref. 3) calculates quantities for a broad variety of thermodynamic processes. MEIT (Ref. 4) predicts boundary layer development,

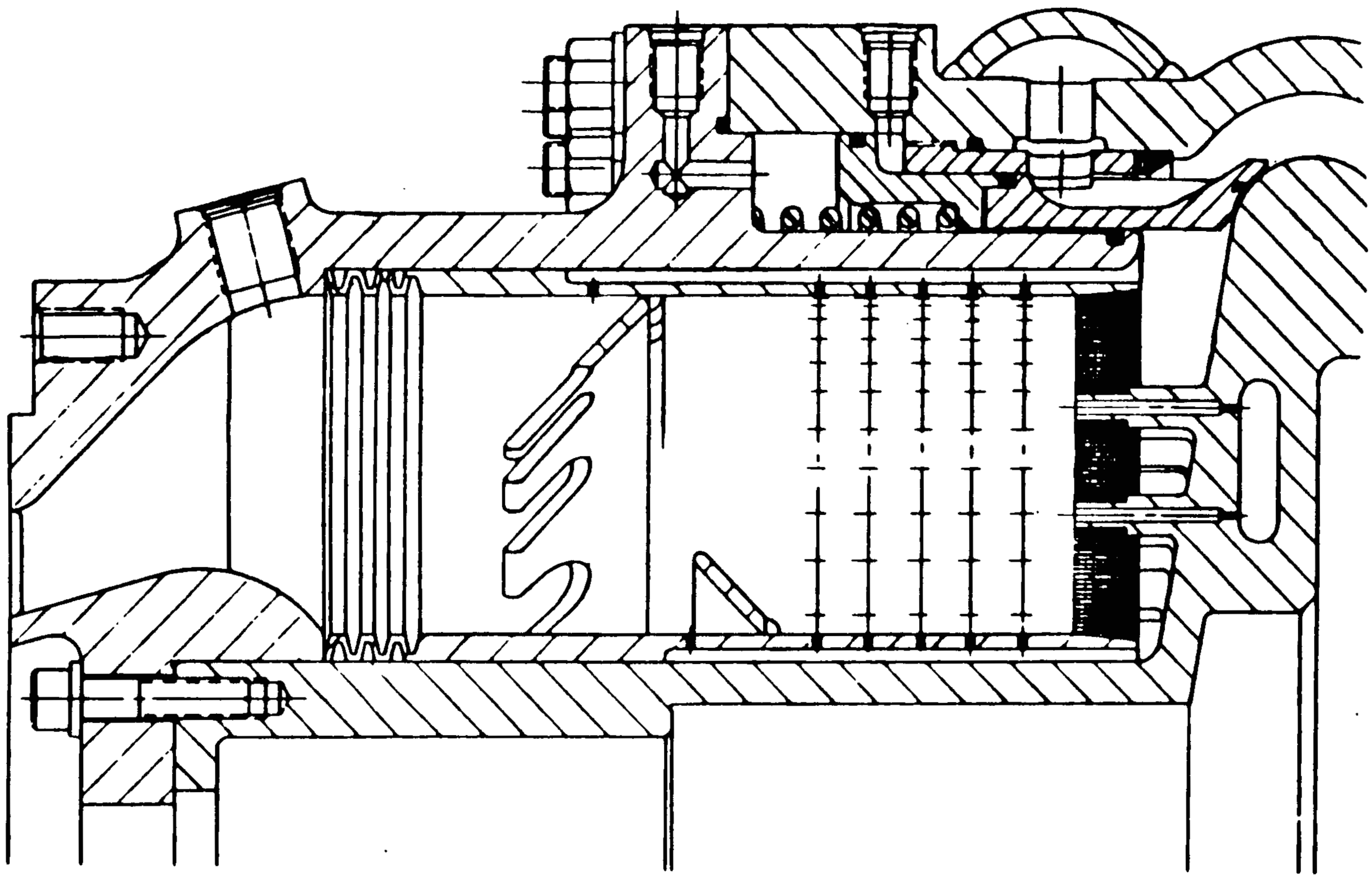


Figure 1: Preburner Configuration

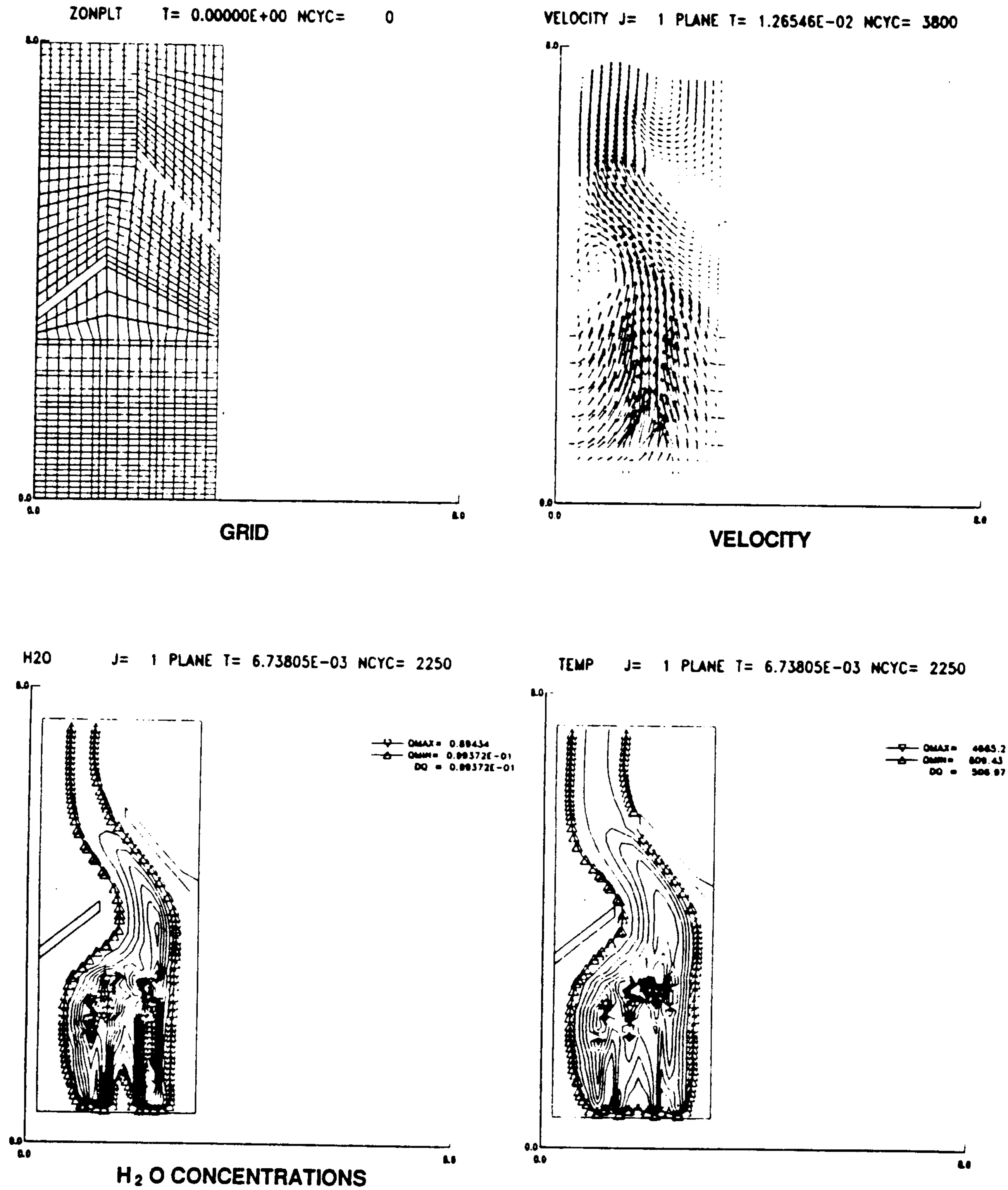

ZONPLT T= 0.00000E+00 NCYC= 0
GRID
VELOCITY J= 1 PLANE T= 1.26546E-02 NCYC= 3800
VELOCITY
H2O J= 1 PLANE T= 6.73805E-03 NCYC= 2250
H₂O CONCENTRATIONS
TEMP J= 1 PLANE T= 6.73805E-03 NCYC= 2250

Figure 2

shear, and heating on a surface in hyperthermal environments. The preburner configuration is shown in Figure 1 and the computational grid and flowfield predictions are shown in Figure 2. The calculations used a mixture ratio of oxygen to hydrogen of 138:1.

Boundary layer edge conditions from KIVA and boundary layer gas properties from ACE were input into the MEIT code. The gas in the boundary layer was assumed to be composed entirely of oxygen. The wall temperature of the deflector was assumed to be the melt/ignition temperature of the material. These values were 3000 degrees Rankine for Inconel and 2440 degrees Rankine for copper. Convective transfer rates for the copper and inconel were different since different wall temperatures were assumed for each material in performing the boundary layer calculation. Table 2 shows the convection rates used. It should be noted that since the wall temperatures were assumed to be at ignition temperature for each material, the convective transfer actually tends to cool the material.

Table 2: Convection Rates

Convection Rate (BTU/ft^2)		
Material	**Minimum**	**Maximum**
Inconel 718	**180.2**	**786.8**
Copper 102	**142.0**	**66.5**

PROP890411-2.0

The conduction term in equation (1) was calculated with the Aerotherm code CMA (Charring Material Thermal Response and Ablation, (Ref 5). For these analyses the surface of the material was held at its melt temperature for the stimulus time and conduction rates were determined at various points in time. Material properties used in these analyses are shown in Tables 3 and 4. MS values were then determined using equation (1). Results from the calculations are shown in Figures 3 through 10.

Table 3: Material Properties For Copper 102

Density (lb/ft³) = 513		
Temperature (R°)	**Specific Heat (BTU/lb-°R)**	**Thermal Conductivity (BTU/ft-sec-°R)**
460	0.0875	0.065
960	0.102	0.061
1460	0.111	0.059
1960	0.12	0.057
2460	0.129	0.052

PROP890411-3.0

Table 4: Material Properties For Inconel 718

Density (lb/ft³) = 558		
Temperature (R°)	**Specific Heat (BTU/lb-°R)**	**Thermal Conductivity (BTU/ft-sec-°R)**
460	0.045	0.001056
2060	0.16	0.003833

PROP890411-4.0

Following are comments pertaining to these results.

Conduction rates for the copper are significantly greater than for the Inconel. Therefore, the copper has a significantly higher MS value for all of the situations analyzed.

The thicker deflection plate experiences higher conduction rates, especially after about 0.05 seconds. This results in a larger MS value.

Larger MS values are also obtained for the location experiencing the greatest convective cooling. However, early in time (< 0.1 seconds) the conduction term is much greater than the convection and therefore the convective cooling does not come into play early in time. Later in time, the material approaches constant temperature and the conduction term approaches zero. As this happens the curves become asymptotic. Copper becomes asymptotic much sooner than inconel. This is because copper has a much higher conductivity and a lower melt temperature. Therefore, the temperature at the backwall reaches melt temperature much sooner and the conduction rate drops to nearly zero. This allows the convection term to dominate the MS value. Even at 10 seconds inconel has not reached its melt temperature at the backwall and is still conducting heat away from the surface.

Higher intial temperature has the effect of lowering the MS parameter of copper. This is due to the fact that as temperature increases the conductivity of copper goes down which reduces the rate of heat conduction away from the surface. However, for inconel the conductivity increases as temperature increases which results in a slightly higher MS parameter for approximately the first 0.0028 seconds.

Based on the MS results obtained, it appears that a 0.5

inch thick copper plate has the lowest chance of ignition and is therefore the best choice for the pre-burner deflector plate.

TWALL = 1076 (°R), THICKNESS = 0.25 IN., HIGH CONVECTION

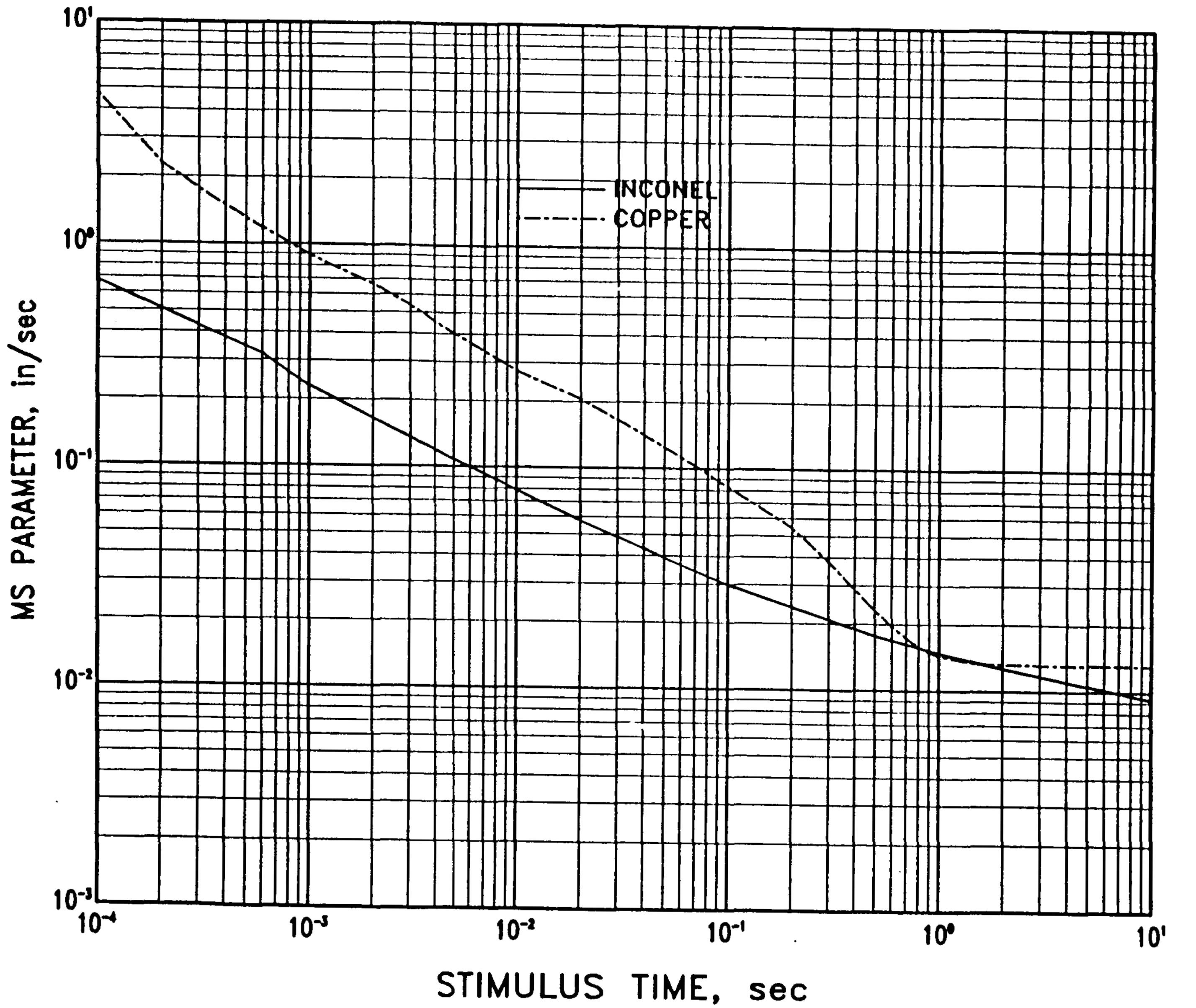


Figure 3

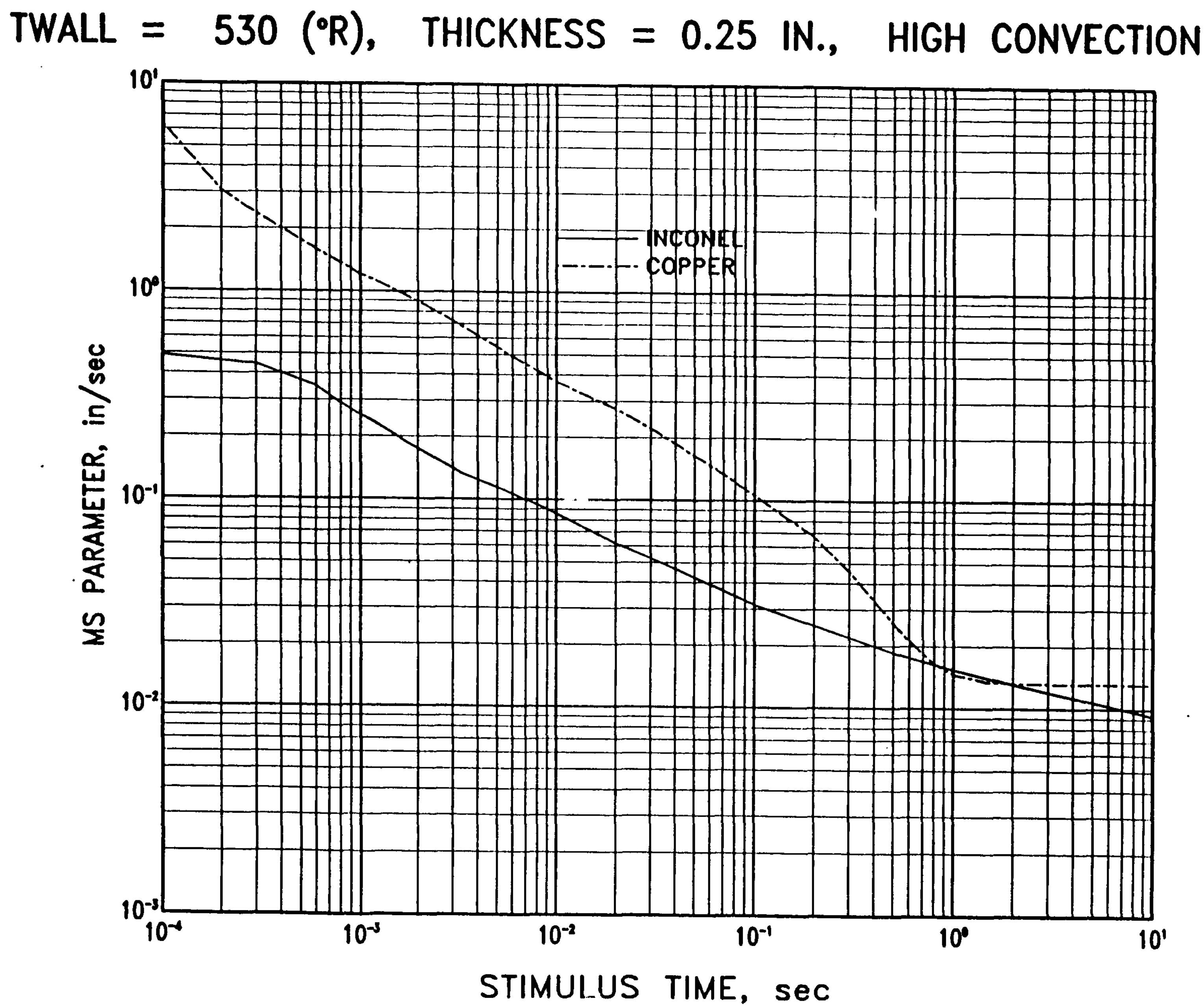

TWALL = 530 (°R), THICKNESS = 0.25 IN., HIGH CONVECTION
INCONEL
COPPER
MS PARAMETER, in/sec
STIMULUS TIME, sec
10¹
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴

Figure 4

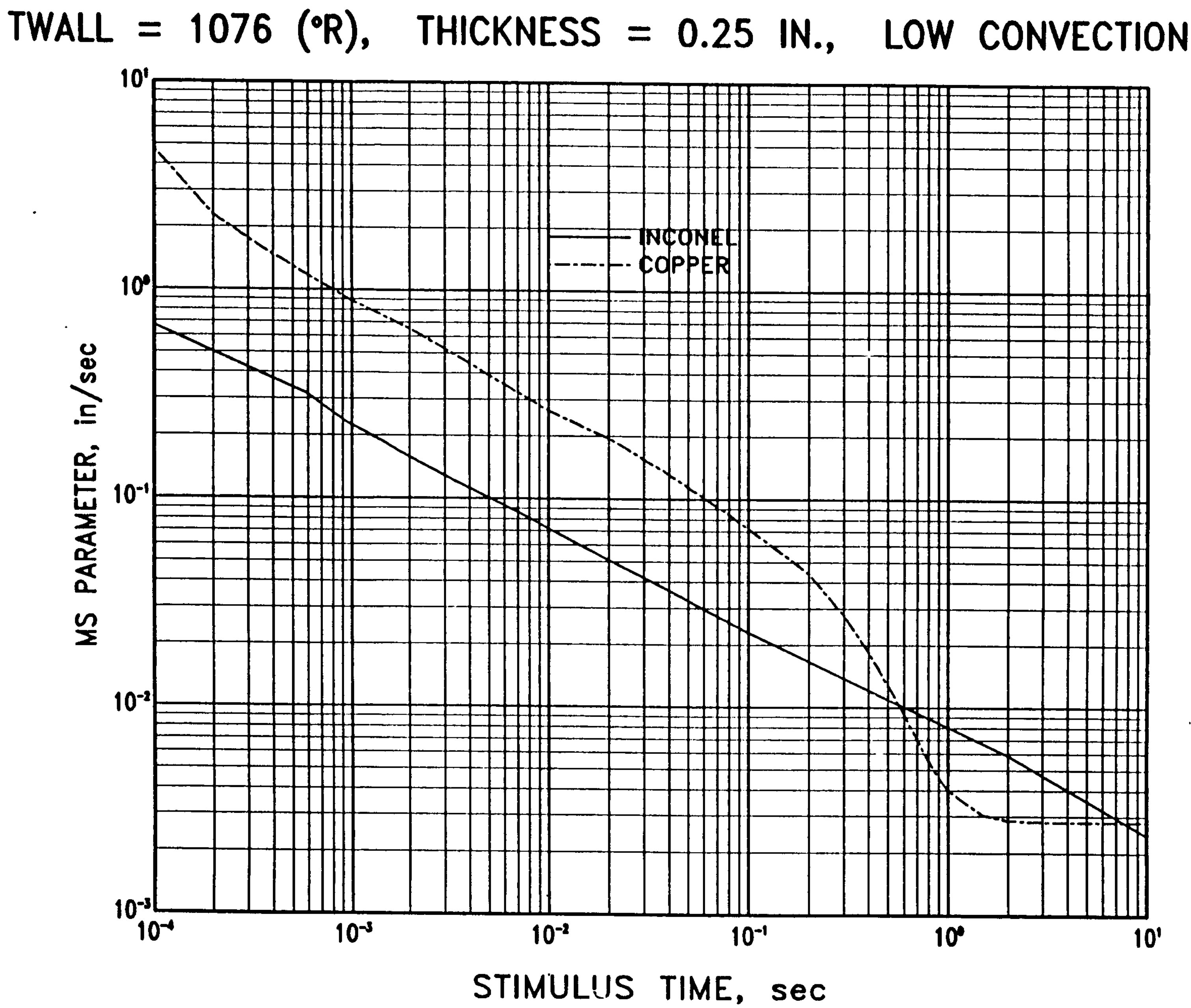

TWALL = 1076 (°R), THICKNESS = 0.25 IN., LOW CONVECTION
INCONEL
COPPER
MS PARAMETER, in/sec
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
STIMULUS TIME, sec

Figure 5

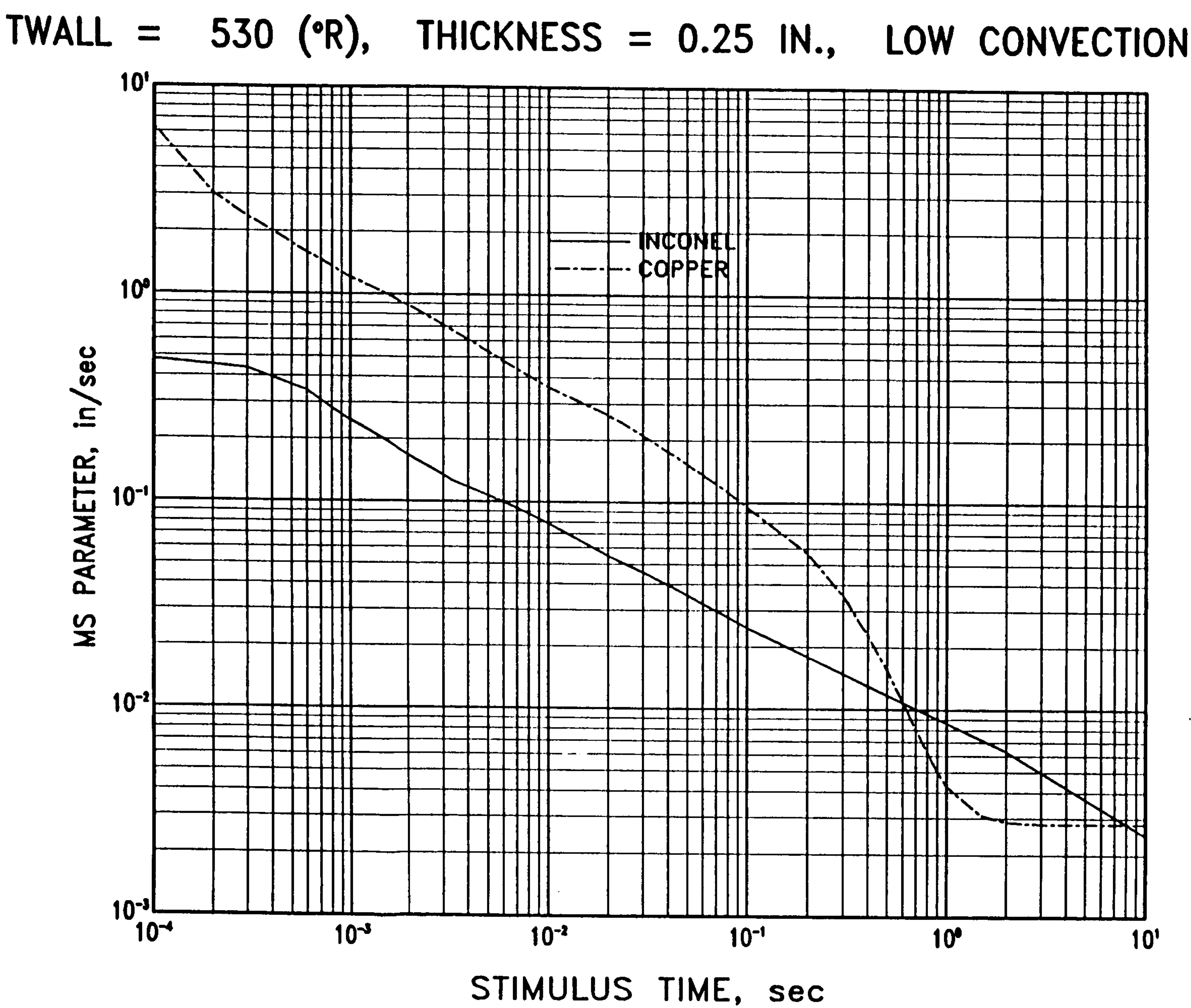

TWALL = 530 (°R), THICKNESS = 0.25 IN., LOW CONVECTION
INCONEL
COPPER
MS PARAMETER, in/sec
STIMULUS TIME, sec
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}

Figure 6

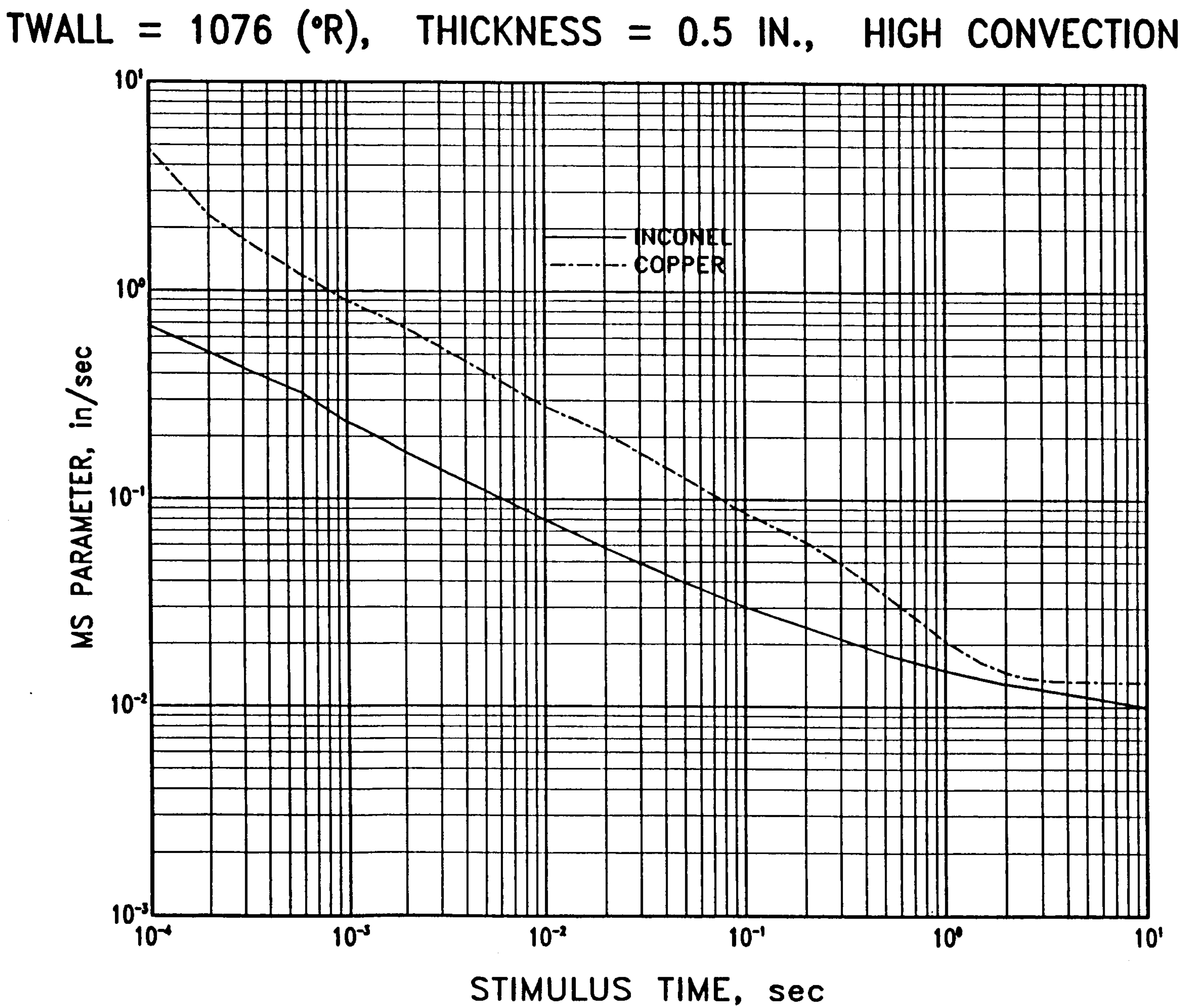
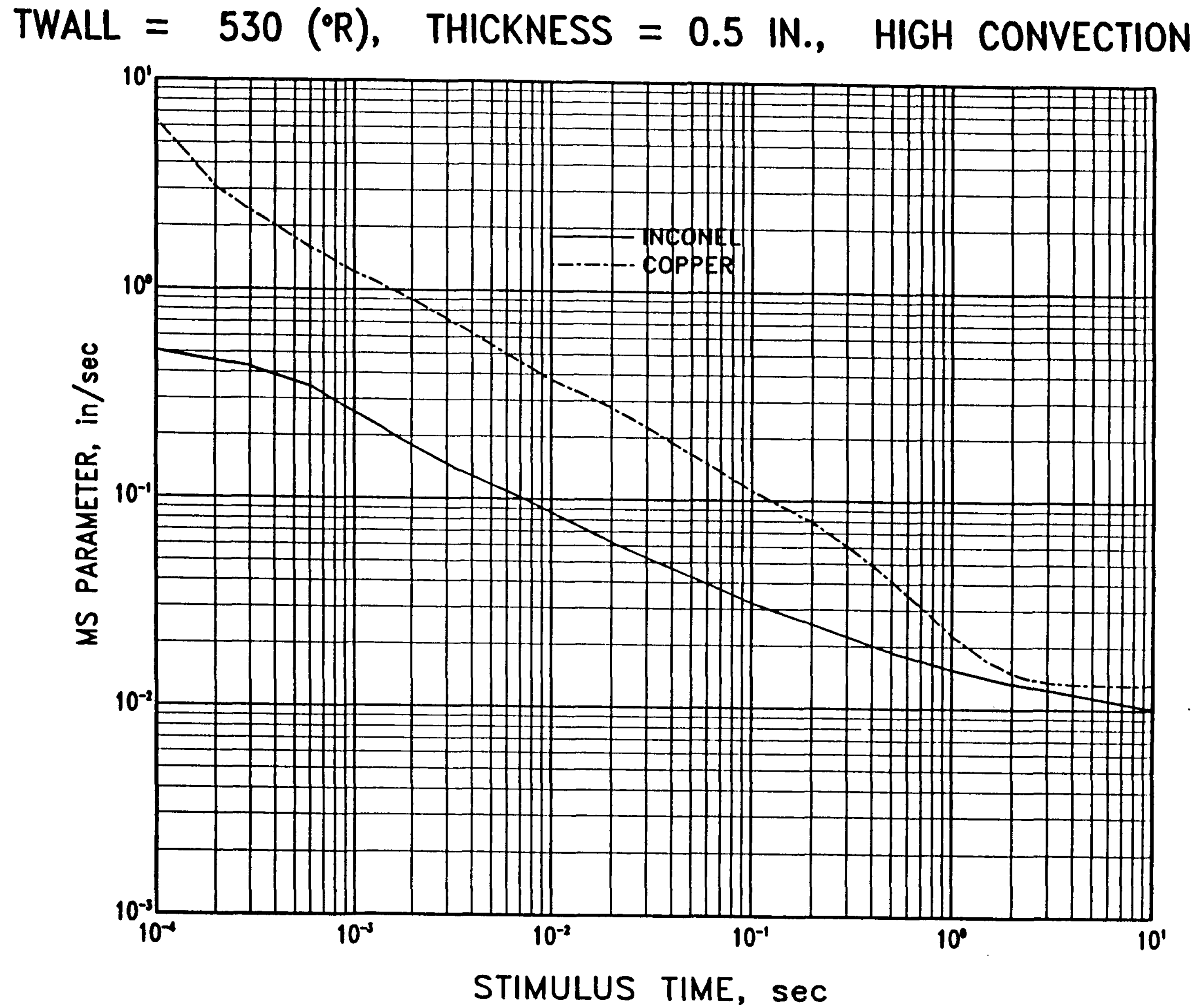

TWALL = 1076 (°R), THICKNESS = 0.5 IN., HIGH CONVECTION
INCONEL
COPPER
MS PARAMETER, in/sec
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
STIMULUS TIME, sec

Figure 7



TWALL = 530 (°R), THICKNESS = 0.5 IN., HIGH CONVECTION
INCONEL
COPPER
MS PARAMETER, in/sec
STIMULUS TIME, sec

Figure 8

TWALL = 1076 (°R), THICKNESS = 0.5 IN., LOW CONVECTION

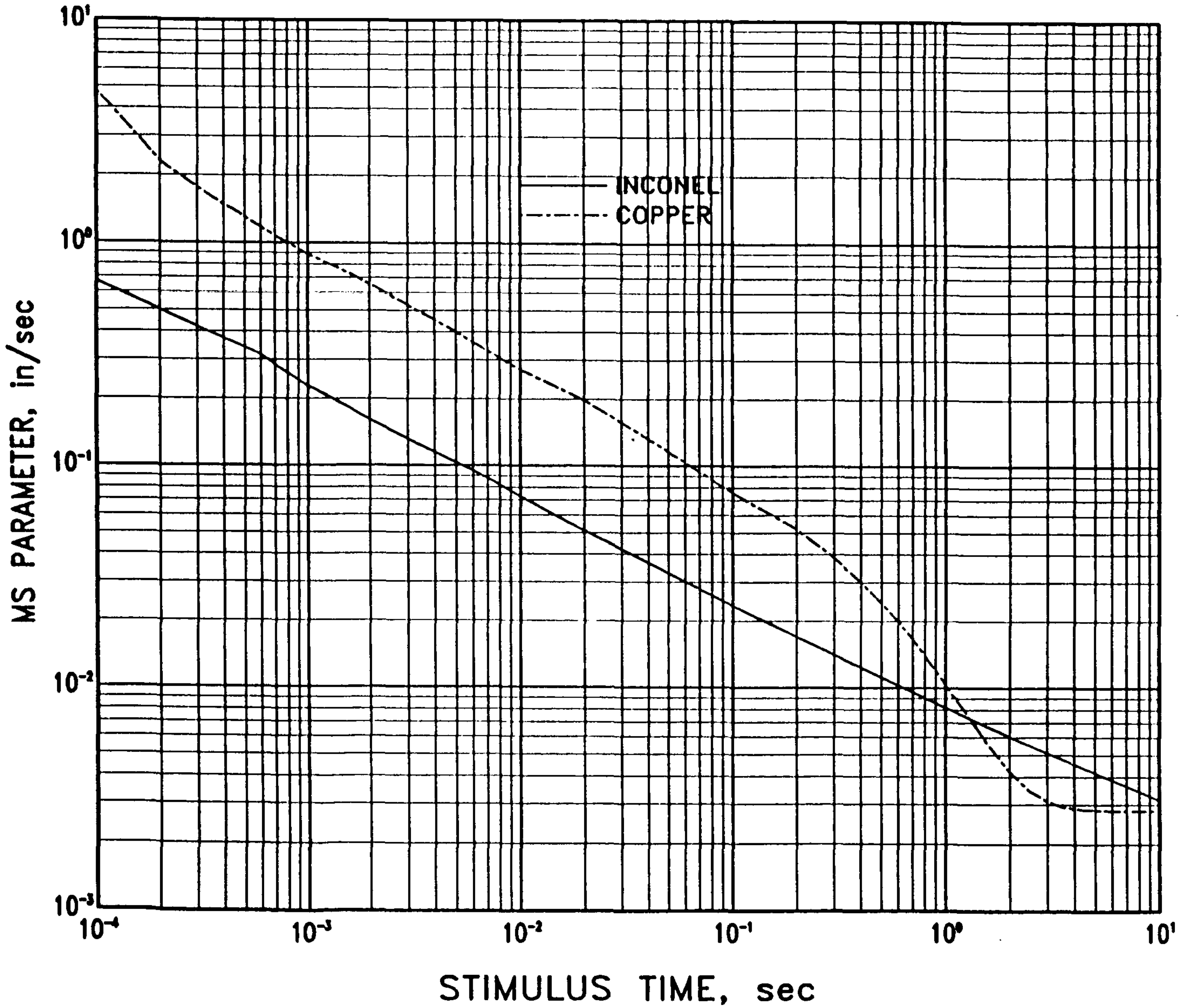
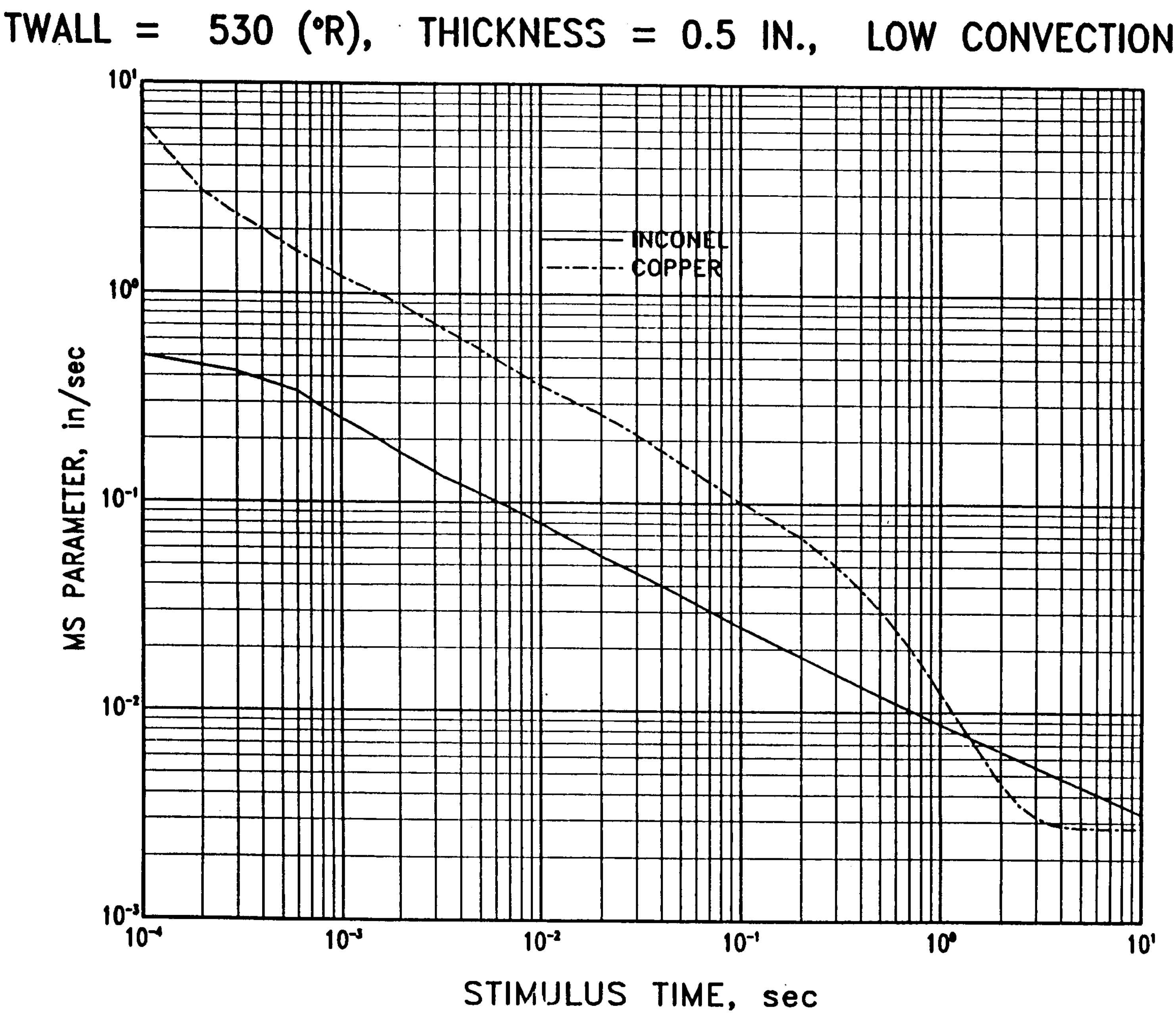


Figure 9



TWALL = 530 (°R), THICKNESS = 0.5 IN., LOW CONVECTION
INCONEL
COPPER
MS PARAMETER, in/sec
STIMULUS TIME, sec

Figure 10

REFERENCES

1. Beveridge, The MS Parameter, Appendix B of Final Report, Contract NASA-36713, Sept 85-Mar 87 Published 26 Feb 1988, MSFC

2. Amsden, A.A., Ramshaw, J.D., O'Rourke, P.J., and Dukowicz, J.K., "KIVA: A Computer Program for Two- and Three-Dimensional Fluid Flows with Chemical Reactions and Fuel Sprays", LA-10245-MS, Los Alamos National Laboratory, February 1985.

3. "User's Manual: Aerotherm Chemical Equilibrium Computer Program", Acurex Report UM-81-11/ATD, August 1981.

4. "User's Manual: Momentum/Energy Integral Technique (MEIT 81)", Acurex Report UM-81-12/ATD, August 1981.

5. "User's Manual: Aerotherm Charring Material Thermal Response and Ablation Program (CMA87)", Acurex UM-87-11/ATD, August, 1987.

APPENDIX B

PRELIMINARY ENGINE SPECIFICATION

FOR

HIGH MIXTURE RATIO LOX/LH_2

BOOSTER/SUSTAINER ROCKET ENGINE

FOREWORD

This document was prepared for studies performed under this contract and is not intended for other use.

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1.0 SCOPE

1.1 REQUIREMENTS

This document sets forth requirements to guide the conceptual design of an oxygen/hydrogen rocket engine which uses high mixture ratio during booster operation and conventional mixture ratio during sustainer operation. The objective is to provide high engine thrust-to-weight ratio with relatively high bulk density propellants during booster operation and high specific impulse during sustainer operation.

1.2 FEATURES

Special featuresof this engine shall be as follows:

a. A single basic engine shall be used in a cluster to provide thrust for earth-to-orbit propulsion.

b. Multiple components (propellant feed system) shall provide a large range of flow rates with a simple engine.

c. The engine shall be capable of being stepped in thrust level and mixture ratio in a prescribed manner.

d. Thrust vector direction shall be provided by a gimbal.

e. The engine shall be provided with alternative nozzle skirts having the appropriate area ratio to enhance operation in the booster or sustainer mode.

f. The turbomachinery for the oxygen and hydrogen feed systems shall be sized for approximately 550,000 lb vacuum thrust level at a mixture ratio of 6, when using one LOX Turbopump and one Hydrogen turbopump.

2.0 APPLICABLE DOCUMENTS

2.1 GOVERNMENT DOCUMENTS

The following government documents form a part of this specification to the extent specified herein.

2.1.1 Specifications, Military

MIL-P-25508E Amendment 3 20 January 1975	Propellant, Oxygen
MIL-P-27201B 30 June 1971	Propellant, Hydrogen
MIL-P-27401C 20 January 1975	Propellant Pressurizing Agent, Nitrogen
MIL-P-27407A 28 November 1975	Propellant Pressurizing Agent, Helium

2.1.2 Specifications, Marshall Space Flight Center

NASA NHB 8060	Flammability, Odor and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion

MSFC-SPEC-106B	Testing Compatibility of Materials for Liquid Oxygen Systems
TBD	Testing Compatibility of Materials for Oxidizer-Rich Products of Combustion at Elevated Temperatures

2.1.3 Publications

Chemical Propulsion Information Agency
CPIA - 14B, July 1967

Selection of Instrumentation for Analysing Combustion Instability in Liquid Propellant Rocket Engines

NASA
Document: JSC 07700, Vol. X, Appendix 10.10
Change No. 38, Natural Environments, Design Reuirements

Handbooks: MIL-HDBK-5B, Notice 1 July 1972
Metallic Materials and Elements for Aerospace Vehicle Structures

NHB 8040.2, January 1970
Apollo Configuration Management Manual

3.0 REQUIREMENTS

3.1 ENGINE IDENTIFICATION

The basic engine identification is "S-2". This choice is based on the selection of an SSME size engine having two oxidizer feed subsystems. Various alternatives to this engine are feasible, including various nozzle skirt exit-to-throat area ratios.

3.2 CHAMBER PRESSURE

The chamber pressure selected for the engine, during booster operation, shall be 3600 psia. Higher and lower chamber pressures, from 2000 to 4000 psi, shall also be considered and curves of their performance developed.

3.3 PROPELLANTS, MIXTURE RATIO RANGE

Liquid oxygen and liquid hydrogen shall be the propellants. The mixture ratio for booster operation is 12 and the mixture ratio for sustainer operation is 6. The feasibility to operate continously over this range of mixture ratios shall be determined. The basic engine concept shall operate at approximately constant mixture ratio depending on the mode, i.e., booster or sustainer.

3.4 FUNCTIONAL REQUIREMENTS

3.4.1 Thrust Profile

The thrust profile for a typical earth-to-orbit trajectory is shown in Figure 3.4-1. The high thrust, high mixture ratio

ACUREX Aerotherm

ENGINE ALTITUDE-THRUST PROFILE

PR0P890227-1.0

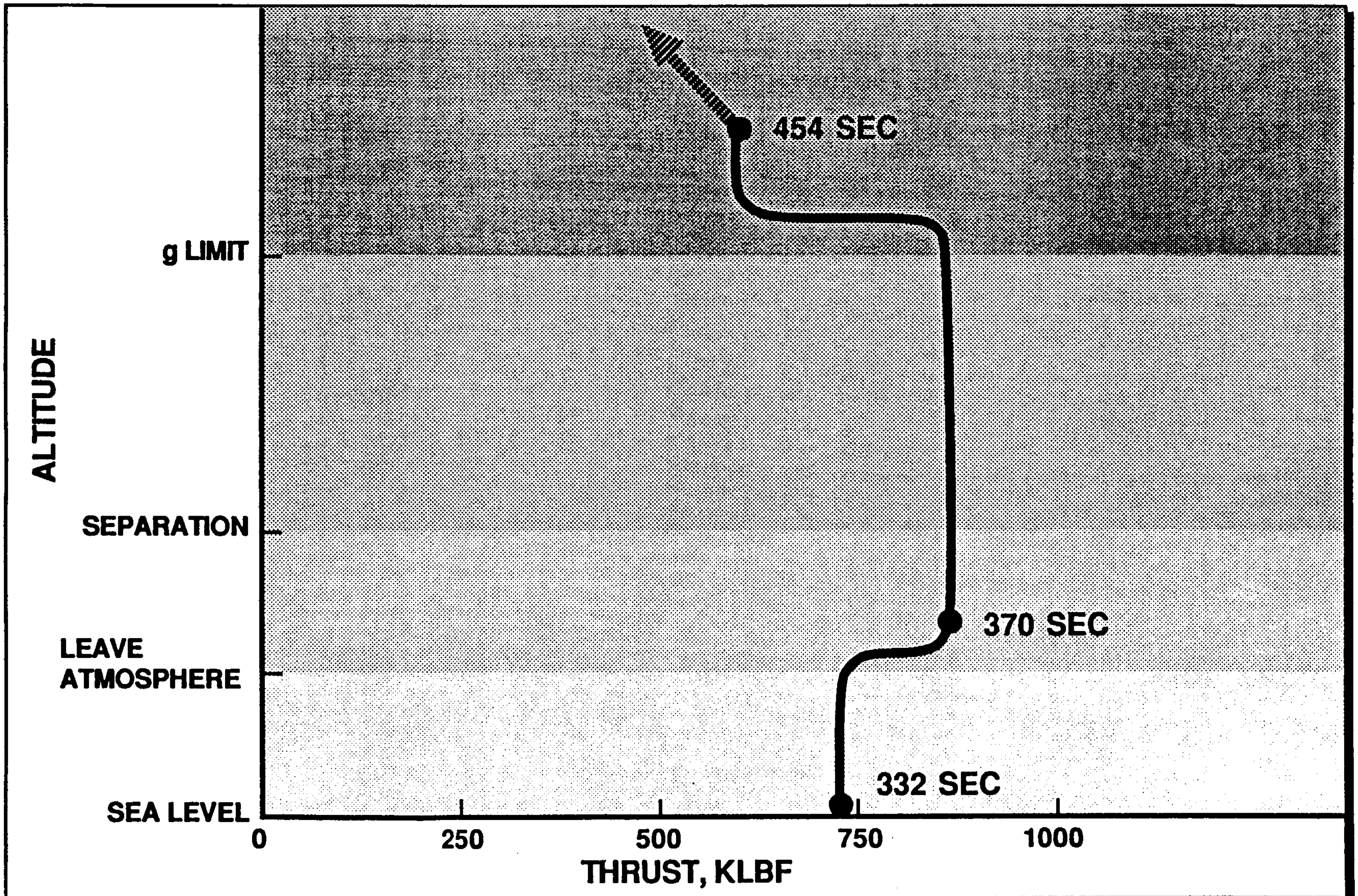

Figure 3.4-1:

mode for the early phase of flight is consistent with the booster phase of the flight. The lower thrust, lower mixture ratio, high specific impulse mode is consistent with the sustainer mode of the powered flight.

3.4.2 Specific Impulse

The specific impulse of the engine depends upon the mixture ratio, the altitude (ambient static pressure) and the exit-to-throat area ratio of the skirt. The relationship of the vacuum specific impulse to the other parameters shall be as shown in Figure 3.4-2.

3.4.3 Interfaces

Engine-vehicle interfaces listed below shall be considered:

Item	Name
1	LOX Inlet Line
2	Fuel Inlet Line
3	LOX Tank Autogenous Line
4	Fuel Tank Autogenous Line
5	Gimbal/Thrust Takeout
6	Gimbal Actuators Mounts
7	Purge/Vent System
8	Start/Shutdown System
9	Electrical System
10	Other

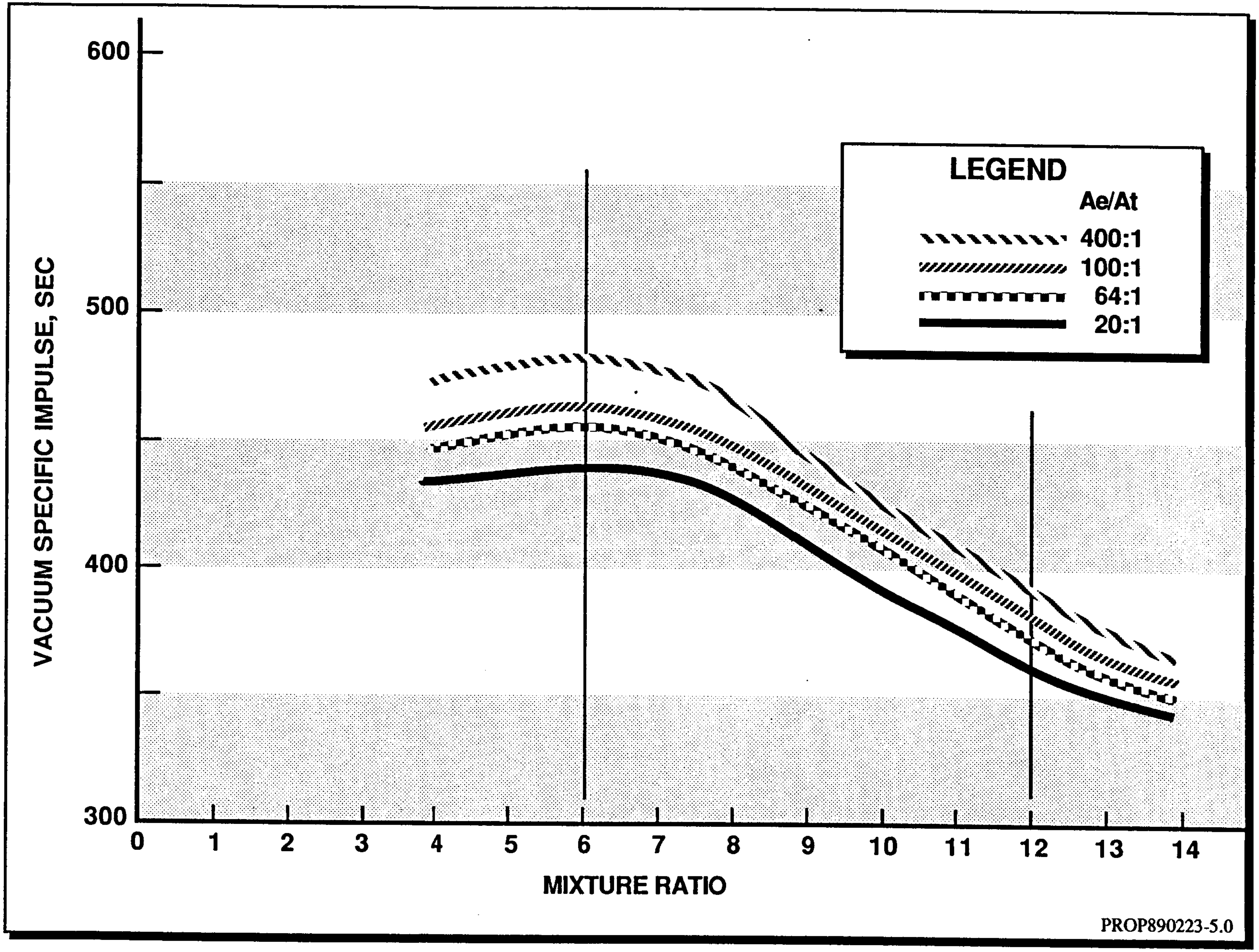
LEGEND
Ae/At
400:1
100:1
64:1
20:1
VACUUM SPECIFIC IMPULSE, SEC
600
500
400
300
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
MIXTURE RATIO
PROP890223-5.0

Figure 3.4-2:

3.5 PHYSICAL REQUIREMENTS

3.5.1 Size/Envelope

As a goal the engine dimensions shall fall within the silhouette shown in Figure 3.5-1.

3.5.2 Weight

3.5.2.1

The engine weight shall include all components and equipment downstream of the suction flanges to the turbopumps, the gimbal interface to the vehicle, the side attachments to the thrust vector actuators and the fluid and electrical lines and connectors.

3.5.2.2

The engine weight shall not exceed the weights shown in FIGURE 3.5-2.

3.5.3 Environment

3.5.3.1 Range

The engine, with prescribed propellant conditioning shall be capable of startup, steady state operation and shutdown at all prescribed thrust levels listed for the environmental conditions listed in Table 3.5-1.

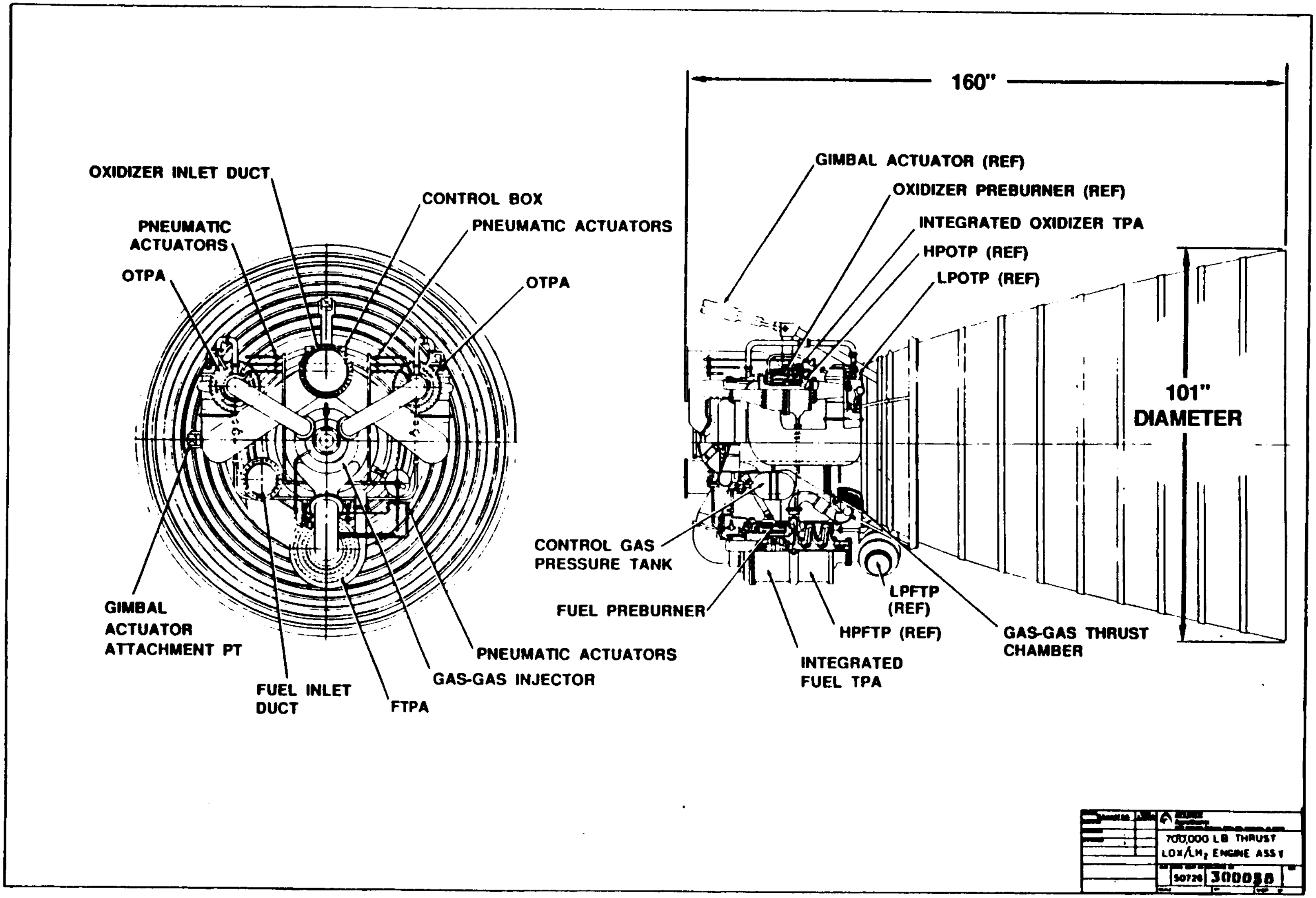
OXIDIZER INLET DUCT
CONTROL BOX
PNEUMATIC ACTUATORS
PNEUMATIC ACTUATORS
OTPA
OTPA
GIMBAL ACTUATOR ATTACHMENT PT
FUEL INLET DUCT
FTPA
GAS-GAS INJECTOR
PNEUMATIC ACTUATORS
160"
GIMBAL ACTUATOR (REF)
OXIDIZER PREBURNER (REF)
INTEGRATED OXIDIZER TPA
HPOTP (REF)
LPOTP (REF)
101" DIAMETER
CONTROL GAS PRESSURE TANK
FUEL PREBURNER
INTEGRATED FUEL TPA
HPFTP (REF)
LPFTP (REF)
GAS-GAS THRUST CHAMBER
700,000 LB THRUST
LOX/LH2 ENGINE ASSY
50720

Figure 3.5-1:

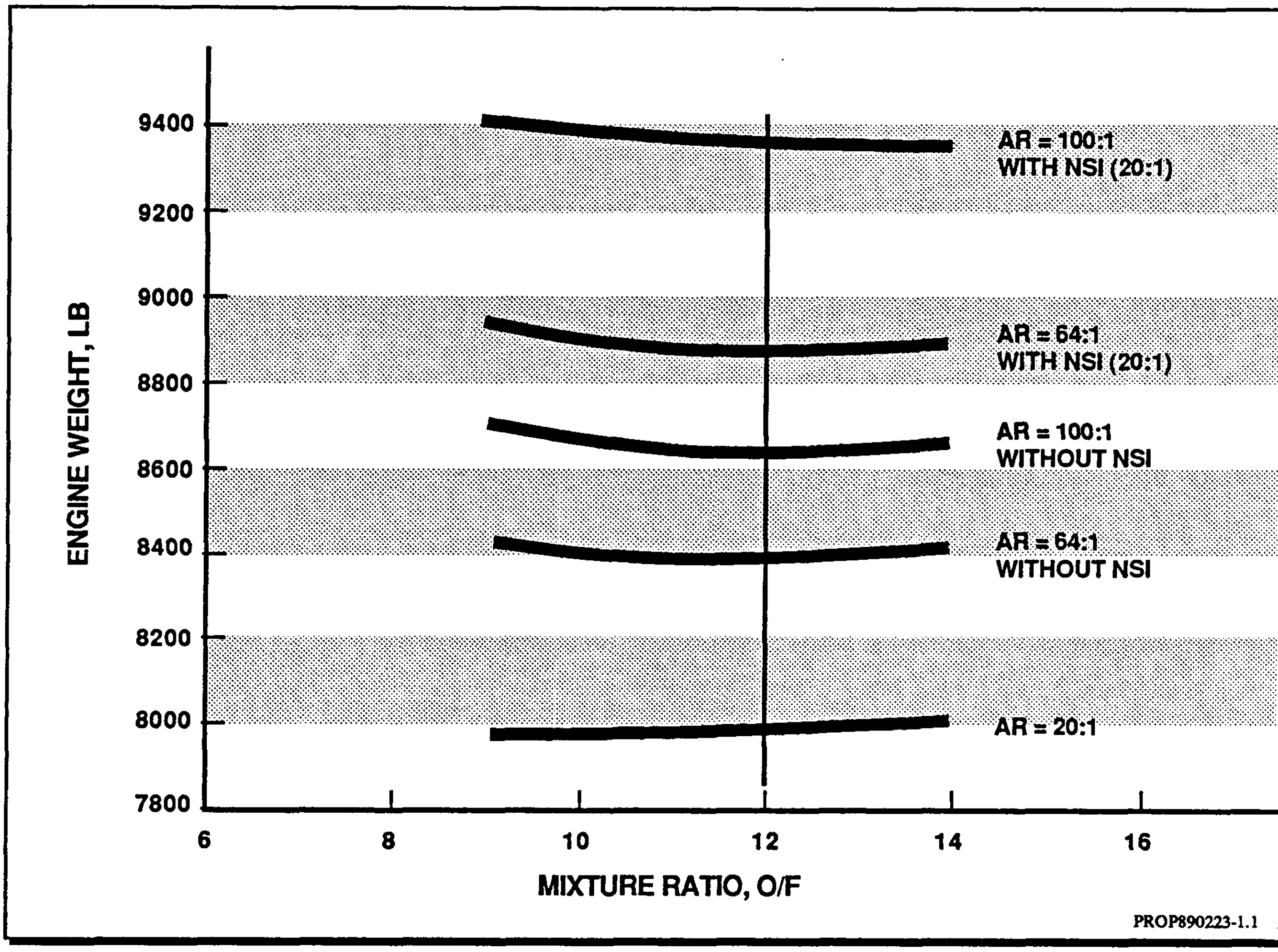

Figure 3.5-2

Table 3.5-1: Environmental Range For Normal Engine Operation

CONDITION	MINIMUM	MAXIMUM
Temperature, °F	–60.0	120.0
Barometic Pressure, Startup, in.–Hg.	28.5	31.0
Relative Humidity, %	0.0	100.0
Noise Level, db	60.0	130.0

PROP890223-2.0

3.5.3.2 Storage/Transport

When packaged for storage/transport, the engine shall not degrade to the extent that it will not perform in a normal manner. Non-metallic materials shall have an installed shelf life of five years. The engine shall be stored and transported in a pressurized container containing a desicant. The temperature range for storage and transportation shall be -60°F to +160°F. Maximum shock loads will be +6 g's horizontal and + 2 g's vertical.

3.5.4 Interchangeability

All major components, i.e. turbopumps, thrust chambers, nozzle skirts etc. shall be physically interchangable without degradation of engine performance, weight, envelope, and without requiring engine recalibration.

3.6 DESIGN CONSIDERATIONS

3.6.1 Structural

Structural/fatigue criteria, Document RSS-8561-21, Structural Load Criteria for SSME dated Jan 1983, are to be used for a design guide only. Detailed structural analyses will be performed at the next stage of the design activity, i.e. preliminary design.

3.6.2 Liquid Oyxgen Compatibility

Materials in contact with oxygen shall be (or have been) tested for compatiblity in accordance with NASA MSFC-SPEC-106B, testing compatibility of materials for liquid oxygen service.

3.6.3 Oxidizer-Rich Gas Compatibility

Materials of construction in contact with oxidizer-rich gases shall be (or have been) tested in accordance with NASA document NHB 8060, Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion.

3.6.4 Protective Treatments

Protective treatments/coatings may be used to extend the service life of the engine. No protective treatment shall be used such that its omission or deterioration would cause a engine/vehicle/personnel safety hazard.

3.6.5 Flammability/Embrittlement

Materials of construction shall be selected from candidates having known flammability/embrittlement characteristics, and design margins shall be defined.

3.6.6 Margin to Ignition, MS Parameter Method

The MS Parameter transient and steady state values shall be computed for all materials in contact with oxygen or oxidizer-rich gases. The margin from ignition shall be computed based upon NASA MSFC SPEC No. (TBD).

3.7 PARAMETRIC DATA

The following parametric data apply to this engine only. These data convey the dual operating modes of this high mixture ratio booster mode engine and conventional mixture ratio sustainer mode engine.

3.7.1 Flow Schematic

The engine flow schematic is shown in Figure 3.7-1. The oxidizer booster pumps are driven by turbines which operate in parallel with the main turbines. The fuel booster pumps are driven with hydrogen gas vapors from the thrust chamber regenerative coolant circuit (similar to SSME). Approximately twenty percent of the hydrogen is used for this regenerative coolant flow.

3.7.2 Flow Rate Schedule

The flow rate schedule is shown Figure 3.7-2. The flow rate schedule pertains to the booster mode of operation.

3.7.3 Pressure Schedule

The pressure schedule shown in Figure 3.7-3 is to be used with the flow schematic shown in Figure 3.7-1. The pressure schedule pertains to the booster mode of operation.

3.7.4 Temperature Schedule

The temperature schedule is shown in Figure 3.7-4. The temperature schedule pertains to the booster mode of operation. Note the modest turbine inlet temperatures.

3.7.5 Specific Parameters

The data, in Table 3.7-1 provides specific information concerning the design of the engine. These parameters show the conservative design values used for this engine.

ACUREX Aerotherm

ENGINE FLOW SCHEMATIC

PC880223-1.B

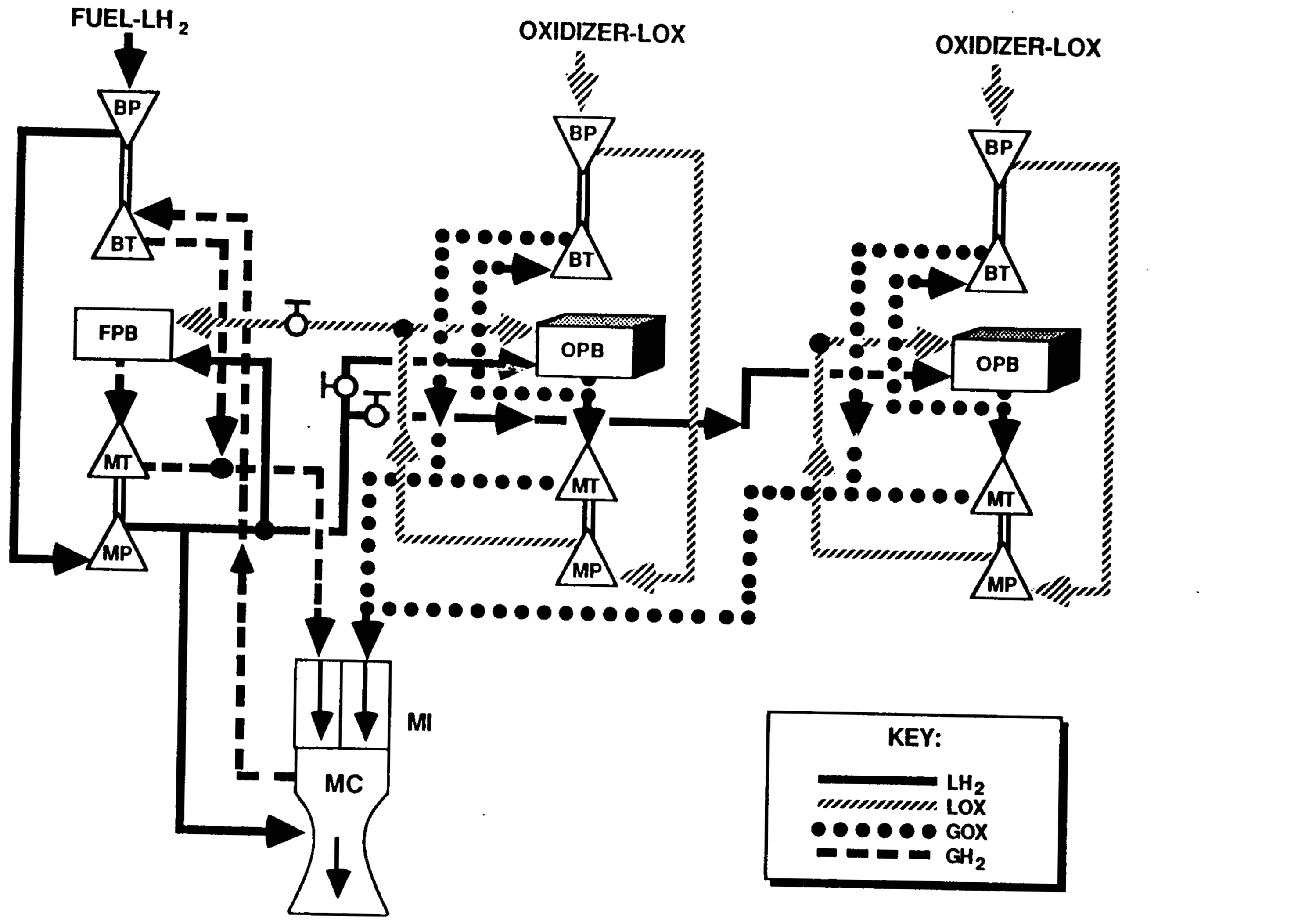

Figure 3.7-1: Engine Flow Schematic

ACUREX
Aerotherm

ENGINE TEMPERATURE FLOW SCHEMATIC

PC880223-1.C

NUMERICAL VALUES IN LB/SEC

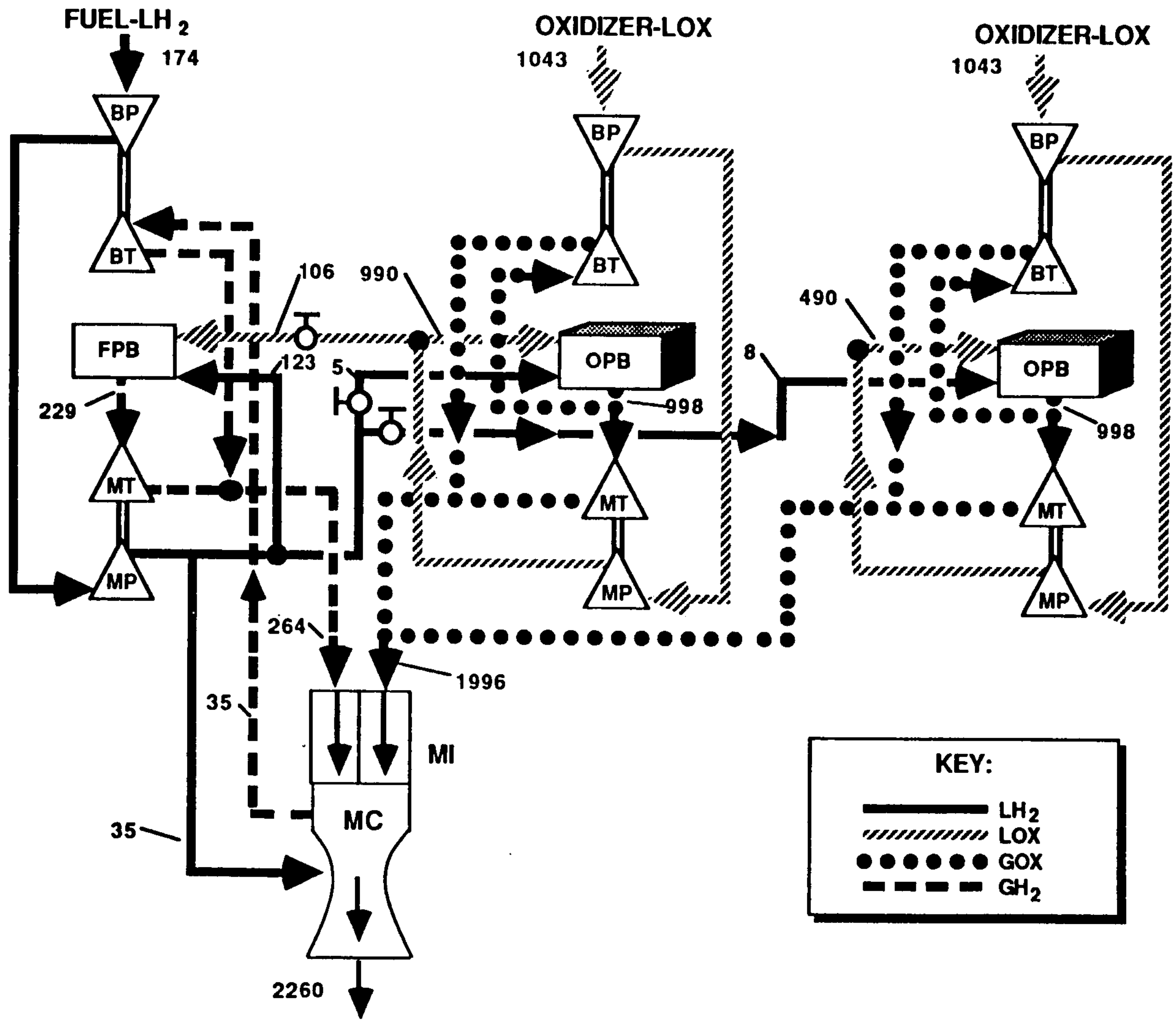

Figure 3.7-2: Flow Rate Schedule

ACUREX Aerotherm

ENGINE PRESSURE SCHEDULE

PC880223-1.E

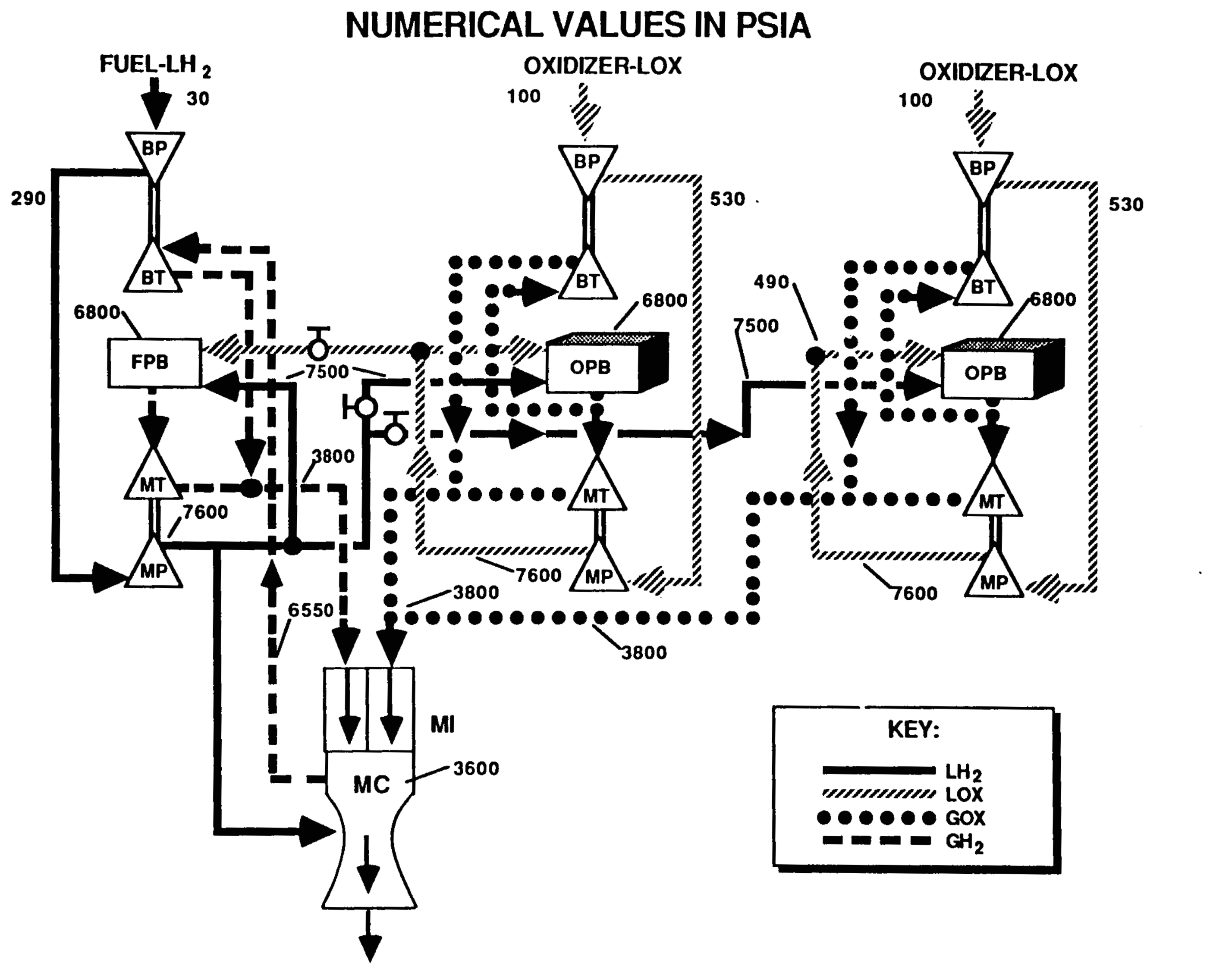

Figure 3.7-3: Pressure Schedule

ACUREX Aerotherm

ENGINE TEMPERATURE SCHEMATIC

PC880223-1.D

NUMERICAL VALUES IN DEGREES RANKINE

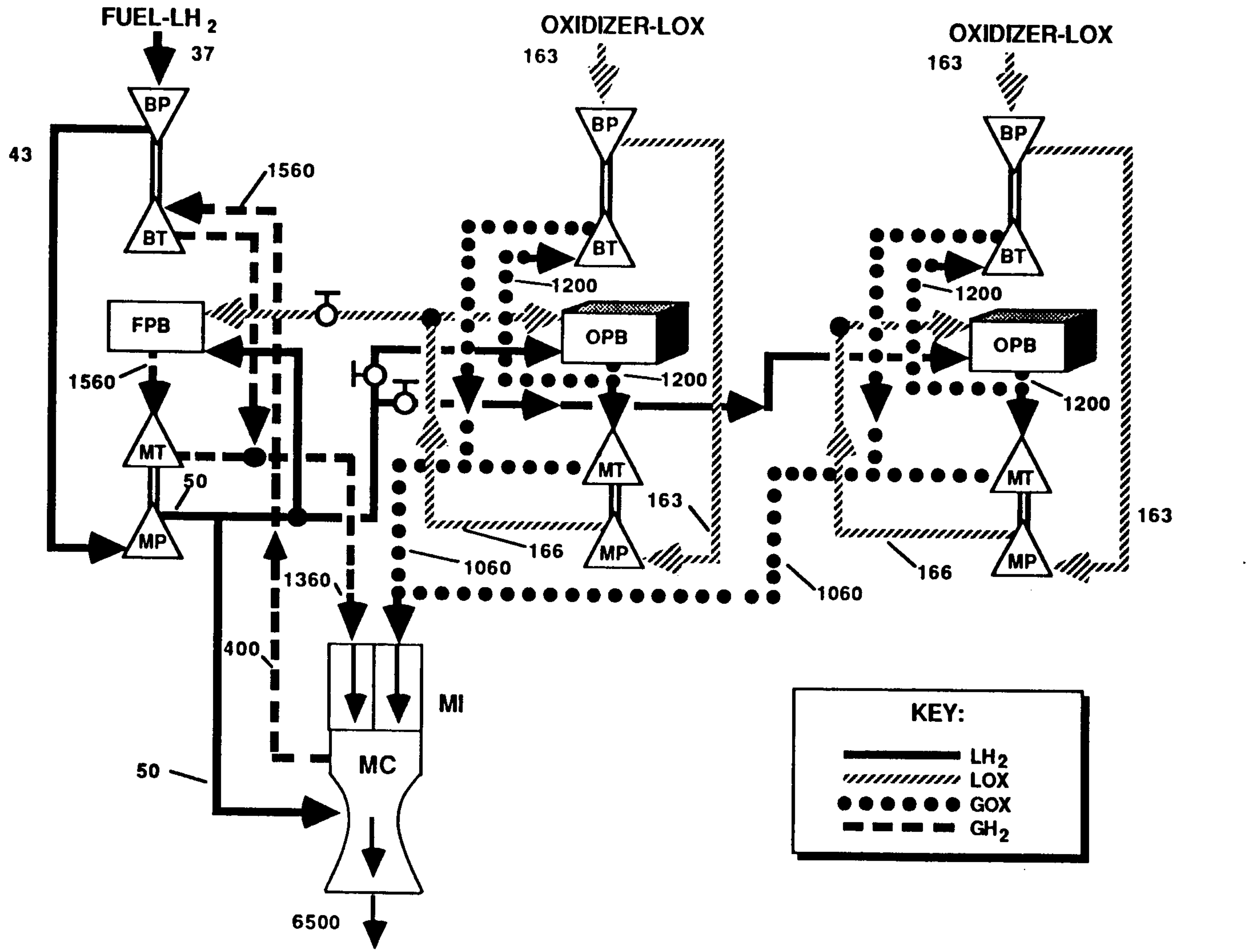

Figure 3.7-4: Temperature Schedule

TABLE 3.7-1

BOOSTER/UPPER STAGE

PARAMETER	BOOSTER	UPPER STAGE
THRUST, VACUUM, lbs	836,000	550,000
MIXTURE RATIO	12	6
CHAMBER PRESSURE, psia	3600	2400
AREA RATIO,EXIT/THROAT	16	60
SPECIFIC IMPULSE, seconds	370	454
THROAT DIAMETER, inch	13.3	13.3
WEIGHT FLOW RATE, lb/sec	2260	1217
OXIDIZER WEIGHT FLOW, lb/sec	2086	1043
FUEL WEIGHT FLOW, lb/sec	174	174
BULK DENSITY PROPELLANTS, lb/cu.ft	33	22
APPROXIMATE THRUST (VAC)/WEIGHT	99	65

APPENDIX C

DROP WEIGHT TESTER

SYSTEM DESIGN DESCRIPTION

Appendix C

Drawing List

Drawing N.	Description
300037	OXIDIZER-RICH PREBURNER
30094	OXYGEN-HYDROGEN GAS-GAS INJECTOR

APPENDIX D

DROP WEIGHT TESTER

DRAWING LIST

APPENDIX D
DWT DRAWING LIST

NOMENCLATURE	DRAWING NUMBER*
Impact Tester Assembly	300050-1
Cell Assembly	300046-1
Upper Housing	400031-1
Center Housing	300027-1
Center Housing	400032-1
Weld Assembly, Center Housing	400052-1
Housing, Preweld	400058-1
Ring, Preweld	400059-1
Base Housing	400033-1
Weld Assembly, Base Housing	400051-1
Base, Preweld	400056-1
Ring, Preweld	400057-1
Heater Barrel	300045-1
Barrel	400034-1
Weld Assembly, Barrel	400053-1
Barrel	400061-1
Tube	400062-1
Striker	400035-1
Striker Tip	RS5005266-X
Cup-Specimen	400025-1
Retainer, Insulator	300044-1
Disc Assembly, Insulator	400049-1
Disc	400054-1
Ring	400055-1
Sample	400012-1
Nut, Gland	400037-1
Washer, Backing	400038-1
Spool	400039-1
Stud	300024-1
Stud	400040-1
Insulator	300061-1
Insulator Blank	300060-1
Heater Coil	400043-1
Stud	300075-1
Washer	400041-1
Base Plate	*300030-1
Base	RS003071
Strut Assembly	*RS003072
Clamp Bar Assembly	*RS003073

DWT890308-1.0

APPENDIX D (Continued)
DWT DRAWING LIST

NOMENCLATURE	DRAWING NUMBER*
Plummet Assembly	R0019387
Body Plummet	RS005251
Roller, Plummet	RSOO5253
Nut, Plummet	RS005254
Nose, Plummet	RS005255
Support, Plummet	RS005256
Bushing, Plummet	RS005260
Spacer, Plummet	RS005725
Support, Plummet	R0019385
Spider, Plumment	R0019386
Bushing, Plummet	R0019388
Support Plummet Lift-Outer	400065-1
Support Plummet Lift, Inner	300041-1
Support Plummet Lift, Inner	RS005272
Support, Lift Trigger	300051-1
Support, Lift Trigger	RS005721
Clamp Assembly, Plummet Catcher	300047-1
Bracket	300048-1
Clamp	RS003074
Latch	RS005263
Magnet, Electro	RS005259
Top Plate Assembly	300042-1
Top Plate Assembly	RS003075
Pulley	RS005275
Bolt	RS005274
Roller	RS005720-005
Clamp Assembly	300052-1
Clamp	300052-2
Clamp	300052-3
Plate	300052-4
Bracket Assembly	300049-1
Base Assembly	300049-2
Angle	300049-3
Plate	300049-4
Angle	300049-5
Plate	300049-6

* 3000XX Series — Acurex Drawings
4000XX Series — Cryomec Propulsion Inc. Drawing
R & RS Series — Rocketdyne Drawings - No copies furnished with this report.

DWT890308-1.1

APPENDIX E

DROP WEIGHT TESTER

SYSTEM DESIGN DESCRIPTION

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

DROP WEIGHT TESTER
SYSTEM DESIGN DESCRIPTION

1.0 DESIGN DESCRIPTION

1.1 SYSTEM DESCRIPTION

The high pressure, high temperature drop weight system is located in Test Bay #3 in Building 4623 at MSFC. The system consists of a drop weight test (DWT) assembly, a control system, a high pressure oxygen compressor, valves, pressure regulators and interconnecting gas lines. The DWT assembly, the oxygen compressor and most of the values, regulators and gas lines are located in the test bay proper. The control console and a nitrogen supply panel are located in the control room adjacent to the test bay. Figure E-1 is the schematic of the system for GOX operation..

1.2 COMPONENT DESCRIPTION

1.2.1 DWT Assembly

The DWT assembly consists of a tower assembly, a plummet assembly, a cell assembly, a plummet catcher assembly, and a plummet latch assembly. The DWT assembly is shown in Figure E-2.

1.2.1.1 Tower Assembly

The tower assembly consists of a base plate, three struts, a clamp bar and a top plate. When assembled the struts form an equilateral triangle with the clamp bar off to one side.

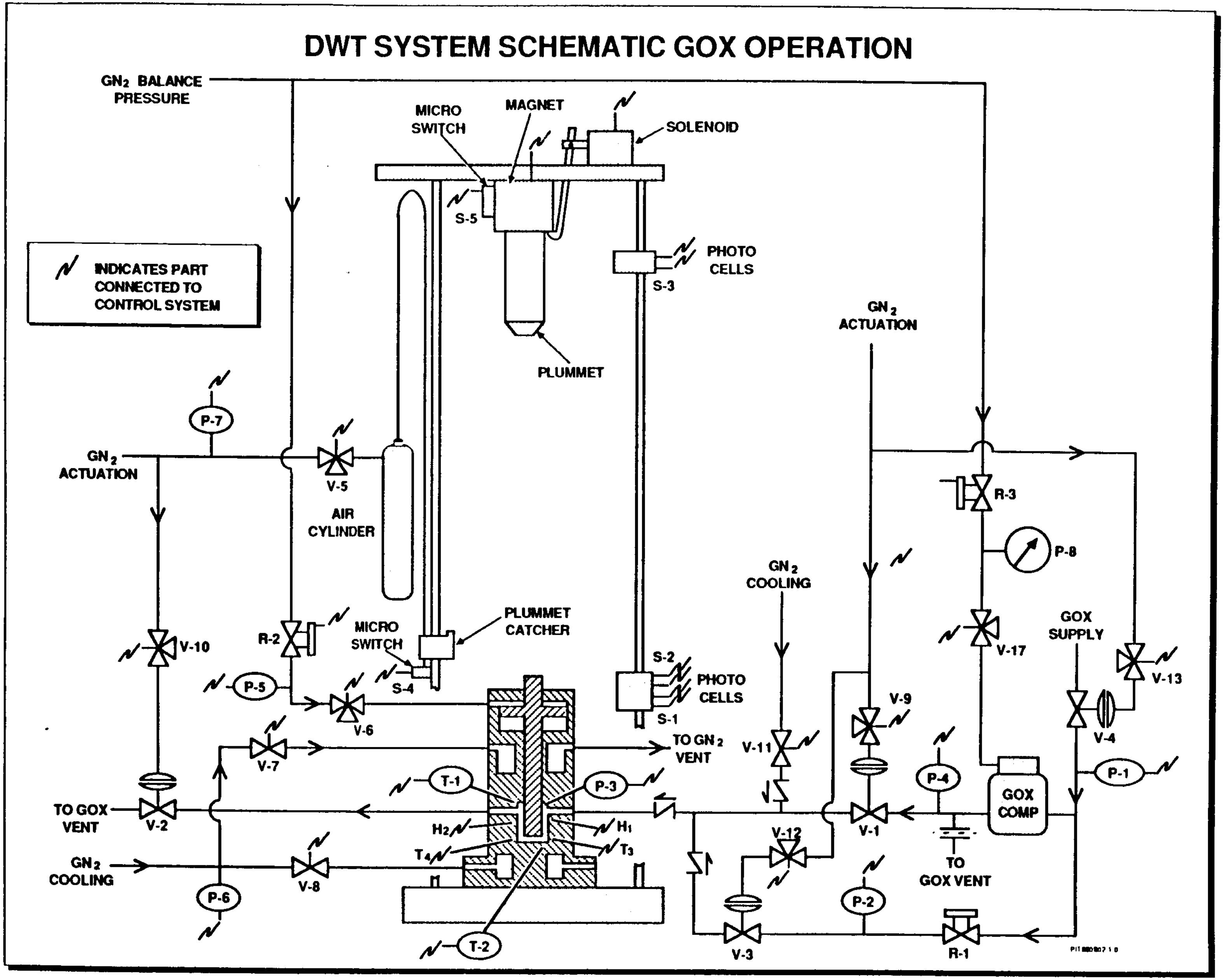

Figure E-1: DWT System Schematic

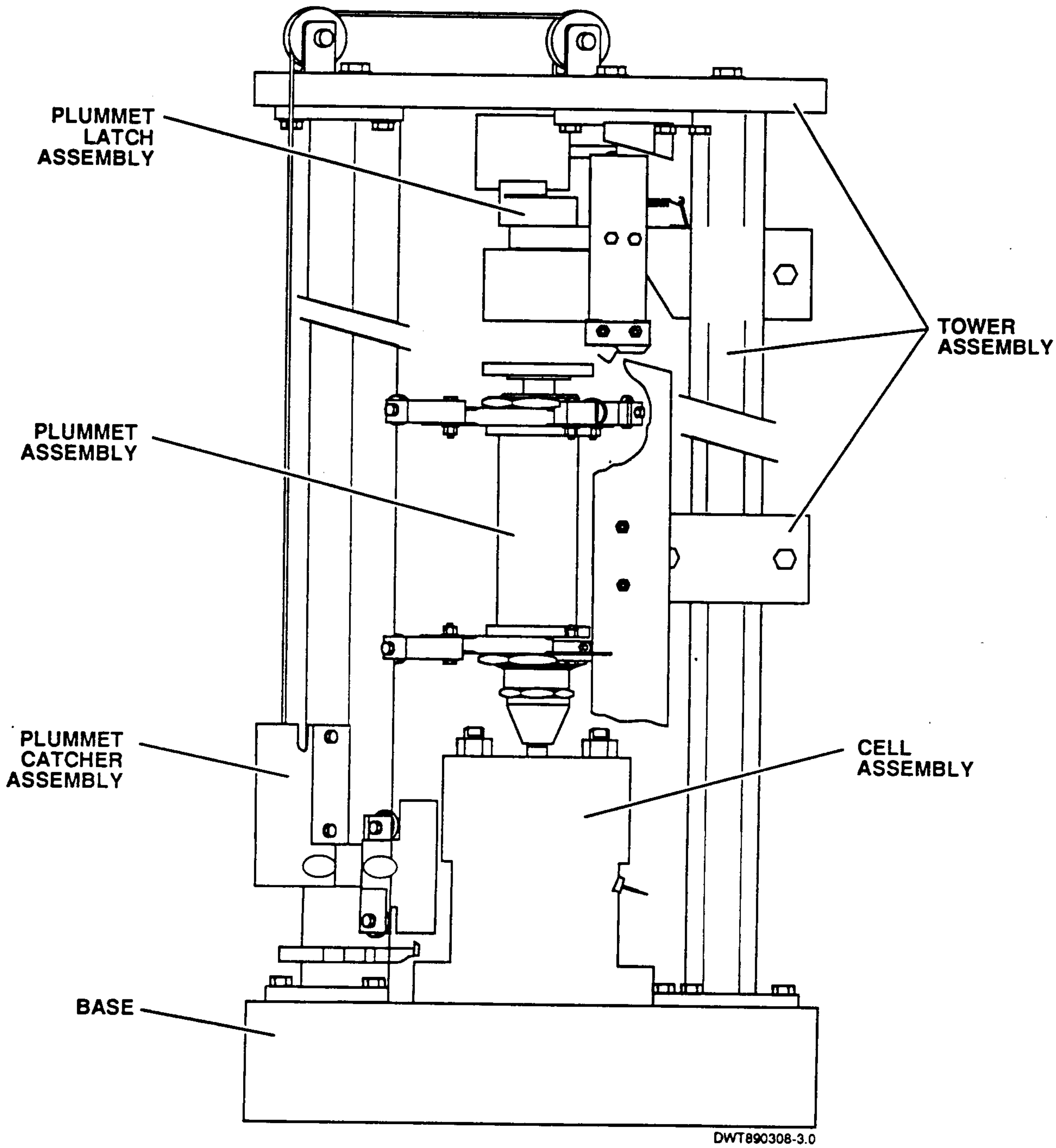

Figure E-2 DWT Assembly

The base plate is 18 inches square by four inches thick and is made of 321 steel. The plate contains the necessary holes to mount the struts, clamp bar and cell assembly. Four holes have been provided to permit anchoring the assembly in a test bay.

The three struts are identical two inch square bars 75 inches long. Each bar has a flange welded on each end for attachment to the base plate and top plate. Bar and flange material is 321 steel.

The clamp bar is exactly like the struts except two inch hex bar is used.

The top plate is an 18 inch diameter by one inch thick plate made of 321 steel. The plate has a bolt hole pattern that matches the bolt hole pattern of the base plate for the struts and clamp bar. The top side of the plate contains two brackets for pulleys.

1.2.1.2 Plummet Assembly

The plummet assembly consists of a body, two spiders, six roller supports, a nose piece, a top plate and twelve rollers.

The body is a 2.5 inch diameter bar 9.25 inches long with a 3.3 inch diameter by 0.30 inch thick flange 1.25 inches from each end. Each end of the bar contains 2.500-12UN-3A by 0.55 inch long threads. The top of the bar is drilled and tapped with 0.500-20 UNF-3B by 0.80 inch deep and the bottom contains 0.875-14UNF-3B by 0.80 inch deep threads. The center of the bar has been drilled to reduce weight. The body material is 321 steel.

The spiders are identical with one located on each end of the body. The spider has three arms 120 degrees apart. The spider is 0.625 inch thick with a 2.5 inch diameter hole in the center. Each spider is pinned to the flange on the body and held onto the body with locking nuts. Each arm of the body has two holes for mounting roller supports. The spider material is 6061-T6 aluminum alloy.

The roller support is a rectangular shaped bracket 2.47 inches long by 2.45 inches wide with an overall thickness of 0.75 inches. The support contains two slots 0.355 inches wide by 0.77 inches deep and 90 degrees apart at one end. The other end has been machined to a lesser thickness (0.20 inch) in a u-shaped configuration to mate with the spider arm. Two slotted holes have been drilled in this end to mate to holes in the spider arm. The support material is 304 steel. The roller is a 1.060 inch diameter by 0.350 inch thick wheel made of Delrin. Two rollers are mounted on each roller support.

The nose piece is 3.2 inches long overall. The nose piece starts with a shaft that contains 0.875-14UNF-3A by 0.50 inches long threads. The shaft extends an additional 0.85 inches at a 0.75 inch diameter. This is expanded to a hex head that is 2.00 inches across flats by 0.35 inches thick. A 2.00 inch diameter is then held for 0.25 inches than tapered to a 1.00 inch diameter over the last 1.25 inches. The nose piece material is 440C steel.

The top plate is 1.5 inches thick with a 3.50 inch diameter for one inch of the thickness and a 1.00 inch diameter for the other 0.50 inch thickness. A 0.531 inch diameter hole is drilled through the center. The top plate material is 416 steel.

The plummet assembly weighs 20.0 ± 0.2 pounds. The outer surface of the body is final machined to obtain this weight.

1.2.1.3 Plummet Catcher Assembly

The plummet catcher assembly consists of an air cylinder, pulleys, a cable and a catcher.

The air cylinder is a 30 inch long Parker Hannifin, Series C unit. Clamps have been provided to mount the unit on one of the flat surfaces of the tower assembly clamp bar.

The pulleys are 2.0 inches in diameter, 0.450 inches thick with a 0.25 inch deep are groove and a 0.391 hole through the center. The pulley material is 321 steel.

The catcher is made up of two vee shaped clamps when bolted together have a 2.0 inch square hole in the center. Each vee leg of the clamp is 3.80 inches wide by 1.00 inch thick and 4.50 inches long. Each leg contains a slot at the top and bottom 1.875 inches out from the vee corner that is 0.312 inches wide by 0.875 inches deep. These slots contain rollers 0.966 inches diameter by 0.30 inches thick. The catcher material is 304 steel.

A 0.125 inch diameter steel cable connects the air cylinder to the catcher via the two pulleys mounted on the tap plate of the tower assembly.

1.2.1.4 Plummet Latch Assembly

The plummet latch assembly consists of a clamp, magnet, solenoid, latch, brackets and a microswitch.

The clamp is a rectangular plate 3.25 inches wide by 9.50 inches long. The clamp is 3.0 inches thick for 4.35 inches of length and 0.75 inch thick the remainder of the length. The thickest section contains a hex opening 2.00 inches across the flats. A 0.125 inch wide slot has been cut into the hex opening at the end of the clamp to provide the spring action required for fastening the clamp onto the tower assembly clamp bar. A 1.00 inch long by 0.50 inch wide slot is located 6.00 inches from the area of the clamp. The clamp contains appropriate holes in the sides and in the 0.75 thick section for attachment of the solenoid bracket, the magnet and the microswitch bracket. The clamp material is 321 steel.

The magnet is a 24 Vdc electromagnet that is 3.50 inches in diameter by 2.55 inches long and contains a hole in the top that contains 0.500-20UNF-3B by 0.5 inch deep threads.

The solenoid is a 24 Vdc solenoid with a plunger that is machined flat on the end to fit into the latch.

The latch is a 6.40 inch long by 0.50 inch wide by 0.25 inch thick bar., The latch is stepped out to 0.75 inches wide, 0.50 inches from the bottom to provide a hook, then tapered to the bottom at a 45 degree angle. The top contains a 0.110 inch wide by 0.50 inch deep groove to mate with the solenoid plunger. A 0.25 inch diameter hole, 2.25 inches from the top has been drilled through the bar. The latch is made of 321 steel.

The microswitch is a model SCB103765, Electro-line Inc., 24 Vdc switch.

Three brackets are attached to the clamp. One is u-shaped and bolts to the top of the clamp to hold the solenoid. A small

L-shaped clamp bolts to the top of the clamp for a spring attachment point. The other end of the spring attaches to the latch. A third bracket is a rectangular flat plate that attaches to the side of the clamp and holds the microswitch.

1.2.1.5 Cell Assembly

The cell assembly is shown in Figure E-3 and as can be seen is made up of numerous parts. The major parts are the upper housing, center housing, lower housing, barrel and striker.

The upper housing is 5.937 inches in diameter and is 3.35 inches long. The housing has four holes, equally spaced, 0.688 inch diameter thru, on a 4.00 inch diameter. The top side of these holes has been countersunk 1.359 inches with a 1.688 inch diameter. The center section has been opened from the bottom to a depth of 1.787 inches with a 3.156 inch diameter then stepped down to a 2.966 inch diameter for 0.827 inches. Two 0.188 inch diameter holes have been drilled from the outer surface into this cavity, each diameter and each hole contains 0.250 NPT threads 0.50 inches deep. In the center, from the top, a 0.656 inch diameter hole was drilled through. The upper part of this hole was counterbored 1.280 inches deep. The lower 0.431 inches has a 0.996 inch diameter, the top 0.190 inches has a 2.063 inch diameter and the remainder contains 1.250-12UNF-3B threads. The bottom surface has six holes equally spaced on a 5.57 inch diameter that contain 0.164-32UNC-3B by 0.45 inch deep threads. The housing was annealed and aged to R_c 34-36 prior to final machining.

The center housing has an overall length of 2.744 inches. From the bottom, the housing has a 5.052 inch diameter for 0.103 inches that opens to a 5.25 inch diameter for 1.775 inches then

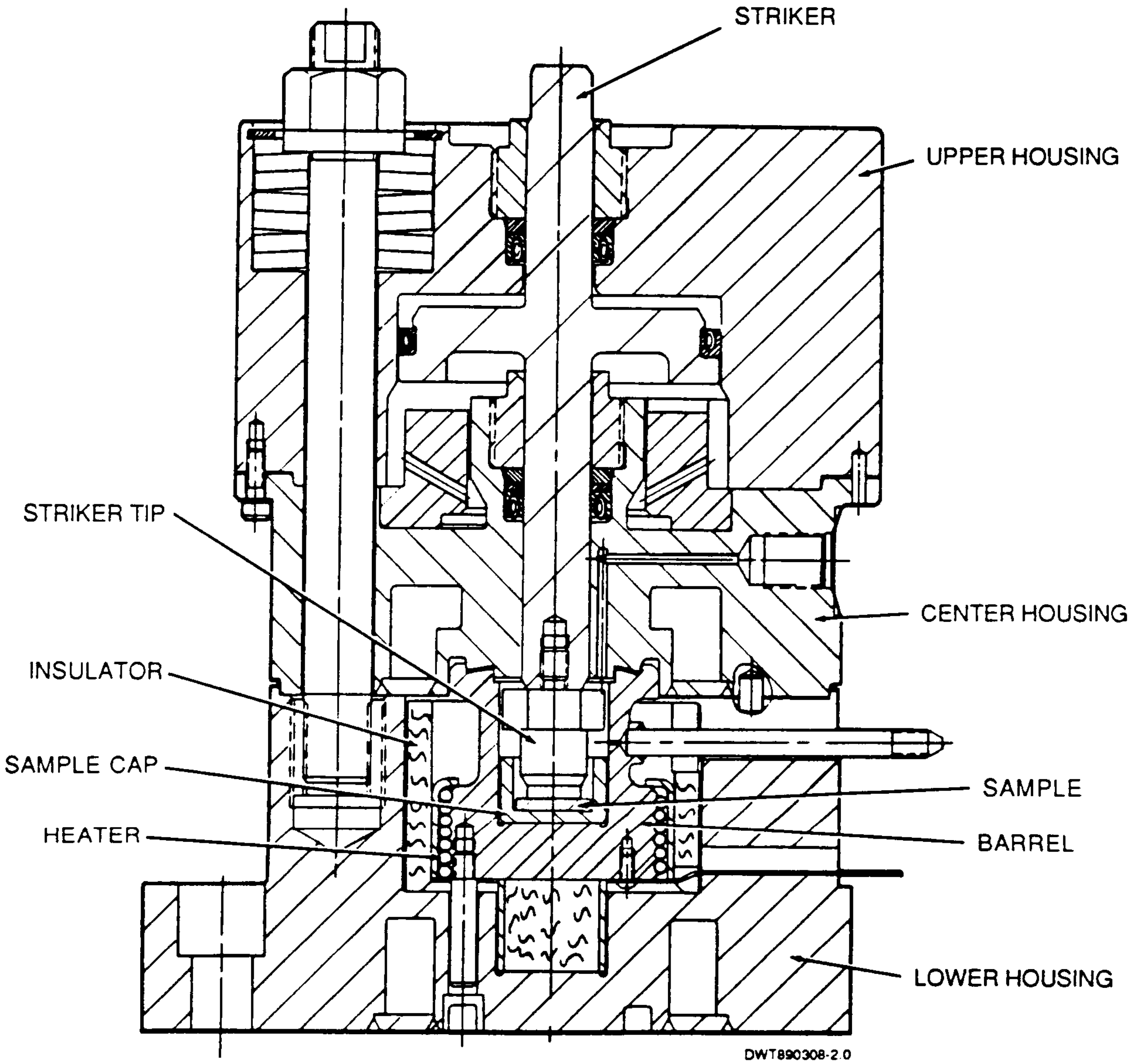

Figure E-3: Cell Assembly

opens to a 5.937 inch diameter for 0.241 inches. The diameter then is 1.625 inches for the last 0.655 inches. Six 0.211 inch diameter holes, equally spaced on a 5.57 inch diameter are in the largest diameter section. A 0.625 inch diameter hole passes through the center of the housing. The upper part of this hole was counterbored 1.15 inches deep. The lower 0.506 inches has a 0.996 inch diameter and the upper portion contain 1.250-12UNF-3B threads. Two grooves have been machined in the top surface that expands from 1.625 inches to 5.937 inches in diameter, one to a 4.876 inch diameter 0.111 inches deep and the other to a 3.25 inch diameter 0.374 inches deep. Seventeen 0.062 inch diameter holes, spaced on an eighteen equal spacing, have been drilled in the bottom of the lower groove into a channel inside the housing. A 0.0188 inch diameter hole, containing 0.250 NPT threads at the outer portion has been drilled into this inner channel. The housing also contains two connecting holes, one drilled from the outer surface inward and the other from the bottom surface upward. The holed drilled from the outer surface contains 0.250-20UNC-2B by 1.00 inch deep threads. The bottom surface has been machined to hold a conoseal gasket and a metallic "O" ring. Four 0.688 inch diameter holes equally spaced on a 4.00 inch diameter have been drilled through the housing. The housing material is 718 Inconel that was annealed and aged to R_c 34-36 prior to final machining.

The lower housing (cell base) is 3.22 inches long with the bottom 1.38 inches being a 5.5 inch square and the top 1.84 inches having a 5.25 inch diameter. Four, 0.562 inch diameter holes, equally spaced on a 6.12 inch diameter have been drilled through the bottom section. Four, 0.830 inch diameter by 1.25 inches deep holes, equally spaced on a 4.0 inch diameter have been drilled into the top section of the base. These four holes each contain an insert with 0.625-11UNC-2B threads. From the top, the center of the housing has been opened to a diameter of 2.75 inches 1.912 inches deep, then stepped to a 1.015 inch diameter, an additional 0.743 inches deep. Four, 0.250 inch diameter holes on a 1.625 inch diameter have been drilled through the housing. The lower portion of the housing contains a inner, circular channel that has an 3.06 inch outer diameter and a 2.18 inch inner diameter and is 0.875 inches deep. Eighteen, 0.062 inch diameter holes equally spaced on a 2.3 inch diameter have been drilled into the top of this channel. Three slots have been cut into the top cylinder. Two slots, 180 degrees apart, are 0.25 inch wide by 0.65 inch deep. The third slot is 90 degrees from the other slots and is 0.42 inch wide by 1.59 inches deep. The housing material Inconel 718 and was annealed and aged to R_c 40-44 prior to final machining.

The heater barrel is 1.863 inches long and has a major outside diameter of 2.04 inches. From the top, the barrel has an opening 1.015 inches in diameter by 1.329 inches deep. The top surface of the barrel has been machined to match the sealing surfaces of the center housing. Four holes have been drilled into the bottom of the barrel. The holes are equally spaced on a 1.625 inch diameter, 0.56 inch deep, and tapped with 0.190-32UNF-2B threads. The barrel has inlet and outlet high pressure gas lines, 180 degrees apart. The bottom 0.890 inches of the major diameter contains single right hand threads, 16 per inch. The barrel material is Inconel 718 and was annealed and aged to R_c 40-44 prior to final machining.

The striker is a one piece piston and rod. The overall length is 5.756 inches. The rod has 0.622 inch diameter. The piston is 0.70 inch thick with a diameter of 2.991 inches. The piston is grooved on the outer diameter for an Omni seal. The bottom of the piston is 2.284 inches above the bottom of the rod.

The bottom of the rod is drilled and tapped with 0.250-28UNF-3B threads. The striker material is Inconel 728 and was annealed and aged to R_c 40-44 prior to final machining.

When assembled, the cell assembly contains heaters around the barrel, insulation around the heaters, thermocouples on the heaters and the barrel, a pressure transducer mounted in the center housing, studs to position the barrel in the base housing and bolts that hold the three main housings together and provide the force required to seal the center housing to the barrel.

1.2.2 High Pressure Oxygen Compressor

The compressor is a single stage, air driven, packed plunger intensifier. All components exposed to oxygen service are made from Monel. The packing is graphite filled teflon requiring no lubrication. A six inch diameter air cylinder drives the 7/16 inch diameter plunger. The air cylinder is shifted by a 4-way pilot operated valve. Air for the pilot parts comes from two trip valves located at each end of the cylinder stroke. The compressor is approximately 26 inches high on a 8.5 inch square base. The base contains four holes for mounting the compressor to the floor.

1.2.3 Valves, Regulators, Interconnecting Lines

As can be seen in Figure E-1, the system contains numerous valves, regulators and lines to connect all the components. The GN_2 system plumbing consists of 1/4 inch stainless steel tubing and 28 Vdc solenoid valves. The system is divided into three separate subsystems; actuation, cooling and balance. The actuation and cooling subsystems are 0-150 psig and the balance is 0-1200 psig. The GOX system plumbing consists of 1/4 inch high pressure stainless steel tubing, fittings and valves. All GOX valves are GN_2 actuated. Two motorized pressure regulators are in the GN_2 balance pressure subsystem; one controls pressure to the balance piston, the other controls the pressure to the oxygen compressor.

1.2.4 Control System

The DWT control system consists of an IBM PCAT compatible computer that performs data acquisition and control functions necessary to operate the drop weight tester. The system contains a color graphics screen that displays a graphic representation of the tester with real-time updates of pressures, temperatures, valve position, and a status of the current control process being performed. The system is designed such that it requires minimal input from the operator and most functions are carried out automatically. The PCL language allows for easy changes in the control process and quick development of new systems using the same hardware. A variety of sensors can be used with this system, such as strain gauges, accelerometers, thermocouples, and pressure transducers, by changing channel definitions in PCL. Data from sensors can be displayed in tabular or graphic form on the color display or printed on the dot-matrix printer. On-line help screens are available to the user during control of the tester to provide addition explanation of how to use the control system. Two shutdown modes are provided to allow for unexpected mechanical failures and bring the tester to a safe condition quickly. Figure E-4 is a block diagram of the control system.

1.2.4.1 Hardware

The control system consists primarily of an ITT PCAT computer, an enhanced graphics adapter (EGA) card, an EGA color

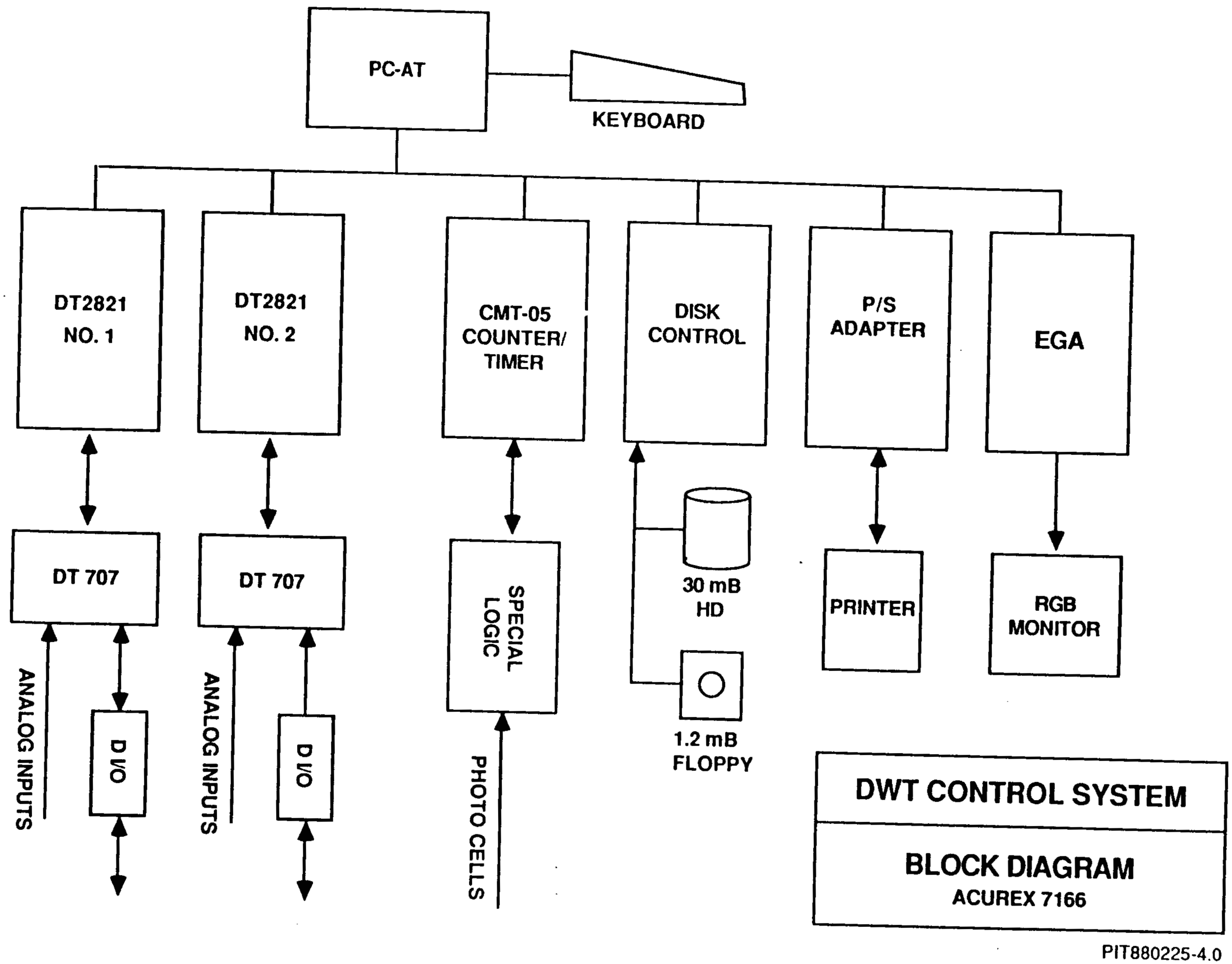

Figure E-4: Block Diagram of the Control System monitor, parallel and serial ports, a 30MB floppy disc, a one MB RAM, an Epson dot-matrix printer, two data translation I/O cards and a Metrabyte counter/timer card.

1.2.4.2 Analog Subsystem

The following is a list of items that make up the analog subsystem:

Number of Input Channels	16 Differential
ADC Range	0/+10, -10/+10 Volts
Programmable Gain Ranges	1, 2, 4, 8
Maximum Input Voltage, power off	-20/20 Volts
Maximum Input Voltage, power on	-35/+35 Volts
Input Impedance	100 Megohms
ADC Resolution	12 Bit, 4096 Counts
Maximum Conversion Rate	50kHz, 20 Microseconds
ADC Accuracy	-.03%/+.03% of Full Scale

1.2.4.3 Digital Subsystem

The following is a list of items that make up the digital subsystem:

Number of Channels	32 Input or Output
Number of Ports	Four 8-Bit Ports

(each port can be configures as input or output)

1.2.4.4 Software

The control system software consists of DOS 3.1, Quick C development system and compiler, PCL process control system development language and custom control software for DWT written in PCL and C.

1.2.5 Instrumentation

The instrumentation in the DWT system consists of seven pressure transducers, three thermocouples, three photo cells and two microswitches.

The pressure transducers are Viatran OEM transducers that utilize a 12 VDC power supply and provide DC voltage output. The following lists the location of the transducer and the range of the transducer.

GN_2 Activation Pressure Supply	0-300 psi
GN_2 Cooling Pressure Supply	0-300 psi
GN_2 Balance Pressure Supply	0-1500 psi
GOX Supply	0-5000 psi
GOX Purge Pressure	0-300 psi
GOX Compressor Outlet Pressure	0-15000 psi
GOX Test Chamber Pressure	0-15000 psi

Two of the thermocouples are spring loaded, stainless steel sheathed, ungrounded, chromel-alumel thermocouple that touch the surface of the heaters. The third thermocouple is a chromel-alumel washer thermocouple and is attached to the outer bottom surface of the barrel.

The photo cells consist of infrared-emitting diodes and a NPN silicon high sensitivity photo transistors with one unit mounted at the top of the DWT that starts a timer as soon as the plummet starts to drop. The other two units are near the bottom and measure the velocity of the plummet at impact. The lowest unit also stops the timer.

The microswitches are arm activated 5 VDC switches. One switch is mounted near the top of the DWT to indicate when plummet is up and latched. The other switch is mounted near the bottom of the DWT and indicates that the plummet catcher is in the down position.

2.0 MAINTENANCE

Table E-1 defines the maintenance for the High Pressure Drop Weight Tester. The maintenance items described in Table E-1 are not intended to be operating procedures or job instructions. Where applicable, manufacturers manuals should be used for maintenance.

3.0 DRAWINGS

The following drawings are the major assembly drawings that make up the DWT. These drawings in turn, identify all the other drawings and components that make up the final DWT assembly. A complete drawing list is provided in Appendix G.

DWG. NO.	TITLE
300050	Impact Tester Assembly (Acurex)
400036	Cell Assembly (Cryomec)
RS005271X	Impact Tester Assembly (Rocketdyne)

4.0 SPARE PARTS

TableE-2 is a suggested list of spare parts and provides vendors from whom the original parts were purchased.

Table E-1: Maintenance

COMPONENT	REQUIRED MAINTENANCE	FREQUENCY	PROCEDURE	REFERENCE
1) PLUMMET ASSY				
a) Rollers	Visually inspect for free movement, flat spots and cracks (12 each).	A,D	Rotate wheels by hand Visually inspect.	DWG# R0019387X
b) Spider	Inspect flathead screw.	A,D	Tighten as required.	DWG# R0019387X
c) Support	Inspect for tightness and impact area.	D	Tighten as required.	DWG# R0019387X
d) Nose Piece	Inspect for tightness and impact area	A	Tighten as required. If nosepiece is damaged, remove and repair by machining or replace.	DWG# R0019387X
e) Jam Nuts	Inspect for tightness (2 places).	A	3.125" Diameter. Tighten as required.	DWG# R0019387X
2) CLAMP ASSY Plummet Catcher				
a) Nuts & Bolts	Inspect all nuts and bolts for tightness	C,D	Torque as required. Apply Loctite 271.	DWG# 300047 Items 14 thru 25
b) Elect. Connectors	Inspect plugs for tightness, check wire for any damage.	C,D	Tighten as required, repair or replace as applicable.	Items 10 & 13
c) Spring	Inspect connecting points.		Visually inspect.	Item 11
d) Latch	Inspect contact area of the plummet support magnet base for wear.	A	Visually inspect.	Item 5
	Inspect Cotter pin.	A	Visually inspect.	Item 12
e) Latch Actuator & Plummet Magnet	Inspect bolt (Item 14) for tightness. Remove and replace magnet or plummet actuator if failure occurs.	D	Tighten as required. Removal – Secure 24VDC power. Disconnect electrical plug (Item 10). Remove spring (Item 11). Remove cotter pin (Item 12) from latch. Holding plummet magnet, loosen and remove bolt (Item 14). Replace in reverse order.	Item 14 Item 7 & 9 Item 10 Item 11 Item 12 Item 14

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Table E-1: Maintenance (cont.)

COMPONENT	REQUIRED MAINTENANCE	FREQUENCY	PROCEDURE	REFERENCE
3) CYLINDER, AIR	Inspect piston for wear, nicks or pitting. Check for blow-by at pressure seals.	B	With piston rod fully retracted (Holding the plummet), check area around piston rod wiper seal for blow-by. If repair is indicated consult vendor manual.	DWG# 300050 Parker Fluid Power Maint./ Installation Sheet.
4) CLEVIS & PULLEY	Inspect for wear and free movement of pulley.	B	Visually inspect.	DWG# 300050 Items 16 & 46
5) CABLE	Inspect for broken strands. Replace cable if found.	A	Visually inspect. Removal of cable. Secure operating press at N2 panel Remove cable clamp at Item 11 (Top Plate Assy). Then pull cable through system. Re-place in reverse sequence. Check operation after installation of cable for required travel of plummet assembly catcher.	
6) TOWER ASSEMBLY				
a) Nuts & Bolts	Inspect for tightness.	C	Tighten as required. Apply Loctite 271.	DWG# 300050 Items 23 & 26
b) Clamp Bar Assy	Inspect for cleanliness and any foreign matter.	A	Clean per NASA NHB 8060, 1B	Item 4 Item 5
c) Strut Assy	Same as Clamp Bar Assy.			
7) CONTROLS & DATA ACQUISITION SYSTEM		D	Per Users Manual.	
8) OXYGEN COMPRESSOR		D	Per Manufacturers Manual	

FREQUENCY
A = Each Test
B = Weekly
C = Monthly
D = As Required

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Table E-2: Spare Parts Lists for High Temperature High Pressure DWT

ITEM	PART NUMBER	COMPANY	NO. REQUIRED
1. OMNI SEAL	AR 10103-334PU	Flourocarbon Inc. 10871 Kyle Street P.O. Box 520 Los Alamitos, CA 90720 (213) 594-0941	10
2. METALLIC "O" RING	U 6318-01936 SEA	Flourocarbon Inc. P.O.Box 9889 Columbia, SC 29290 (803) 799-3606	100
3. INSULATOR BLANKET	DWG No. 30006-1	Aerospex Corporation 1433 Roosevelt Drive National City, CA 92050 Randy Newcomb (619) [illegible]74-2211	20
4. HEATER CABLE	62H36A5X Option 2F 2" ID Closed Coil	Thermal Corporation 1027 Indian Creek Road Huntsville, AL 35806 Alica McCarver (205) 837-1122	20
5. INSULATOR DISC	DWG No. 400049-1		2
6. CENTER HOUSING	DWG No. 300027-1		2
7. PRESSURE BARREL	DWG No. 300045-1		2
8. STRIKER	DWG No. 400035-1		2

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APPENDIX F

DROP WEIGHT TESTER

DAS

OPERATING MANUAL

TABLE OF CONTENTS

LIST OF FIGURES

DROP WEIGHT TESTER
DAS
OPERATING MANUAL

1.0 STARTUP

Turn on DAS using main power switch on front of rack. If screen is still blank after 30 seconds check to see if the monitor power switch is on. Various startup messages will appear on the screen and end with a prompt "C:\>". At the prompt type DWT and press return.

2.0 MAIN MENU

On the main menu are 4 selections:

1) system parameters (section 3.0)
2) run test (section 4.0)
3) test analysis (section 5.0)
4) exit system

Below the menu is the number of tests that have been run under the current configuration. If a test was aborted through the use of one of the shutdown keys this number will not increment. To select a menu item press the highlighted letter in that item. The exit system selection will return you to the DOS prompt, to restart the DAS type DWT and press return.

3.0 CONFIGURING A TEST

3.1 How To Enter Data

After entering the system parameters screen from the main menu selection, test data will be displayed to be viewed or changed. The prompt at the bottom of the screen should read "Enter Selection", whenever this appears the user can select which option to edit. Options are selected by pressing the highlighted letter in the option description. The prompt will change to ask for the proper data for the selected item. To enter a blank entry for an item, press return only at the prompt. To change an entry, select the item and retype the new value. Pressing the return key at any time will restore the "Enter Selection" prompt. All entries may be typed in either upper or lower case. To exit and save all changes press the "X" key.

4.0 RUNNING A TEST

Selecting "R" from the main menu brings up the system schematic for displaying the status of the test in graphic and numerical form.

4.1 Symbol Definitions

The status screen has several symbols that represent physical hardware in the system or data point.

Ovals - Pressure and temperature sensor readings

Connecting lines - Pipes between valves and fixtures

Double triangles - Valves or regulators under computer control

If a pipe or valve turns red, it indicates that some pressure is present. A green pipe or valve indicates ambient conditions.

4.2 MESSAGE FORMATS

1. Waiting For An Event

A sensor name and setpoint will be displayed in the lower left corner of the screen. When the sensor valve reaches the setpoint the program will continue with the next control step.

2. Waiting For Operator Input

The program will not continue until the operator has pressed a key to show that he is ready to proceed. A message will be displayed indicating which key is to be pressed to continue.

4.3 WHEN OPERATOR RESPONSE IS REQUIRED

Operator response is required at the following points in the control program under the normal operating conditions.

1. Adjust Balance Pressure

Up and down arrow keys are used to change the balance pressure setpoint. The balance pressure requlator will adjust the pressure to match the setpoint. When the proper pressure is achieved press return to continue.

2. Drop Plummet

At this point the operator should make a visual check of the tester to verify that everything is ready for the drop.

Press return for the drop. Press return to drop the plummet.

3. Test Complete

After the test the operator must press return to return to the main menu.

5.0 DATA ANALYSIS

The data analysis screens are used to view the test results after a successful test. The graphics snapshots show pre and post test conditions in graphic form. The snapshot listing shows a test summary in tabular form that can be quickly sent to the printer. The plots show the high speed sample data taken during the drop for temperature and pressure of the chamber. Any of the graphic screens can be printed out by pressing the print screen key. A screen dump of this type takes approximately 2 minutes and 15 seconds to complete. If the printer is not ready for printing and the print screen key is pressed the computer will wait the 2 minutes as if it was printing, then return to normal operation. To avoid this wait, the printer status will be printed in red in the lower left corner of the screen if the printer is not ready. If the printer is ready, no message will appear and the print screen key can be pressed. The print screen key should never be pressed during the run test phase of operation as all control will stop for 2 minutes without means of recovery. If this should happen accidentally and valves are in a state that must be changed in two minutes the computer can be rebooted and the test restarted.

5.1 GRAPHICS SNAPSHOTS

The graphics pretest and graphics posttest snapshots show the test chamber conditions just before the drop and just after the high speed samples are finished. The data is presented in the same form as the system schematic during the test so that data can be found in familiar places on the screen. The print screen key is required to print out this infomation.

5.2 PRESSURE AND TEMPERATURE GRAPHICS

A temperature and a pressure graph of each test is also available. The data is presented on the screen and can be printed out in the same manner as the pre and post test snapshots. The data is plotted prior to test during the actual drop and posttest. Pressure and/or temperature spike are captured.

6.0 SPECIAL KEYS DURING OPERATION

6.1 Safe Shutdown key

The F1 key will start a safe shutdown procedure that vents all pressures and cools any hot fixtures before allowing the operator to continue to the main menu. Before starting the procedure ask the user if he wants to continue the safe shutdown, if any key other than "Y" is pressed the control will continue from where it left off. If the users continues the shutdown procedure the shutdown process will be initiated. The same steps used to shutdown the cell after a successful drop are used in this procedure, such that pressing the F1 key after the plummet has been dropped and returned is not necessary unless the plummet sense switch has malfumctioned. Note that at any time during the safe shutdown procedure if the process is waiting on an event that will not occur due to a hardware malfunction the emergency shutdown can be executed.

6.2 EMERGENCY SHUTDOWN KEY

The F10 key will start an emergency shutdown procedure that closes all valves and turns off any other digital outputs. The procedure will start immediately when the F10 key is pressed without a user prompt. A message will be displayed informing the operator that the shutdown procedure has started. When finished the user will be asked to press return to continue to the main menu.

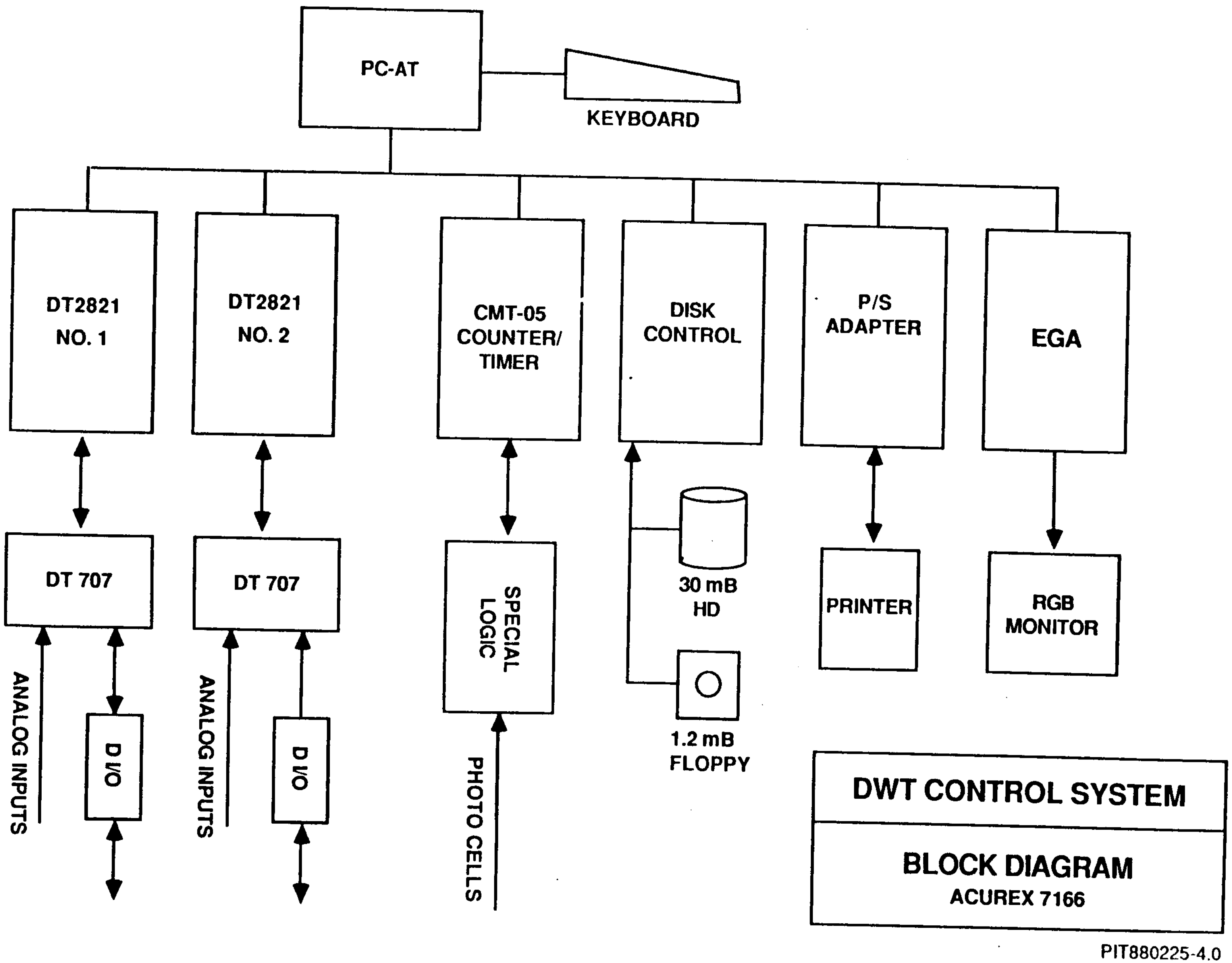
PC-AT
KEYBOARD
DT2821 NO. 1
DT2821 NO. 2
CMT-05 COUNTER/ TIMER
DISK CONTROL
P/S ADAPTER
EGA
DT 707
DT 707
SPECIAL LOGIC
30 mB HD
1.2 mB FLOPPY
PRINTER
RGB MONITOR
ANALOG INPUTS
D I/O
ANALOG INPUTS
D I/O
PHOTO CELLS
DWT CONTROL SYSTEM
BLOCK DIAGRAM
ACUREX 7166
PIT880225-4.0

Figure F-1

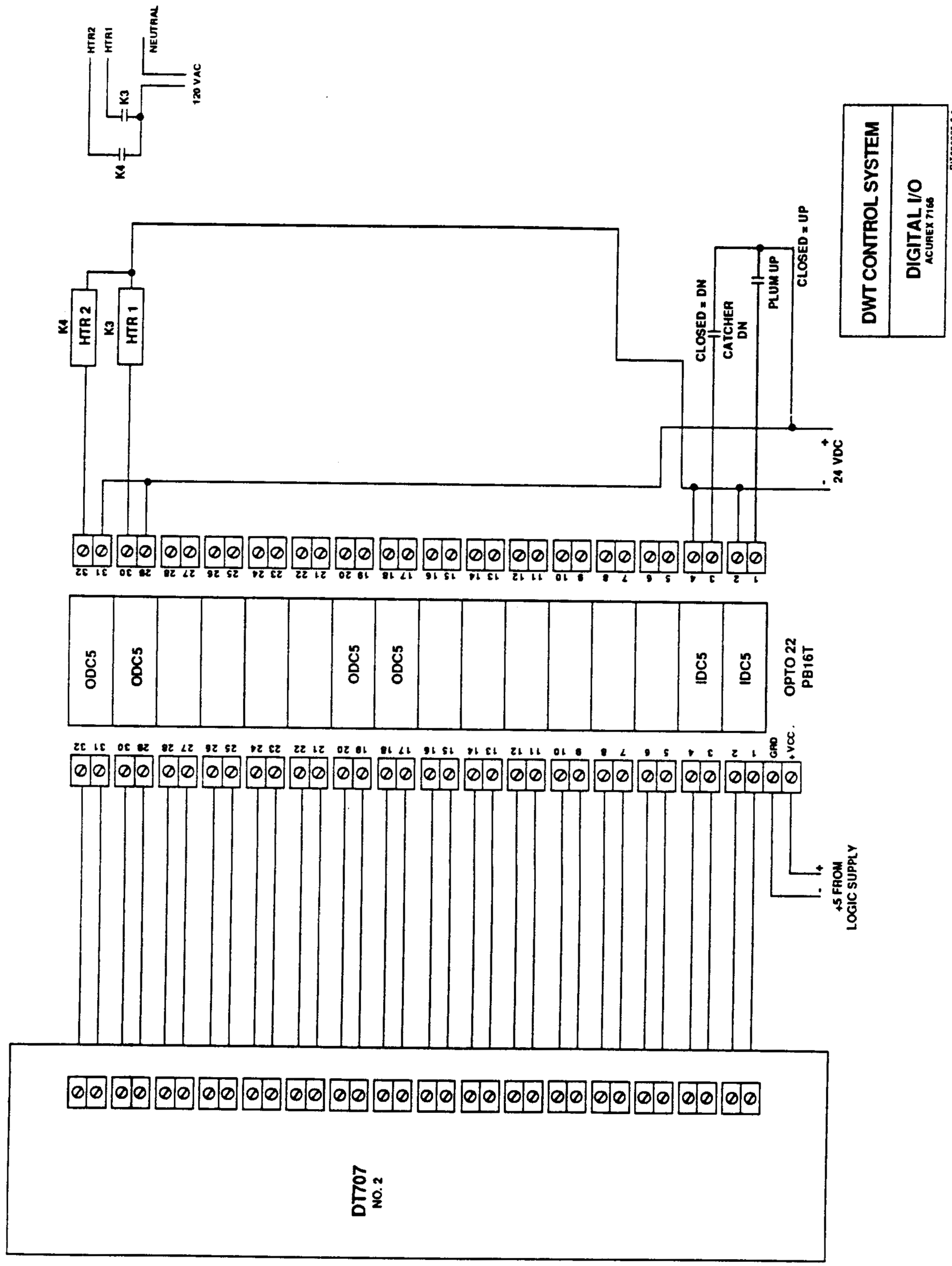
DWT CONTROL SYSTEM
DIGITAL I/O
ACUREX 7166
DT707
NO. 2
OPTO 22
PB16T
ODC5
ODC5
ODC5
ODC5
IDC5
IDC5
+5 FROM
LOGIC SUPPLY
GRD
+VCC
24 VDC
HTR 2
HTR 1
K4
K3
HTR2
HTR1
NEUTRAL
120 VAC
CLOSED = DN
CATCHER
DN
PLUM UP
CLOSED = UP

Figure F-2

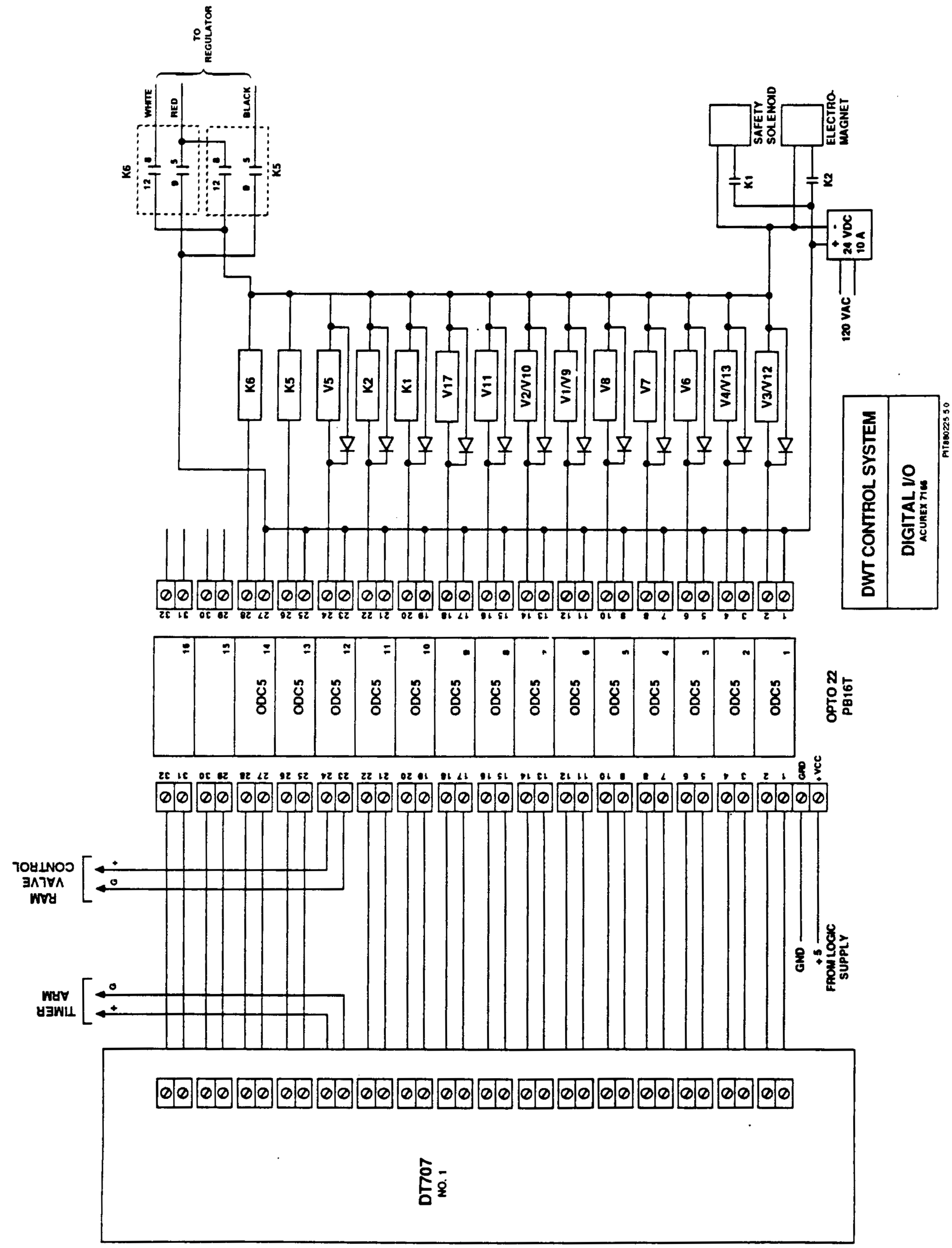
TO REGULATOR
WHITE
RED
BLACK
K6
K5
SAFETY SOLENOID
ELECTRO-MAGNET
K1
K2
24 VDC
10 A
120 VAC
K6
K5
V5
K2
K1
V17
V11
V2/V10
V1/V9
V8
V7
V6
V4/V13
V3/V12
DWT CONTROL SYSTEM
DIGITAL I/O
ACUREX 7166
ODC5
OPTO 22
PB16T
GND
+VCC
RAM VALVE CONTROL
TIMER ARM
GND
+5
FROM LOGIC SUPPLY
DT707
NO. 1

Figure F-3

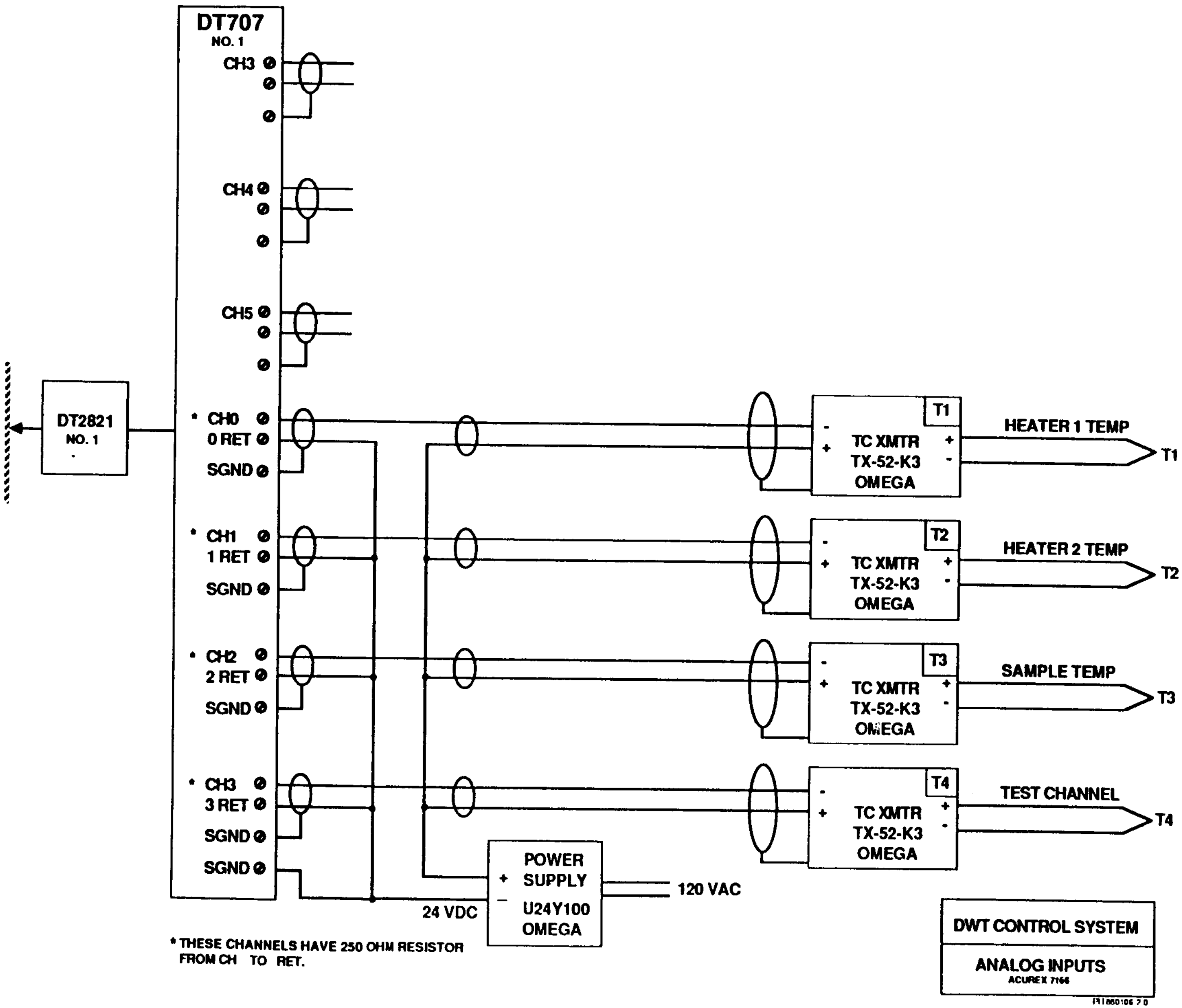
DT707
NO. 1
CH3
CH4
CH5
* CH0
0 RET
SGND
* CH1
1 RET
SGND
* CH2
2 RET
SGND
* CH3
3 RET
SGND
SGND
DT2821
NO. 1
T1
TC XMTR
TX-52-K3
OMEGA
HEATER 1 TEMP
T1
T2
TC XMTR
TX-52-K3
OMEGA
HEATER 2 TEMP
T2
T3
TC XMTR
TX-52-K3
OMEGA
SAMPLE TEMP
T3
T4
TC XMTR
TX-52-K3
OMEGA
TEST CHANNEL
T4
POWER
SUPPLY
U24Y100
OMEGA
24 VDC
120 VAC
* THESE CHANNELS HAVE 250 OHM RESISTOR
FROM CH TO RET.
DWT CONTROL SYSTEM
ANALOG INPUTS

Figure F-4

C-2

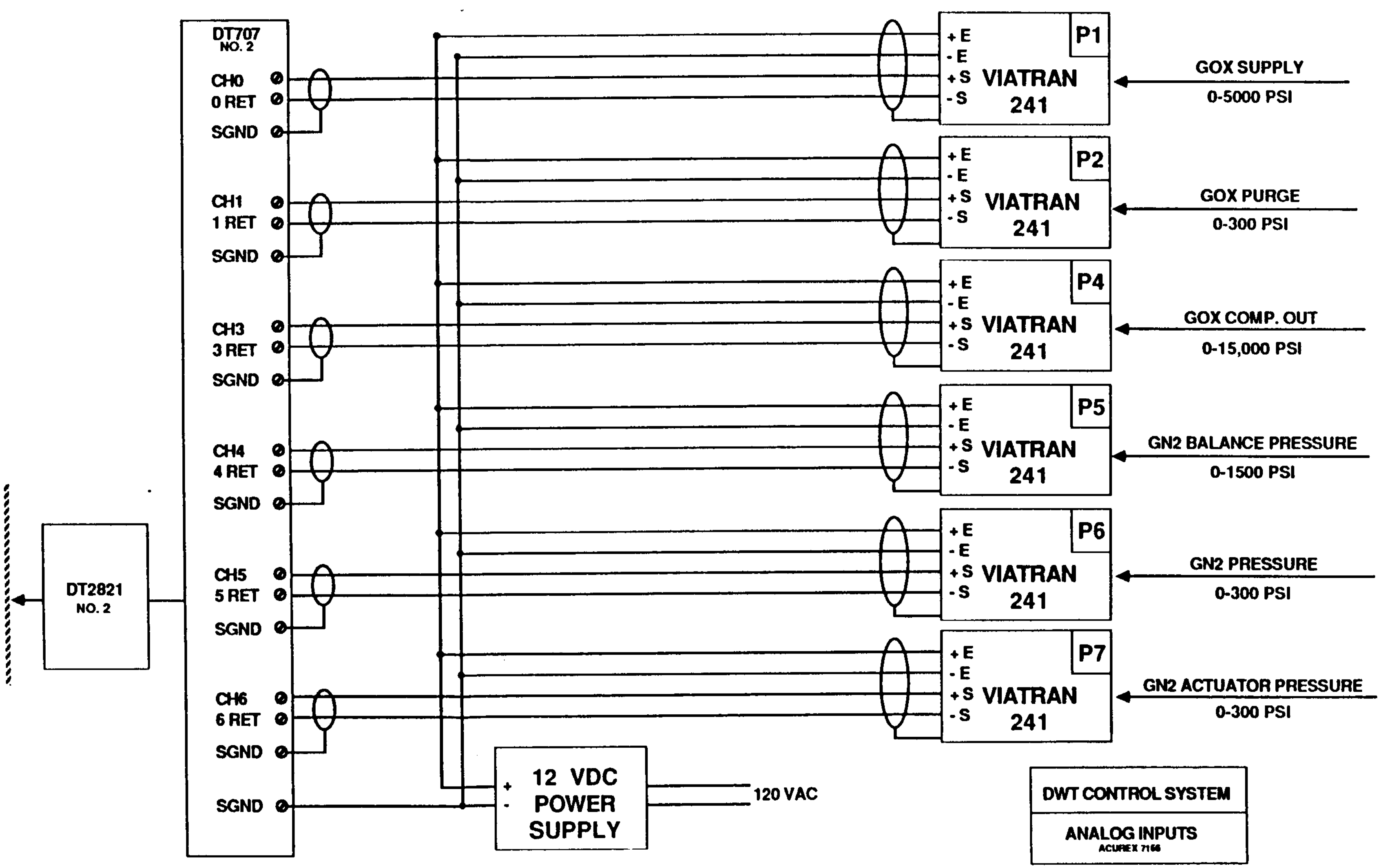
DT707
NO. 2
CH0
0 RET
SGND
CH1
1 RET
SGND
CH3
3 RET
SGND
CH4
4 RET
SGND
CH5
5 RET
SGND
CH6
6 RET
SGND
SGND
DT2821
NO. 2
+E
-E
+S
-S
VIATRAN
241
P1
P2
P4
P5
P6
P7
GOX SUPPLY
0-5000 PSI
GOX PURGE
0-300 PSI
GOX COMP. OUT
0-15,000 PSI
GN2 BALANCE PRESSURE
0-1500 PSI
GN2 PRESSURE
0-300 PSI
GN2 ACTUATOR PRESSURE
0-300 PSI
12 VDC
POWER
SUPPLY
120 VAC
DWT CONTROL SYSTEM
ANALOG INPUTS

Figure F-5

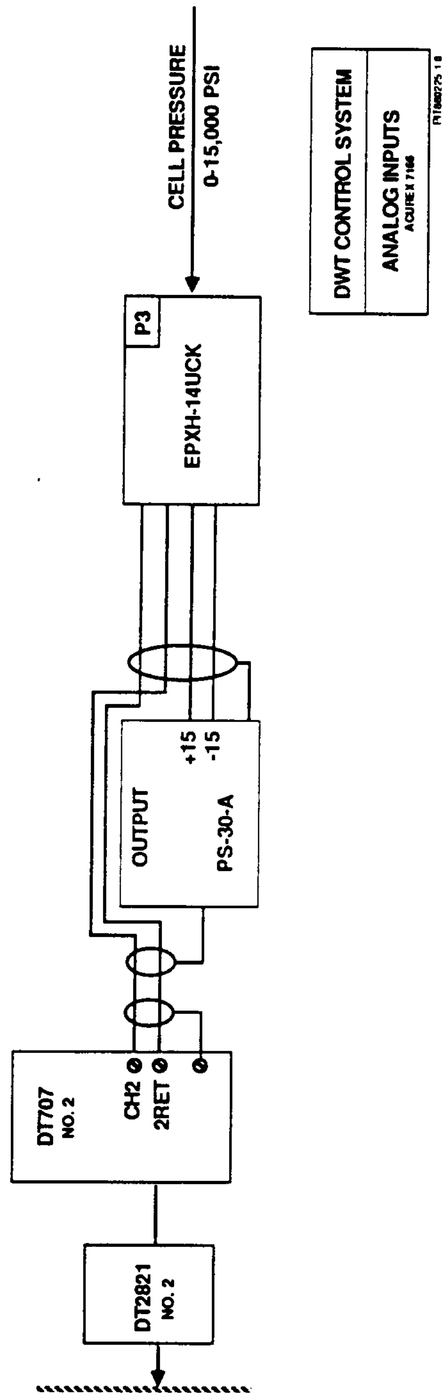
CELL PRESSURE
0-15,000 PSI
DWT CONTROL SYSTEM
ANALOG INPUTS
P3
EPXH-14UCK
OUTPUT
+15
-15
PS-30-A
DT707
NO. 2
CH2
2RET
DT2821
NO. 2

Figure F-6

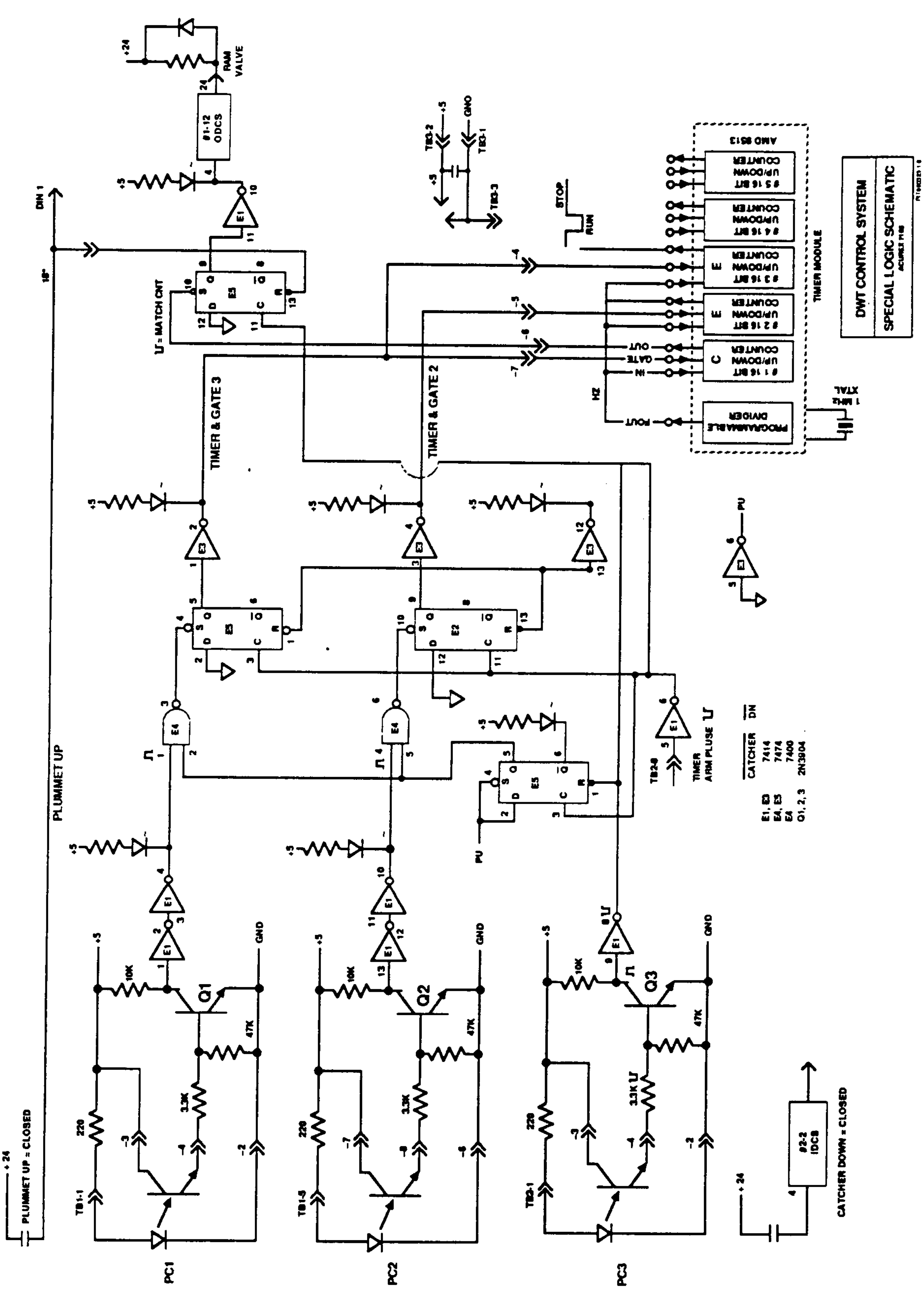
DWT CONTROL SYSTEM
SPECIAL LOGIC SCHEMATIC
TIMER MODULE
TIMER & GATE 3
TIMER & GATE 2
PLUMMET UP
PLUMMET UP = CLOSED
CATCHER DOWN = CLOSED
RAM VALVE
PC1
PC2
PC3
Q1
Q2
Q3

Figure F-7