Solid Particle Fire Extinguishants for Aircraft Applications

G.C. Harrison
Walter Kidde Aerospace, Inc.
4200 Airport Drive N.W.
Wilson, North Carolina 27893

Abstract:

At the previous Halon Technical Working Conference in 1992, our Halon substitute agent evaluation in a small scale engine simulator was reported. Subsequently, a solid particle fire suppression agent was tested. The results were promising enough, when compared to Halon 1301, to lead us to a wider investigation of solid powdered extinguishants. The study was extended to include solid particulate suppression agent made in some unique ways. Very fine aerosols generated by pyrotechnic compositions are among those studied.

Examples of fire suppression by solid particulates using various means of dispersion are presented. These data are evaluated as fire extinguishants applicable to aircraft systems.

Introduction:

Aircraft fire extinguishing opportunities occur principally in engine nacelles, auxiliary power units, dry bay compartments and cargo bays. Each of these applications have different requirements and a variety of test facilities are needed in order to evaluate and design fire suppression systems. In this paper, the facilities at Walter Kidde Aerospace, Inc. are described and the test data for solid particle fire extinguishing agents are reviewed.

Experimental Test Facilities:

At the previous NMERI Halon Alternatives Technical Working Conference in May, 1992; we reported on a Small Scale Aircraft Engine Simulator (SSEFS) and the evaluation of some halon substitute agents. The SSEFS facility is shown in figure one. The blower connects to a 24 inch square plenum chamber five feet long. The plenum chamber narrows to a 12 inch square duct which contains a fire pan located seven feet from the duct entrance. A regulated nitrogen gas tank is connected directly to the dry powder test vessel (see figure two) which replaces the discharge nozzle just in front of the blower outlet. To perform a test shot, a weighed amount of solid particulate is sealed in the test vessel and mounted in the plenum chamber. After the pan fire is ignited, the blower is adjusted to achieve the desired air speed. When the temperature of the diesel fuel in the pan fire reaches 300°F, the nitrogen pressurizing gas is applied until the sealing disk bursts, at about 230 PSIG, and the powdered agent is dispensed. Sufficient tests are run to determine the weight required for fire extinguishing at each selected air speed.

A second facility is the Fire Test Chamber described in figure three. It is being used to evaluate fire suppression of one or more small pan fires under zero or low air flow conditions. The chamber volume is 0.77 cubic meter and there are provisions to control airflows. **A** computer data acquisition system is used. Miniature optical flame detectors sense the "fire-out" condition and thermocouples are available for temperature measurements.

We use a smaller version of the powder injector described in figure two, but a radial distribution head is more appropriate in this application.

Figure four shows our new Aircraft Cargo Bay Simulator which is nearly complete. We will be able to test against combinations of larger panfires, wood crib fires' and rag filled, paper board box fires.

Dry Chemical Powder Work:

The WKAI small scale engine simulator was used to compare the fire suppression capability of several commercial dry chemical powders to halon 1301 under engine nacelle air flow conditions. These data are presented in Table One.

TABLE **ONE**

Weight of Agent for
Fire Extinguishment
as a Function of Air Speed

Air Speed	weight (grams)			
(meters/second)	Halon 1301	$NaHCO_3$	$KHCO_3$	$KC_2N_2H_3O_3$
2.0	154	137	150	75
6.0	218	113	165	80
10.0	209	98	70	**45**

Each of the solid particulate materials also contains flow promoting, anti-caking ingredients in small amounts **(2** to 4 weight %). The **32** square inch pan fire used a flame stabilizer one inch high and contained diesel fuel.

Some preliminary testing with sodium bicarbonate has been done in the Fire Test Chamber with a four inch diameter diesel fuel fire pan. Successful fire extinguishing has occurred at agent concentrations as low as 60 grams per cubic meter. See figures 5 to 8.

Good deflagration suppression was demonstrated with sodium bicarbonate in a 1.9 cubic meter spherical chamber at the Fenwal Safety Systems Combustion Research Center in Holliston, Massachusetts.

The tests used 5 percent propane air and corn starch explosions.

Sodium bicarbonate from a radial head powder extinguisher gave outstanding results in the Wright Patterson Air Force Base Dry Bay Gunfire Evaluation Program **(VF-0-01).** The powder dispenser was pressurized with nitrogen and opened using an electrically initiated gas generating cartridge.

The SSEFS data are in agreement with results reported by R.L. Altman (1) in a NASA Ames Research Center Technical Brief. He ranked the fire suppression dry chemicals against a jet engine fuel fire as follows:

$K_2CO_3 > KC_2N_2H_3O_3 > KHCO_3 > NaHCO_3 >$ KCL. He also concluded that dry powders are more weight effective than halons 1202, 1211, 1301 and 1011.

More recently, similar results were reported by C.T. Ewing et al (2). In their excellent work with n-heptane fires, they concluded that $KHCO_3$ was more effective than $KC_2N_2H_3O_3$.

<u>Propellant Generated Solid Particulate</u>:

Conventional dry chemical fire suppression technology coupled with ordnance smoke, flare and propellant technology logically suggest that propellant generated solids could find application in fire extinguishing. A brief review of the literature reveals that this idea is not new. A flare-like propellant stick has been produced and sold for extinguishing chimney fires since 1949 **(3).** In 1967, A.I. Sidorov (4) obtained a Soviet patent 192669 on "Smoke Pyrotechnic Composition for Quenching Underground Fires". It teaches the use of metal carbonates in pyrotechnic compositions used for fire suppression. In 1976, U.S. patent 3,972,820 (5) issued on a "Fire Extinguishing Composition" comprising a heat and gas producing pyrotechnic composition with a binder and oxidizer, and having dispersed therein a halogen containing fire extinguishing agent. When ignited, the pyrotechnic thermally disseminates the fire extinguishing agent on to the fire.

McHale (6) published a paper titled "Flame Inhibition by Potassium Compounds" which describes the use of potassium salts, bicarbonate and sulfate, to suppress afterburn flames in composite double base rocket propellant. (Double base means both nitrocellulose and nitroglycerin in the propellant).

In 1987, M. Gozalishvili (7) described the thermal dispersion of alkali metal salts (chlorides and bicarbonates) for use as flame inhibitors. Potassium bicarbonate was specifically mentioned. A report by R. Reed et al (8) was published in the 18th International Pyrotechnics Seminar Proceedings on the subject of "Fire Extinguishing Pyrotechnics". Pyrotechnic nitrogen gas generators with additives were used to suppress fires.

Someone experienced in both fire and ordnance technologies can readily translate these references into design specifications for fire extinguishing propellants.

A. Oxidizer:

In order to maximize the potassium salt concentration, only two oxidizing agents are sensible:

1. Potassium Nitrate (KNO,)
2. Potassium Perchlorate ($KClO_4$)

B. Fuels:

The choice of fuel depends upon the design strategy which *can* be a two part or three part system.

In the two part system, the binder alone acts as the fuel.

In the three part system, the binder and a metal powder are co - fuels. We prefer this approach since this makes the propellant a true heat generating mixture. Enough heat *can* be generated to vaporize fire suppression additives such as potassium carbonate, potassium bicarbonate, potassium chloride and many others well known in fire technology.

Among the metal fuels; Al, Mg, Zr, Ti and some alloys are readily available as fine powders. Al and Mg are the least expensive.

C. Oxidizer/Fuel Ratio:

Computer propellant evaluation programs are common in ordnance work. With these you *can* estimate the thermodynamic properties of propellants and the composition of the output generated.

If the oxidizer/fuel ratio is low, considerable concentrations of hydrogen gas are generated. This has caused burning propellants to develop dangerous overpressures in confined volumes at explosive speeds.

On the other hand, if the oxidizer/fuel ratio is too high, high concentrations of oxygen gas can be generated which may make fire suppression especially difficult.

In the three-part strategy, the heat output should be balanced against the energy absorbed by the vaporizable additives so that liquid or gaseous compounds which will condense to solids upon cooling are not expelled from the fire suppressor container. If expelled, they *can* condense on the surrounding surfaces in solid deposits which may not be easily removed.

Propellant calculations are attached in appendix one to demonstrate these design parameters. Examples of propellant bum data are shown in figures 9, 10, 11, and 12. Figure 13 demonstrates a free bum of the fire pan.

Results and Recommendations:

Sodium bicarbonate has shown excellent results as a hydrocarbon fire extinguishing agent under conditions of high and low airflow, in dry bay deflagration quenching and in propane gas explosion suppression

Even though other solid particle agents may be more effective, sodium bicarbonate is not corrosive to aircraft aluminum, is easily cleaned up after use, and is non-toxic to personnel and the environment

There is some confusion about the thermal stability of sodium bicarbohate.

The "apparent thermal instability" of sodium bicarbonate is due to a careless quotation of chemical facts. Sodium bicarbonate is stable in dry air melting at about 270°C with **loss** of CO, to form sodium carbonate CO_2 and water.

$$2NaHCO_3 = Na_2\,CO_3 + CO_2 + H_2O$$

In aqueous solution, or in the moist state, $NaHCO_3$ slowly loses CO_2, even at ordinary temperature (or about 20°C). Above 65°C, in aqueous solution or the moist state, the evolution of CO_2 becomes vigorous.

The key to this "apparent thermal instability" is the moist state. Because it is a salt **of a** very weak acid, carbonic acid, hydrolysis occurs readily.

$$NaHCO_3 + H_2O \rightleftarrows NaOH + H_2\,CO,$$

$$H_2CO_3 \rightleftarrows H_2O + CO, \uparrow$$

Fortunately, in a sealed dry fire extinguisher, this hydrolysis does not occur. Dessikarb, the commercial extinguishing sodium bicarbonate, contains dehydrating agent, silica, which keeps the system very dry. As a result, the sodium bicarbonate remains stable up to 270°C (518°F) before decomposing thermally.

Sodium bicarbonate is a non-hazardous, non-toxic and totally unregulated material.

If ingested orally in doses greater than 5 grams per kilogram of body weight, it causes alkalosis. Alkalosis is high alkalinity in the blood and body fluids. Alkalosis is treated by drinking lots of water, In an average person weighing 70 kilograms, greater than 5 grms/kg is more than 350 grams (more than 3/4 of a pound). I believe that this quantity is difficult to ingest.

As with any dust, temporary discomfort may occur. There are however, no known long term effects.

We believe that sodium bicarbonate is an excellent fire extinguishing agent for most aircraft applications with the exception of manned spaces.

Pyrotechnically generated aerosols (PGA) are best suited to Cargo Bay aircraft applications. As a means for generating ultra fine particle fire suppression solids, PGAs work as a **total** flooding agent. Their aerosol properties give them excellent three dimensional distribution characteristics and long term suspension. They suppress fires by heat absorption cooling, inert gas generation and chemical mechanisms.

They are zero ODP, low toxicity, non-corrosive and show significant weight reductions compared to halon 1301.

REFERENCES

1. Altman, R.L., Technical **Support** Package ARC-11553, "Extinguishing Fuel-Leak Fires with Dry Chemical", NASA Ames Research Center, Moffett Field, CA.

2. Ewing, C.T., Hughes, J.T., and Carhart, H.W. Vol.I, Proceedings and Report of the Fire Safety/Survivability Symposium, 6-8 November, 1990.

3. Private Communication

4. A.I. Sidorov et al, Soviet Patent 192669, filed 6-2-67.

5. H.E. Filter and D.L. Stevens, **U.S.** Patent 3,972,820, granted 8-3-76.

6. McHale, E.T., Combustion and Flame (1975), 24, 277-279.

7. Gozalishvili, M. et al, Proc. Georg. Acad. Sci., 1987, 126 337

8. Reed, R., Brady, R.L. and Hitner, J.M., Proceedings of the Eighteenth International Pyrotechnics Seminar, July 1992, 701 - 713.

WALTER KIDDE
Aerospace, Inc.
Wilson, North Carolina 27893 U.S.A.

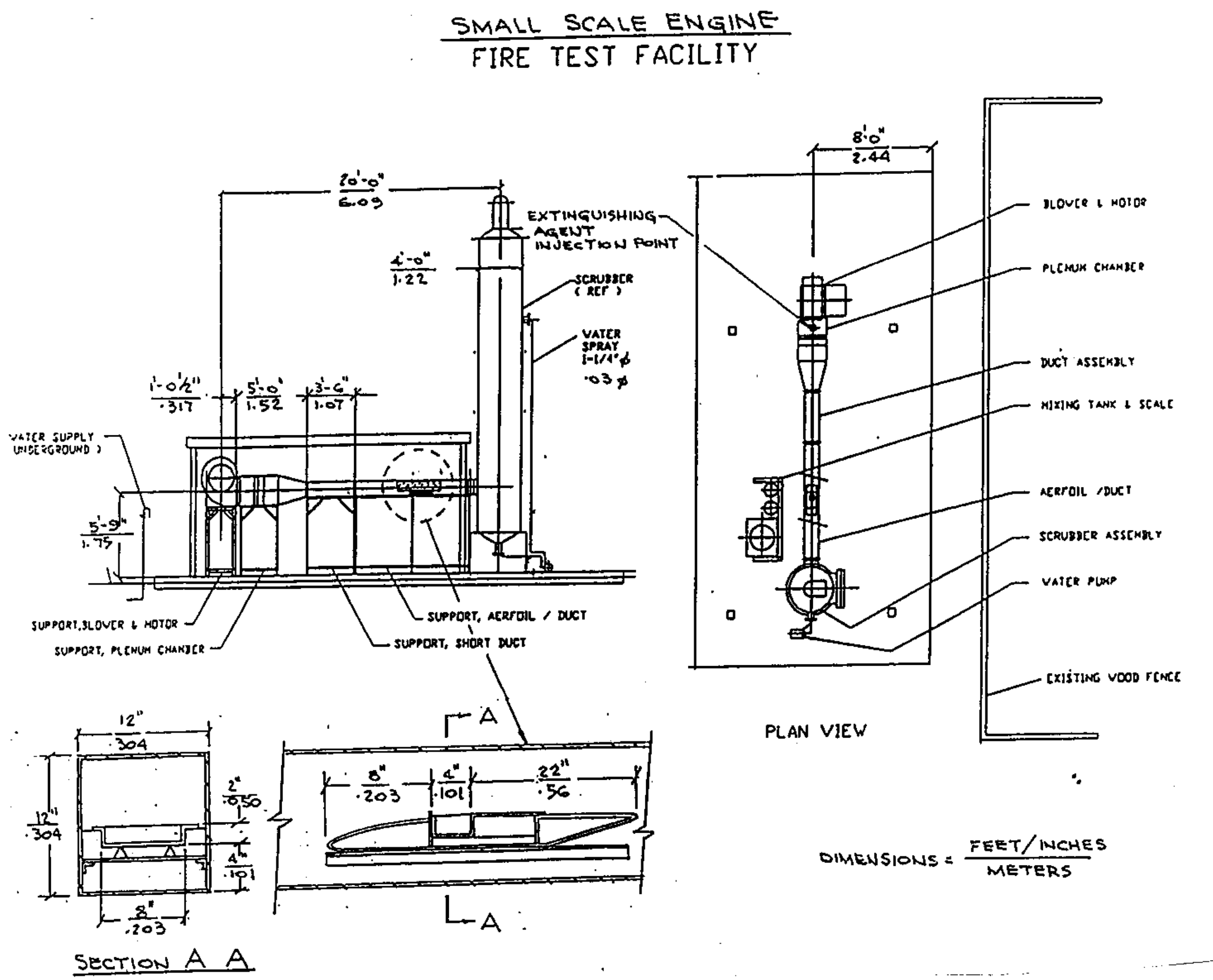


FIGURE ONE

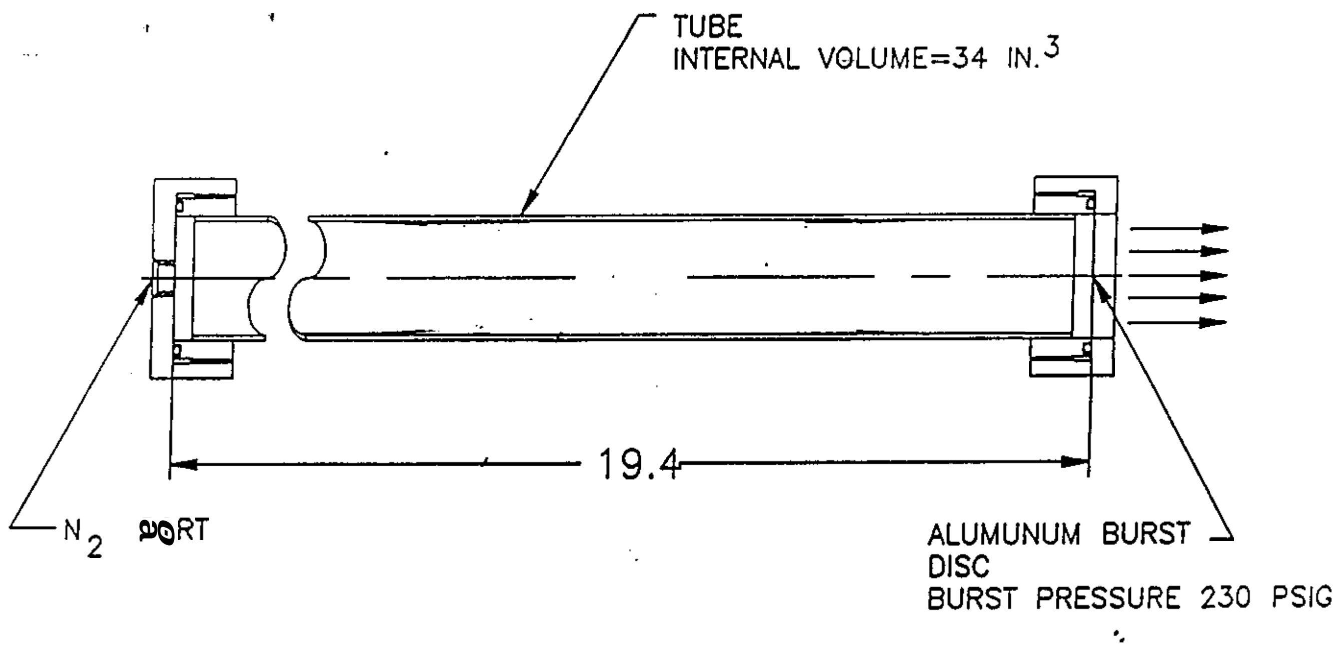


FIGURE TWO

DRY POWDER TEST VESSEL FOR SSEFS

WALTER KIDDE
Aerospace, Inc.
Wilson, North Carolina 27893 U.S.A.

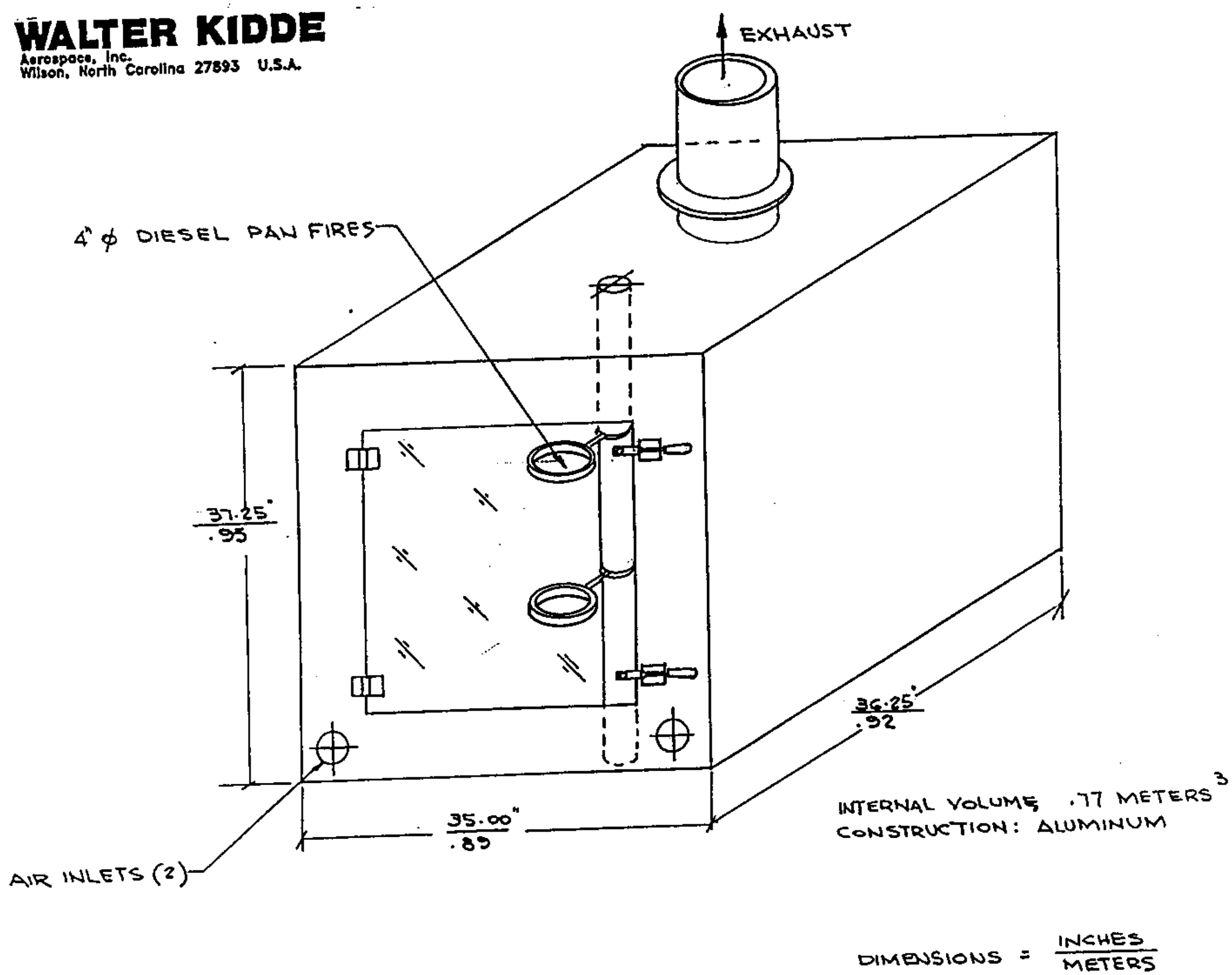


FIGURE THREE

FIRE TEST CHAMBER

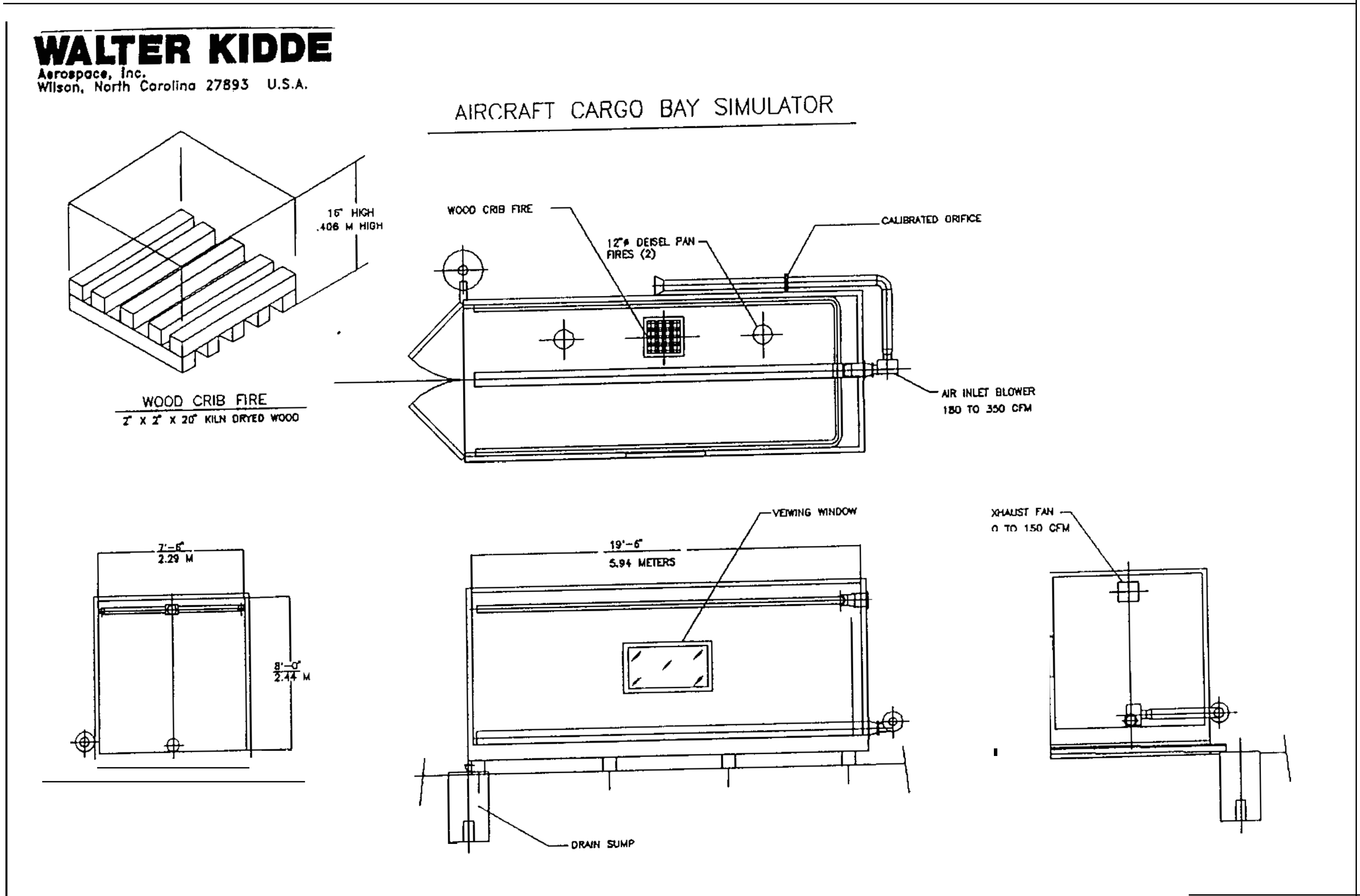
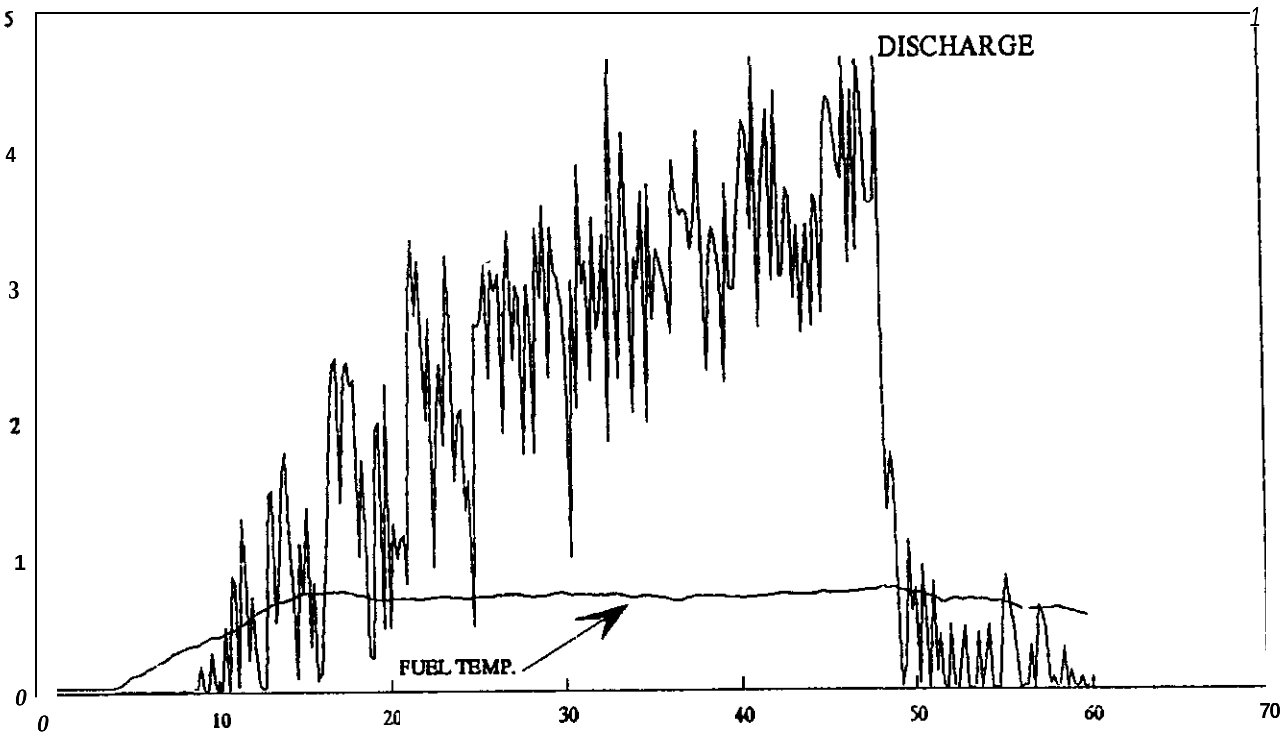


FIGURE FOUR

AIRCRAFT CARGO BAY SIMULATOR

SODIUM BICARBONATE

0.20 POUNDS



TIME (IN SECONDS)

FIGURE FIVE

MOD **C**
FIRE OUT 12 SEC.

MODIFIED SODIUM BICARBONATE

0.20 POUNDS

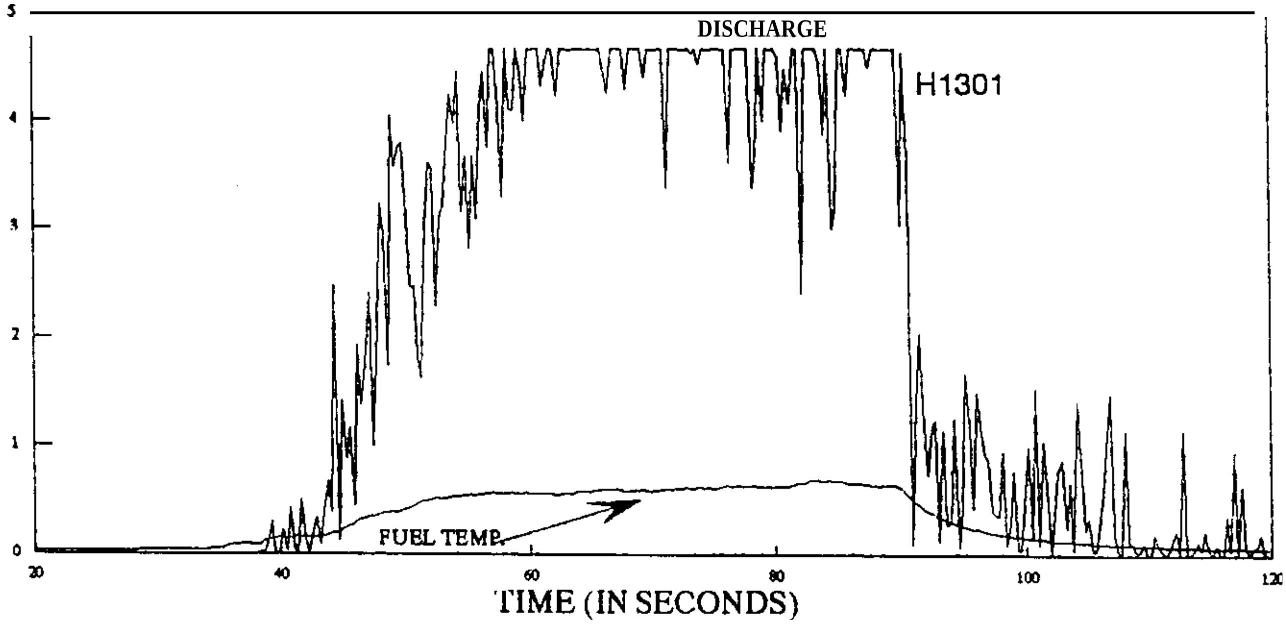


FIGURE **SIX**

MOD **AS**
FIRE NOT QUENCHED

SODIUM BICARBONATE

0.15 POUNDS

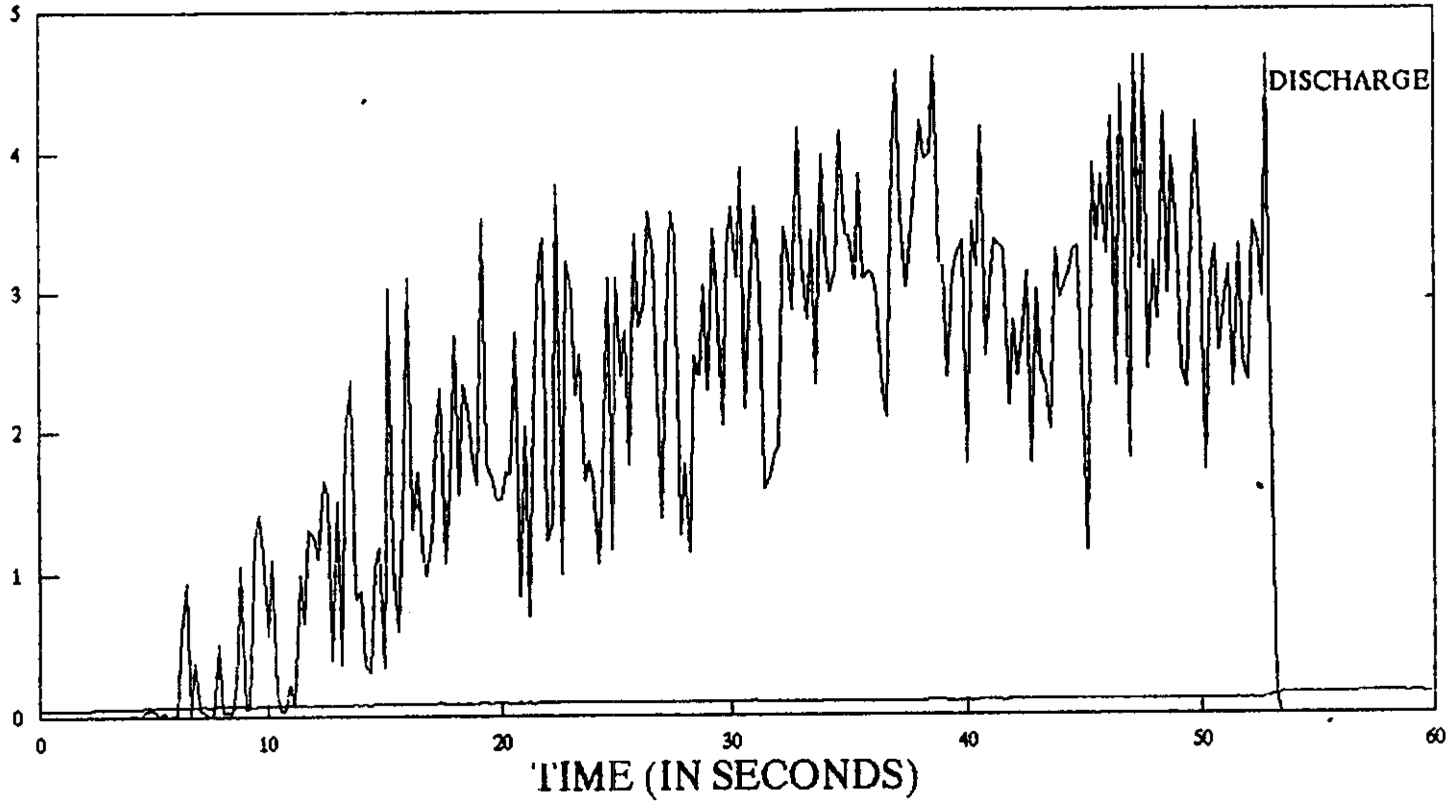
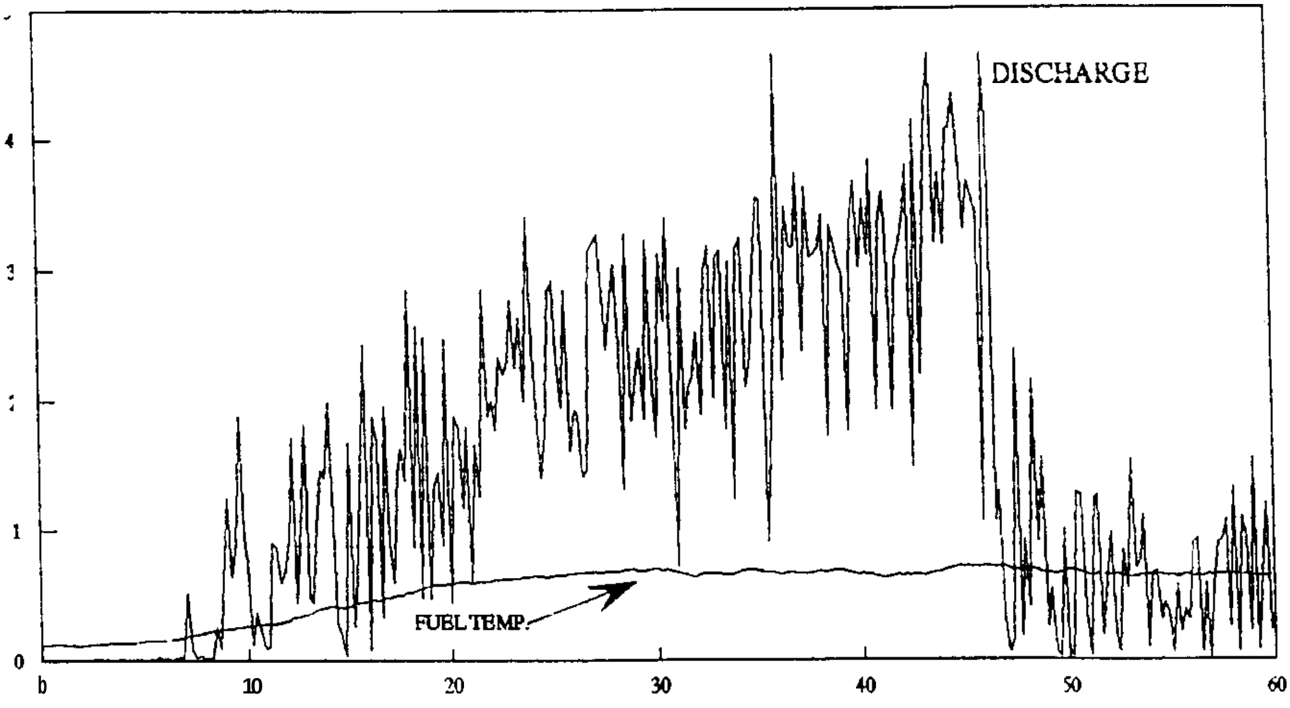


FIGURE SEVEN

MOD ALC
FIRE OUT 0.6 SEC.

SODIUM BICARBONATE

0.10 POUNDS



TIME (IN SECONDS)

FIGURE EIGHT

MOD ALC
FIRE **OUT** 13.8 SEC.

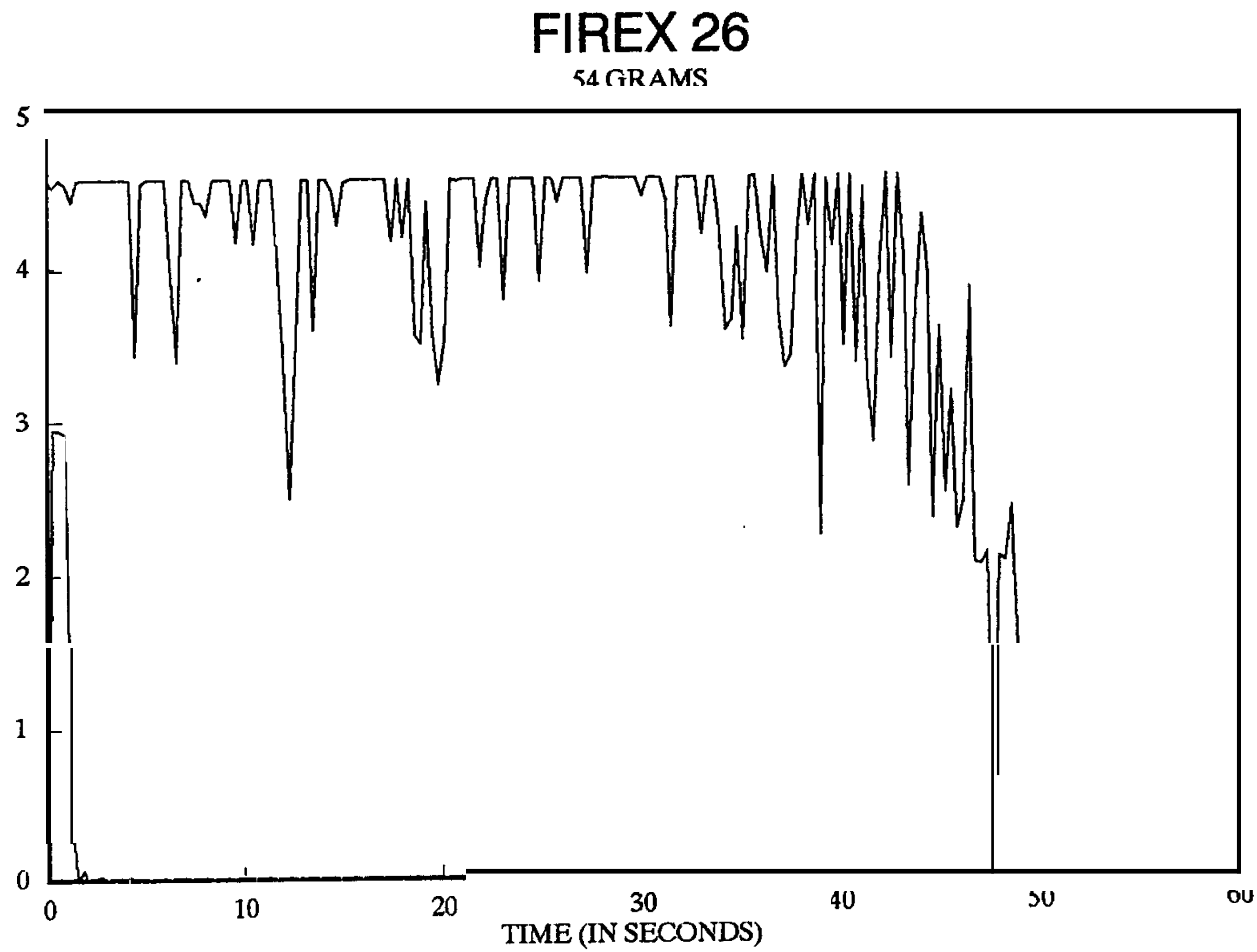


FIGURE NINE

FIREX 26

54 GRAMS

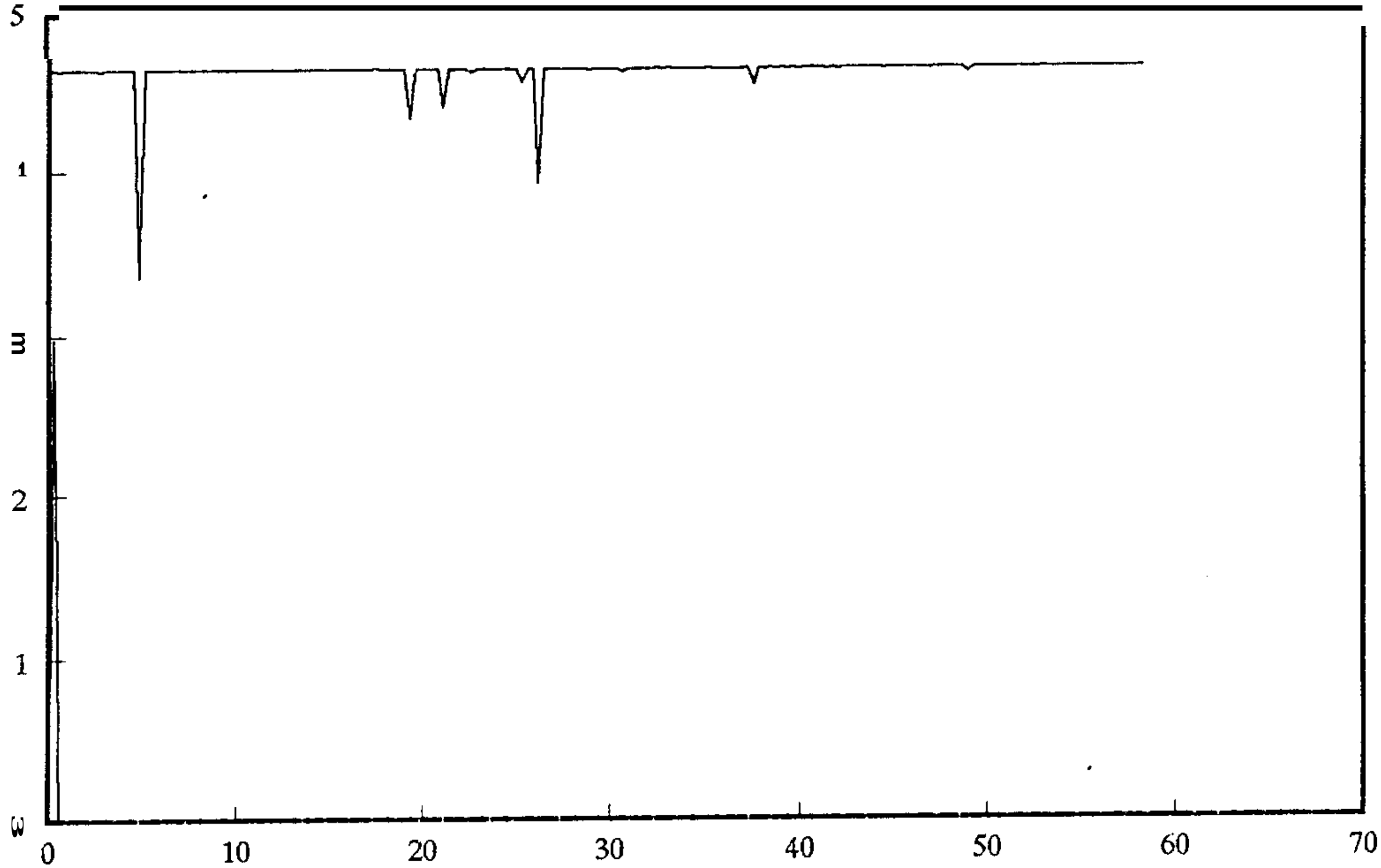


FIGURE TEN

AIR LEAK

FIREX 26

118 GRAMS

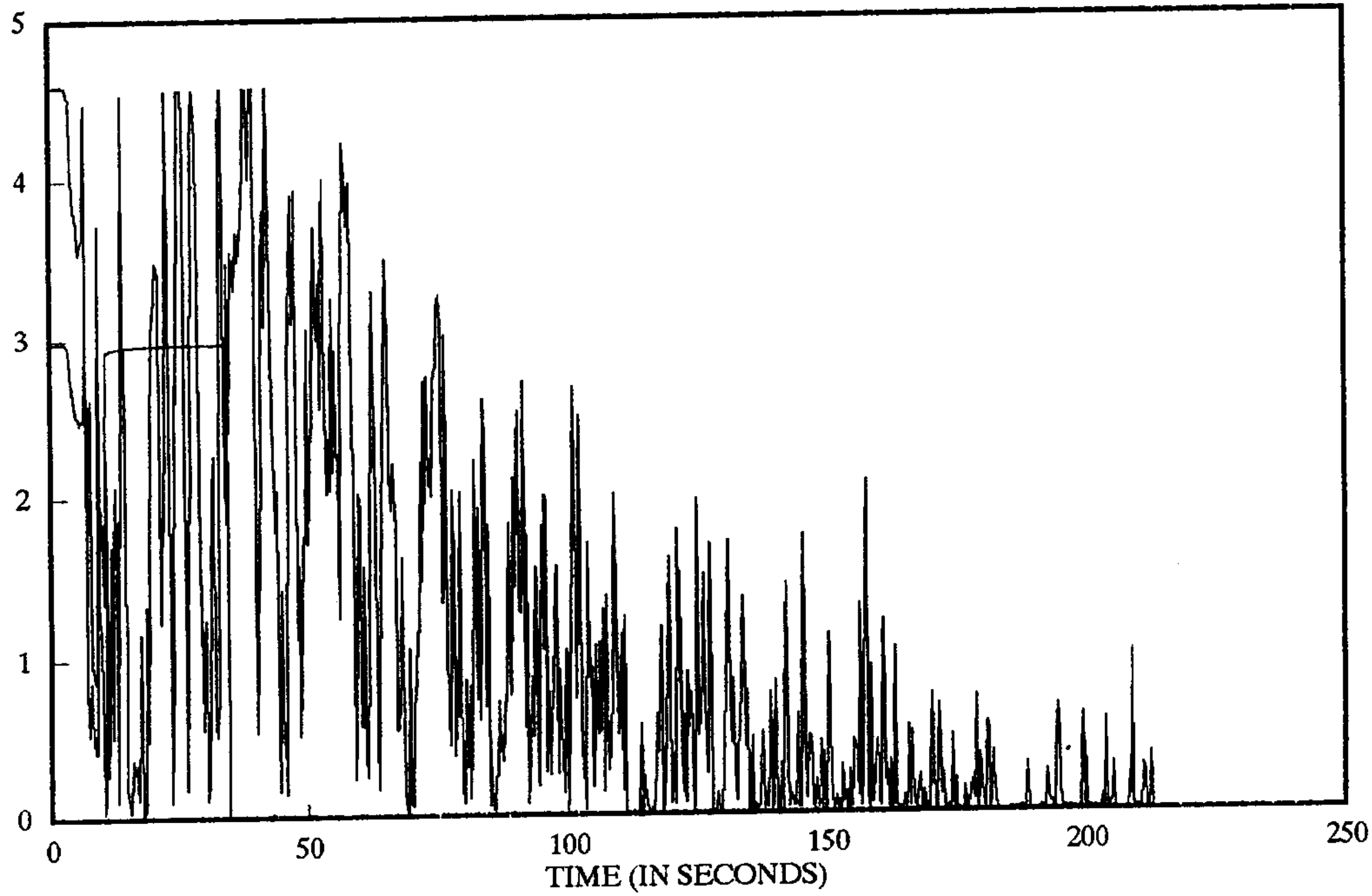


FIGURE ELEVEN

BLOW OUT PANELS OPENED

FIREX 26

72.5 GRAMS

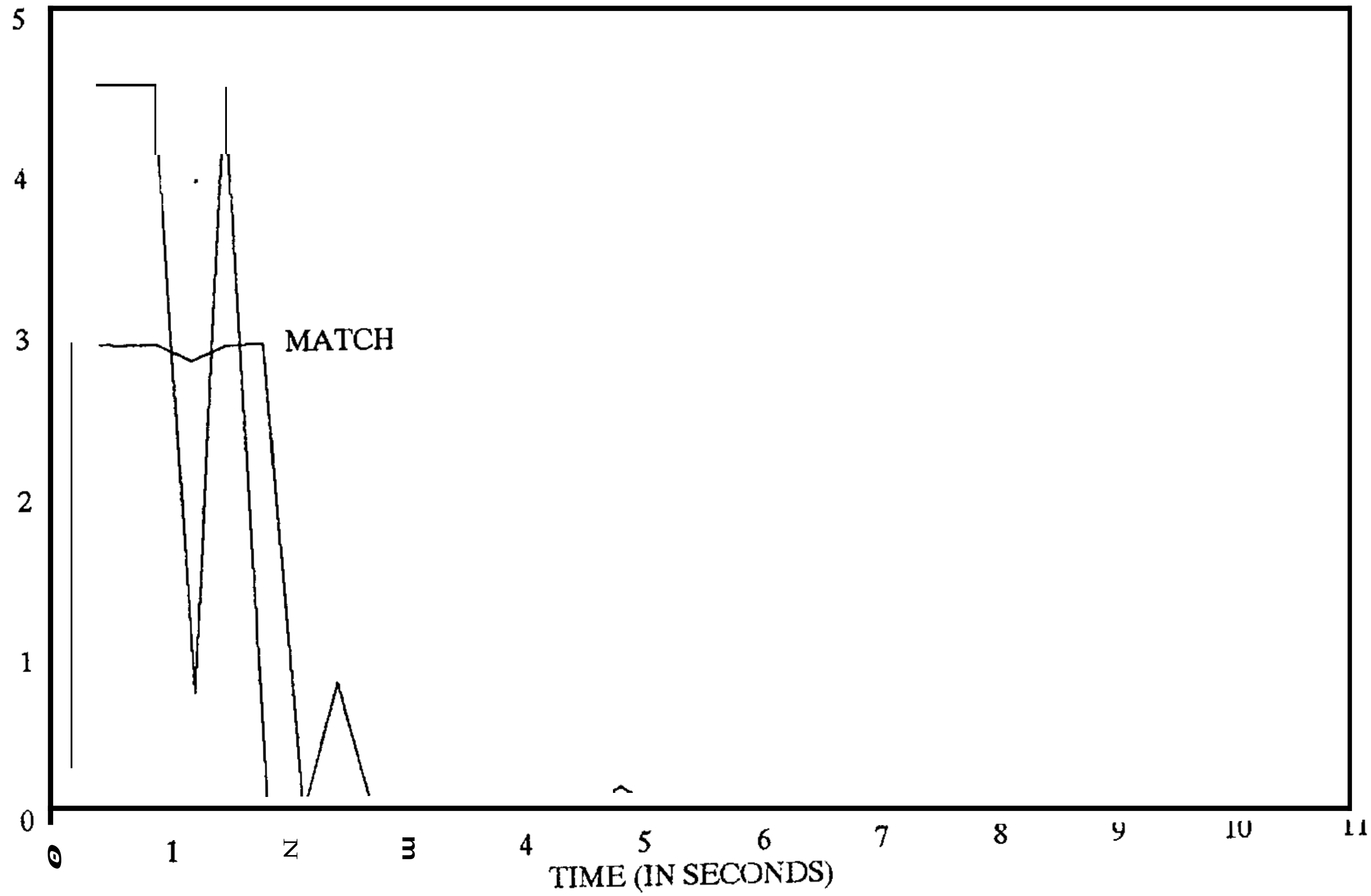


FIGURE TWELVE

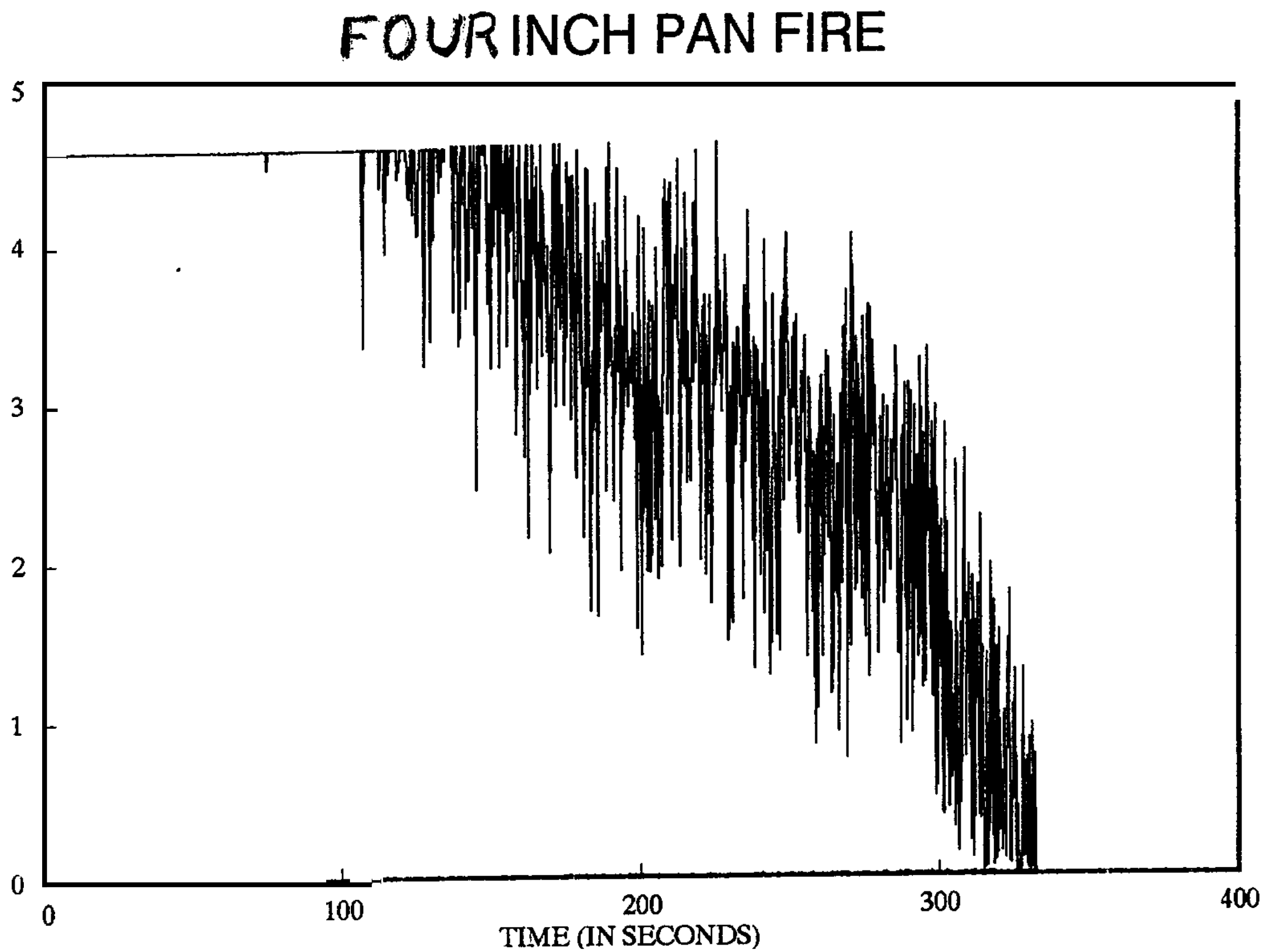


FIGURE THIRTEEN

APPENDIX ONE

Sample Propellant Calculations

KHF2& KHF2* KO2& KH& KO4Cl& K2O& K2O2& Zr&
H2O* Kh
1 FIREX24 Run using June 1988 Version of PEP.
Case 1 of 1 0 1900 at 0: 0: 0. 0 am

CODE		WEIGHT	D-H	DENS	COMPOSITION
822	POTASSIUM PERCHLORATE (KCLO4)	52.800	-742	.09100	1CL 1K 4O
1040	ZIRCONIUM	14.000	0	.23110	1ZR
817	POTASSIUM CHLORIDE	26.200	-1397	.07170	1CL 1K
1032	VITON A	7.000	-1890	.06580	206H 274C 342F

?HE PROPELLANT DENSITY IS ,08988 LB/CU-IN OR 2.4879 GM/CC
?HE TOTAL PROPELLANT WEIGH? IS 100.0000 GRAMS

NUMBER OF GRAM ATO OXYGEN TOO HIGH :DIENTS

ACIDS TOO HIGH #1

.144248 H ·480 F
.732480 CL

****************************CHAMBER RESULTS FOLLOW ************************

T(K)	T(F)	P(ATM)	P(PSI)	ENTHALPY	ENTROPY	CP/CV	GAS	RT/V	
1874.	2914.	6.80	100.00	-89.01	107.41	1.1683	1.341	5.072	TCRE

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL= 10.774 11.781
NUMBER MOLS GAS AND CONDENSED= 1.3412 .2291

.43600	O2	.40124	KCl	.19180	c02	.13304	ZrO2&
.12087	HF	.09915	K2Cl2	.09609	KCl*	.03460	KF
.02043	ZrF4	.01914	HCl	.01104	Cl	.00318	c12
2.04E-03	H20	1.12E-03	K2F2	2.74E-04	OCl	1.24E-04	HO
6.99E-05	O	5.51E-05	CO	2.19E-05	F	1.35E-05	KHO
1.18E-05	ClF	1.15E-05	HOCl	1.20E-06	H02	6.66E-07	K
6.36E-07	H2F2	1.65E-07	KO	1.43E-07	H2	1.09E-07	H
1.02E-07	COF2						

?HE MOLECULAR WEIGHT OF ?HE MIXTURE IS 63.681

TOTAL HEAT CONTENT (298 REF! = 280.489 CAL/GM
SENSIBLE HEAT CONTENT (298 REF)= 280.274 CAL/GM

****************************EXHAUST RESULTS FOLLOW ************************

T(K)	T(F)	P(ATM)	P(PSI)	ENTHALPY	ENTROPY	CP/CV	GAS	RT/V	
1560.	2348.	1.00	14.70	-97.54	107.41	1.1572	1.279	.782	TCRE

SPECIFIC HEAT (MOLAR) CF GAS AND TOTAL= 10.827 12.039
NUMBER MOLS GAS AND CONDENSED= 1.2788 .2751

.43801	O2	.34253	KCl	.19185	C02	.14327	KCl*
.13181	ZrO2&	.13049	HF	.11218	K2Cl2	.02167	ZrF4
.02069	KF	.01204	HCl	,00497	Cl	.00261	Cl2
8.44E-04	H20	8.08E-04	K2F2	6.65E-05	OCl	1.56E-05	HO
6.64E-06	O	3.78E-06	CO	3.08E-06	ClF	2.81E-06	F
2.32E-06	HOCl	1.22E-06	KHO	1.58E-07	H2F2		

THE MOLECULAR WEIGHT OF THE MIXTURE IS 64.355

TOTAL HEAT CONTENT (298 REF) = 227.835 CAL/GM
SENSIBLE HEAT CONTENT (298 REF)= 227.746 CAL/GM

KHF2& KHF2* KO2& KH6 KO4Cl& K2O& K2O2& Zr&
H2O* K&

1 FIREX25 Run using June 1988 Version of PEP.
Case 1 of 1 0 1900 at 0: 0: 0. 0 am

CODE		WEIGHT	D-H	DENS	COMPOSITION
822	POTASSIUM PERCHLORATE (KCLO4)	32.000	-742	.09100	1CL 1K 40
1040	ZIRCONIUM	14.000	0	.23110	1ZR
817	POTASSIUM CHLORIDE	18.000	-1397	.07170	1CL 1K
1032	VITON A	10.000	-1890	.06580	206H 214C 342F
816	POTASSIUM CARBONATE	26.000	-1495	.08770	1C 30 2K

THE PROPELLANT DENSITY IS .08995 LB/CU-IN OR 2.4898 GM/CC
THE TOTAL PROPELLANT WEIGHT IS 100.0000 GRAMS

NUMBER OF GRAM ATOM[illegible] IENTS

.206069 H 14 F
.472378 CL

KClO4 REDUCED
K2CO3 ADDED
O2 and ACIDS LOW
#2

****************************CHAMBER RESULTS FOLLOW ***************************

T(K)	T(F)	P(ATM)	P(PSI)	ENTHALPY	ENTROPY	CP/CV	GAS	RT/V	
2225.	3545.	6.80	100.00	-106.66	113.98	1.1751	1.444	4.711	TCRE

SPECIFIC HEAT !MOLAR) OF GAS AND TOTAL= 11.458 12.057
NUMBER MOLS GAS AND CONDENSED= 1.4440 .1535

.45662	C02	.43526	KCl	.30106	KF	.15347	ZrO26
.07155	O2	.06667	H20	.04943	KHO	.01976	HF
.01809	K2Cl2	01064	K2F2	.00558	CO	.00499	K
2.38E-03	HO	7.91E-04	HCl	4.04E-04	KO	3.90E-04	O
1.53E-04	H2	1.38E-04	Cl	3.70E-05	H	6.11E-06	HO2
4.44E-06	F	3.89E-06	K2H2O2	1.04E-06	OCl	6.87E-07	KH
2.28E-07	K2	2.19E-07	HOCl				

THE MOLECULAR WEIGHT OF THE MIXTURE IS 62.600

TOTAL HEAT CONTENT (298 REF: = 358.524 CAL/GM
SENSIBLE HEAT CONTENT (298 REF:= 351.421 CAL/GM

****************************EXHAUST RESULTS FOLLOW ***************************

T(K)	T(F)	P(ATM)	P(PSI)	ENTHALPY	ENTROPY	CP/CV	GAS	RT/V	
1764.	2715.	1.00	14.70	-117.47	113.98	1.1733	1.413	.708	TCRE

SPECIFIC HEAT (MOLAR: OF GAS AND TOTAL= 11.522 12.133
NUMBER MOLS GAS AND CONDENSED= 1.1128 .1535

.46191	C02	.41250	KCl	.28592	KF	.15347	ZrO2&
.07710	H20	.06865	O2	.04221	KHO	,02986	K2Cl2
.02356	K2F2	.00906	HF	.00107	K	.00041	HO
2.93E-04	CO	1.35E-04	HCl	4.27E-05	KO	2.67E-05	O
1.33E-05	H2	8.87E-06	Cl	6.22E-06	K2H2O2	1.14E-06	H
6.90E-07	H02	1.07E-07	F				

THE MOLECULAR WEIGHT OF THE MIXTURE IS 63.846

TOTAL HEAT CONTENT (298 REF) = 271.866 CAL/GM
SENSIBLE HEAT CONTENT (298 REF): 263.702 CAL/GM

1 FIREX13 Run using June 1988 version of PEP,
Case 1 of 1 0 1900 at 0: 0: 0. 0 am

CODE		WEIGHT	D-H	DENS	COMPOSITION		
822	POTASSIUM PERCHLORATE (KCLO4)	41.000	-742	.09100	1CL	1K	40
63	ALUMINUM (PURE CRYSTALINE)	9.000	0	.09760	1AL		
878	SODIUM CARBONATE	26.000	-2550	.09150	1C	30	2N
408	ETHYTENE VINYL ACETATE	12.000	-1683	.03450	6C	10H	20
817	POTASSIUM CHLORIDE	12.000	-1397	.07170	1CL	1K	

THE PROPELLANT DENSITY IS .07451 LB/CU-IN OR 2.0624 GM/CC
THE TOTAL PROPELLANT WEIGHT IS 190.0000 GRAMS

NUMBER OF GRAM A *HYDROGEN DANGEROUSLY HIGH* REDIENTS

1.051285 H *#3* 90598 NA
.333580 AL

*****************************CHAMBER RESULTS FOLLOW **************************

T(K)	T(F)	P(ATM)	P(PSI)	ENTHALPY	ENTROPY	CP/CV	GAS	RT/V	
1793.	2768.	6.80	100.00	-133.68	143.74	1.1520	1.916	3.551	TCRE

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL- 10.219 12.826
NUMBER MOLS GAS AND CONDENSED: 1.9156 .3336

.65165	CO	.33358	NaAlO2&	.27140	H2O	.26178	KCl
.22442	C02	.20857	H2	.08594	NaCl	.06677	KHO
.04951	K2Cl2	~~.03706~~	~~Na~~	.02906	K	.02380	NaHO
4.95E-03	Na2Cl2	2.23E-04	HCl	2.10E-04	NaH	8.19E-05	H
8.19E-05	KH	6.32E-05	K2H2O2	4.11E-05	Na2	1.90E-05	Na2H2O2
1.42E-05	K2	7.08E-06	HO	4.60E-07	NaO	3.42E-07	CH2O
3.37E-07	KO	1.09E-07	CHO				

THE MOLECULAR WEIGHT OF THE MIXTURE IS 44.460

TOTAL HEAT CONTENT (298 REF) = 419.531 CAL/GM
SENSIBLE HEAT CONTENT (298 REF)= 390.793 CAL/GM

*****************************EXHAUST RESULTS FOLLOW **************************

T(K)	T(F)	P(ATM)	P(PSI)	ENTHALPY	ENTROPY	CP/CV	GAS	RT/V	
1495.	2231.	1.00	14.70	-145.40	143.74	1.1497	1.858	.538	TCRE

SPECIFIC HEAT (MOLAR! OF GAS AND TOTAL= 10.083 12.838
NUMBER MOLS GAS AND CONDENSED: 1.8578 .3503

.61738	CO	.33358	NaAlO2&	.24720	H20	.24637	H2
.24201	CO2	.24092	KCl	.06991	K2Cl2	.06466	NaCl
.04969	KHO	.03334	Na	.02626	K	.01667	Na2CO3*
.01414	NaHO	.00571	Na2Cl2	.00007	K2H2O2	.00006	NaH
3.80E-05	HCl	1.97E-05	KH	1.80E-05	Na2H2O2	1.41E-05	Na2
1.12E-05	H	4.06E-06	K2	3.23E-07	HO		

THE MOLECULAR WEIGHT OF THE MIXTURE IS 45.288

TOTAL HEAT CONTENT (238 REF) = 336.279 CAL/GM
SENSIBLE HEAT CONTENT (298 REF)= 310.103 CAL/GM

**********PERFORMANCE: FROZEN ON FIRST LINE, SHIFTING ON SECOND LINE**********

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1 FIREX21          Run using June 1988 Version of PEP,
  Case  1 of  1     0    1900 at  0: 0: 0. 0 am

   CODE                                          WEIGHT    D-H     DENS      COMPOSITION
    822 POTASSIUM PERCHLORATE (KCLO4)            55.000    -742    .09100    1CL   1K    40
     63 ALUMINUM (PURE CRYSTALINE)                9.000       0    .09760    1AL
    878 SODIUM CARBONATE                         26.000   -2550    .09150    1C    30    2N
   1032 VITON A                                  10.000   -1890    .06580   206H 274C 342F

 THE PROPELLANT DENSITY IS  ,08828 LB/CU-IN OR  2.4436 GM/CC
 THE TOTAL PROPELLANT WEIGHT IS  100.0000 GRAMS

 NUMBER OF GRAM A   KClO4 INCREASED                    GREDIENTS
                    BINDER HAS LESS HYDROGEN
    .206069 H                                         342114 F
    .490598 NA        HYDROGEN GONE            #4     396949 K

****************************CHAMBER RESULTS FOLLOW     ************************

  T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY  CP/CV    GAS    RT/V
 2468. 3984.   6.80    100.00  -126.01   138.20  1.1349  1.610   4.225   TCRE

 SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL:    11.942   14.537
 NUMBER MOLS GAS AND CONDENSED=   1.6101    ,2413

    .50556 CO2         .30337 C2          .23993 KCl         .21322 NaAlO2&
    .15144 NaCl        .06984 KHO         ,06063 KF          .05829 AlF4-
    .04950 NaHO        .03852 H20         .03651 Na          .03359 NaF
    .02806 Al2O3*      .01958 K           .01382 CO          .00633 HO
  5.92E-03 AlOF2     5.04E-03 NaO       3.32E-03 O         2.81E-03 KO
  2.41E-03 HF        1.94E-03 K2Cl2     5.44E-04 Na2Cl2    3.84E-04 HCl
  2.19E-04 Cl        1.74E-04 H2        1.40E-04 H         1.36E-04 K2F2
  8.47E-05 Na2F2     2.59E-05 HC2       2.04E-05 AlOF      1.08E-05 Na2
  8.96E-06 NaH       5.21E-06 AlHO2     3.73E-06 F         3.28E-06 KH
  2.80E-06 OCl       2.56E-06 K2H2O2    2.14E-06 K2        2.01E-06 Na2H2O2
  2.31E-07 AlOCl     2.26E-07 HOCl

 THE MOLECULAR WEIGHT CF THE MIXTURE IS   54.013

 TOTAL HEAT CONTENT (298 REF:    = 534.581 CAL/GM
 SENSIBLE HEAT CONTENT (298 REF)= 530.320 CAL/GM
****************************EXHAUST RESULTS FOLLOW     ************************

  T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY  CP/CV    CAS    RT/V
 2149. 3409.   1.00     14.70  -137.98   138.20  1.1328  1.560    .641   TCRE

 SPECIFIC HEAT (MOLAR) CF GAS AND TOTAL:    11.963   14.472
 NUMBER MOLS GAS AND CONDENSED=   1.5596    .2676

    .51446 CO2         .29801 O2          .26762 NaAlO2&     .25980 KCl
    .13387 NaCl        .06442 AlF4-       .06287 KHO         .05495 KF
    .05069 H2O         .03589 NaHO        .02662 Na          ,02430 NaF
    .01573 K           .00492 CO          .00357 HO          .00187 HF
  1.69E-03 NaO       1.52E-03 AlOF2     1.32E-03 O         1.23E-03 K2Cl2
  9.93E-04 KO        2.56E-04 Na2Cl2    2.14E-04 HCl       9.54E-05 H2
  8.37E-05 Cl        7.03E-05 K2F2      5.12E-05 H         4.23E-05 Na2F2
  7.44E-06 HO2       2.17E-06 AlOF      1.66E-06 NaH       1.59E-06 Na2
  1.23E-06 K2H2O2    7.34E-07 Na2H2O2   7.21E-07 F         5.90E-07 KH
  4.98E-07 OCl       4.86E-07 AlHO2     3.53E-07 K2

 THE MOLECULAR WEIGHT OF THE MIXTURE IS   54.728
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KCl& KCl* K& K* KO2& KO4Cl& K2O& K2O2&
MgO* K&

1 FIREX27 -3 Run using June 1988 Version of PEP,
Case 1 of 1 0 1900 at 0: 0: 0. 0 am

CODE	WEIGHT	D-H	DENS	COMPOSITION		
User POTASSIUM PERCHLORATE (KCLO4)	37.000	-742	.09100	1CL	1K	40
User MAGNESIUM (PURE CRYSTALINE)	25.000	0	.06280	1MG		
User POTASSIUM CHLORIDE	12.000	-1397	.07170	1CL	1K	
User POTASSIUM CARBONATE	16.000	-1495	.08770	1C	30	2K
User CPVC	10.000	204	.01810	6CL	3C	

THE PROPELLANT DENSITY IS .05858 LB/CU-IN OR 1.6216 GM/CC
THE TOTAL PROPELLANT WEIGHT IS 100.0000 GRAMS

NUMBER OF GRAM ATO[illegible] MgO* LIQUID in exhaust. [illegible]IENTS

.236356 C 1 til CL
.659519 K

*****************************CHAMBER RESULTS FOLLOW *************************

T(K)	T(F)	P(ATM)	P(PSI)	ENTHALPY	ENTROPY	CP/CV	GAS	RT/V	
3504.	5847.	6.80	100.00	-66.10	125.21	1.1133	1.263	5.387	TCRE

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL= 8.950 11.726
NUMBER MOLS GAS AND CONDENSED- 1.2628 .8403

.84025	MgO*	.55199	KCl	.16746	CO	.09911	K
.09442	Mg	.07827	02	.06889	C02	.06005	O
.04694	MgO	.04173	Cl	.02667	MgCl2	.01968	MgCl
6.21E-03	KO	1.08E-03	K2Cl2	2.08E-04	OCl	2.33E-05	C12
2.06E-05	K2	2.52E-06	COCl	5.84E-07	Mg2Cl4	1.14E-07	03

THE MOLECULAR WEIGHT OF THE MIXTURE IS 47.551

TOTAL HEAT CONTENT (298 REF) = 719.781 CAL/GM
SENSIBLE HEAT CONTENT (298 REF)= 719.781 CAL/GM

*****************************EXHAUST RESULTS FOLLOW ***************************

T(K)	T(F)	P(ATM)	P(PSI)	ENTHALPY	ENTROPY	CP/CV	GAS	RT/V	
3106.	5131.	1.00	14.70	-81.70	125.21	1.1107	1.238	.808	TCRE

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL= 8.888 11.686
NUMBER MOLS GAS AND CONDENSED= 1.2379 .8591

.75464	MgO*	.56302	KCl	.15475	CO	10445	MgO&
.10375	Ma	.09329	K	.08160	CO2	07908	02
.05036	O	.04399	Cl	.02732	MgO	,02352	MgCl2
.01429	MgCl	.00248	KO	.00036	K2Cl2	,00010	OCl
1.20E-05	C12	4.12E-06	K2	5.18E-07	COCl	1.28E-07	Mg2Cl4

THE MCLECULAR WEIGHT OF THE MIXTURE IS 47.687

TOTAL HEAT CONTENT (298 REF) = 621.047 CAL/GM
SENSIBLE HEAT CONTENT (298 REF:= 621.047 CAL/GM

*********PERFORMANCE: FROZEN ON FIRST LINE, SHIFTING ON SECOND LINE*********

1 FIREK30 Run using June 1988 Version of PEP,
Case 1 of 1 0 1900 at 0: 0: 0. 0 am

CODE		WEIGHT	D-H	DENS	COMPOSITION		
User	POTASSIUM PERCHLORATE (KCLO4)	29.500	-742	.09100	1CL	1K	40
User	MAGNESIUM (PURE CRYSTALINE)	20.500	0	.06280	1MG		
User	POTASSIUM CHLORIDE	15.000	-1397	.07170	1CL	1K	
User	POTASSIUM CARBONATE	25.000	-1495	.08770	1C	30	2K
User	CPVC	10.000	204	.01810	6CL	3C	

THE PROPELLANT DENSITY IS .05891 LB/CU-IN OR 1.6308 GM/CC
THE TOTAL PROPELLANT WEIGHT IS 100.0000 GRAMS

NUMBER OF GRAM A Reduce Heat Output #6 REDIENTS
Increase Heat Vaporizables
.301474 C MgO Liquid in Chamber 55279 CL
.775863 K S O U —.

****************************CHAMBER RESULTS FOLLOW ************************

T(K)	T(F)	P(ATM)	P(PSI)	ENTHALPY	ENTROPY	CP/CV	GAS	RT/V	
3299.	5479.	6.80	100.00	-78.18	120.92	1.1128	1.231	5.527	TCRE

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL. 9.344 11.920
NUMBER MOLS GAS AND CONDENSED= 1.2308 .7940

.79397 MgO* Liquid	.62595 KCl	.18120 CO	.13754 K
.12026 CO2	.06276 O2	.03071 O	.02699 Mg
.01413 MgO	.01307 Cl	.00816 KO	.00422 MgCl2
3.62E-03 MgCl	2.06E-03 K2Cl2	6.26E-05 OCl	4.99E-05 K2
4.05E-06 Cl2	1.04E-06 COCl		

THE MOLECULAR WEIGHT OF THE MIXTURE IS 49.389

TOTAL HEAT CONTENT (298 REF; = 654.234 CAL/GM
SENSIBLE HEAT CONTENT (298 REF)= 654.234 CAL/GM

*****************************EXHAUST RESULTS FOLLOW ************************

T(K)	T(F)	P(ATM)	P(PSI)	ENTHALFY	ENTROPY	CP/CV	GAS	RT/V	
3025.	4986.	1.00	14.70	-93.11	120.92	1.1286	1.289	.776	TCRE

SPECIFIC HEAT (MOLAR) CF GAS AND TOTAL= 9.084 10.946
NUMBER MOLS GAS AND CONDENSED. 1.2893 ,7641

.76412 MgO& Solid	.61953 KCl	.18069 CO	.15137 K
.12078 CO2	.07537 O2	,05437 Mg	.03848 O
.01978 Cl	.01472 MgO	.00519 MgCl2	.00452 MgCl
3.93E-03 KO	4.99E-04 K2Cl2	4.26E-05 OCl	1.14E-05 K2
3.05E-06 Cl2	2.83E-07 COCl		

THE MOLECULAR WEIGHT OF THE MIXTURE IS 48.699

TOTAL HEAT CONTENT (238 REF) = 569.517 CAL/GM
SENSIBLE HEAT CONTENT (298 REF): 569.517 CAL/GM

**********PERFORMANCE: FROZEN ON FIRST LINE. SHIFTING ON SECOND LINE**********

IMPULSE	IS EX	T*	P*	C*	ISP*	OPT-EX	D-ISP	A*M	EX-T
110.6	1.1132	3122.	3.96	3020.5		1.89	180.4	.93903	2715.
114.0	.9882	3238.	4.14	3372.4	119.1	1.92	185.9	1.04841	3025.