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AFRPL-TR-66-226

DEVELOPMENT OF LOW TEMPERATURE GAS GENERATOR TECHNOLOGY

Final Report

Dr. Donald R. Poole
Rocket Research Corporation
Seattle, Washington

December 1966

Air Force Rocket Propulsion Laboratory
Research and Technology Division
Air Force Systems Command
Edwards, California

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FOREWORD

This technical report was prepared for the Air Force Rocket Propulsion Laboratory, Research and Technology Division, Edwards Air Force Base, California, by Rocket Research Corporation, Seattle, Washington, under Contract AF 04(611)-11376. This Final Report covers the period January 3, 1966, through November 14, 1966. The Air Force Project Officers were Capt. Joel A. Tolson and Lt. James R. Noyce. The Rocket Research Corporation Program Manager was Dr. Donald R. Poole.

This report has been assigned a secondary report number RRC-66-R-74 by Rocket Research Corporation.

This report contains no classified information extracted from classified documents.

This technical report has been reviewed and approved.

W. H. Ebelke, Colonel, USAF
Chief, Propellant Division

ABSTRACT

The objective of this program was to characterize monopropellant hydrazine-based monopropellants which, by the use of ammonia and ammonia-water diluents, are capable of producing clean, low temperature gases when passed through a catalytic decomposition chamber. During the course of the 2-month program, thermochemical calculations were performed on a large number of cases involving various compositions of hydrazine, ammonia, and water. The effect of varying the amount of ammonia dissociation was investigated in the above calculations. Based upon the results of the thermochemical calculations and preliminary physical property testing, seven different solutions composed of various concentrations of hydrazine, water and/or ammonia were selected for further evaluation. The freezing points of the solutions were determined; and the vapor pressures, densities, and viscosities were measured over a wide temperature range. A low temperature gas generator was designed to produce approximately 60 standard cubic feet of gas per minute and to operate at a nominal chamber pressure of 300 psi. This gas generator was fired with each of the seven monopropellants in order to determine their steady state performance characteristics. In addition, a 1 lbf gas generator thruster was fired in pulse mode operation at various pulse widths and duty cycles with each of the seven monopropellants. The complete test results are presented in tabular form.

TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
I	CONTRACT SCOPE	1
	1.1 General	1
	1.2 Thermochemical Calculations (Phase I)	1
	1.3 Propellant Characterization (Phase II)	1
	1.4 Gas Generator Testing (Phase III)	1
II	THERMOCHEMICAL CALCULATIONS	3
	2.1 Computer Program Description	3
	2.2 Chamber Conditions	3
	2.3 Thermochemical Data	4
	2.4 Discussion of Results	6
III	PROPELLANT CHARACTERIZATION	13
	3.1 Preliminary Evaluation	13
	3.2 Selection of Propellants	18
	3.3 Physical Properties Determinations	18
	3.4 Summary of Propellant Physical Properties	33
IV	REACTOR TEST PHASE	41
	4.1 General	41
	4.2 Gas Generator Design	41
	4.3 Reactor Testing	45
	4.4 Results of Test Firings	52
	4.5 Summary and Conclusions	60
	APPENDIX	63
	REFERENCES	85

LIST OF FIGURES

<u>Figure Number</u>		<u>Page</u>
1	Heat of Solution, Ammonia-Hydrazine Solutions	7
2	Heat of Solution, Water-Hydrazine Solutions	8
3	Hydrazine-Water System, Chamber Temperature vs %H ₂ O for Various Ammonia Dissociation	11
3a	Hydrazine-Water System, Chamber Temperature vs %H ₂ O for Various Ammonia Dissociation	12
4	Hydrazine-Ammonia System Chamber Temperature vs %NH ₃ for Varying Ammonia Dissociation	73
5	Hydrazine-Ammonia System Chamber Temperature vs %NH ₃ for Varying Ammonia Dissociation	74
6	Hydrazine, Equal Weight %H ₂ O and NH ₃ System Chamber Temperature vs % Additive for Varying Ammonia Disso- ciation	75
7	Hydrazine, Equal Weight %H ₂ O and NH ₃ System Chamber Temperature vs % Additive for Varying Ammonia Disso- ciation	76
8	Performance of the Hydrazine-Ammonia System as a Function of Temperature and NH ₃ Dissociation	77
9	Performance of the Hydrazine-H ₂ O System as a Function of Temperature and NH ₃ Dissociation	78
10	Performance of the Hydrazine-Equal Wt %H ₂ O and NH ₃ System as a Function of Temperature and NH ₃ Disso- ciation	79
11	70% Hydrazine, 30% NH ₃ System Reaction Product Composition	80
12	50% Hydrazine, 50% NH ₃ System Reaction Product Composition	81
13	60% Hydrazine, 40% NH ₃ System, Reaction Product Composition	82
14	70% Hydrazine, 30% H ₂ O System, Reaction Product Composition	83
15	55% Hydrazine, 45% H ₂ O System, Reaction Product Composition	84
16	Freezing Point vs Weight % Additive for Various N ₂ H ₄ Solutions	15
17	Vapor Pressure vs Temperature 29.89% H ₂ O, 30.07% NH ₃ , 40.04% N ₂ H ₄	16

LIST OF FIGURES (Cont'd)

Figure Number		Page
18	Vapor Pressure vs Temperature, 60.06% H ₂ O, 9.87% NH ₃ , 30.07% N ₂ H ₄	17
19	Freezing Point vs Weight-% H ₂ O for N ₂ H ₄ + H ₂ O Solutions	22
20	Temperature Effect on Vapor Pressure of N ₂ H ₄ + H ₂ O Solutions	23
21	Temperature Effect on Vapor Pressure of 40% N ₂ H ₄ / 60% H ₂ O	24
22	Temperature Effect on Vapor Pressure of 65.0% N ₂ H ₄ , 26.25% H ₂ O, 8.75% NH ₃	26
23	Temperature Effect on Vapor Pressure of Hydrazine-Ammonia- Water Solutions	27
24	Rolling Ball Viscometer Schematic	28
25	Viscometer Loading Schematic	29
26	Temperature Effect on Viscosity of N ₂ H ₄ + H ₂ O Solutions	30
27	Temperature Effect on Viscosity of Hydrazine-Ammonia- Water Solutions	31
28	Temperature Effect on Viscosity of Hydrazine-Ammonia- Water Solutions	32
29	Temperature Effect on Density of N ₂ H ₄ + H ₂ O Solutions	34
30	Temperature Effect on Density, 40.0% N ₂ H ₄ , 60% H ₂ O and 65.0% N ₂ H ₄ , 26.25% H ₂ O, 8.75% NH ₃	35
31	Temperature Effect on Density, 45.0% N ₂ H ₄ , 27.5% H ₂ O, 27.5% NH ₃	36
32	Temperature Effect on Density, 35.0% N ₂ H ₄ , 32.5% H ₂ O, 32.5% NH ₃	37
33	Temperature Effect on Density, 30.0% N ₂ H ₄ , 70% NH ₃	38
34	Low Temperature Gas Generator Assembly	42
35	LTGG Reactor Instrumentation	47
36	1 lbf Thruster Instrumentation	48
37	Reactor Test Schematic	49
38	Performance as a Function of Hydrazine Content	58
39	Characteristic Exhaust Velocity During Pulse Mode Operation	59

LIST OF TABLES

<u>Table Number</u>		<u>Page</u>
I	Heat of Formation of Hydrazine Solutions	5
II	Theoretical Performance Hydrazine-Water System, Chamber Pressure = 300 psia, Exhaust Pressure = 14.7 psia	64
III	Theoretical Performance, Hydrazine-Ammonia System, Chamber Pressure = 300 psia, Exhaust Pressure = 14.7 psia	67
IV	Theoretical Performance, Hydrazine-Equal Weight Percent Water-Ammonia System	70
V	Theoretical Performance Selected Hydrazine-Ammonia-Water Systems, Chamber Pressure = 300 psia, Exhaust Pressure = 14.7 psia	9
VI	Composition and Freezing Points of Hydrazine-Ammonia-Water Solutions	14
VII	Compositions of Selected Low Temperature Gas Generator Pro- pellants	19
VIII	Physical Properties of Low Temperature Gas Generator Propellants	39
IX	Gas Generator Design Parameters	46
X	Instrumentation Parameters	50
XI	Pulse Mode Firing Sequence	51
XII	LTGG Reactor Test Data	53
XIII	1 lbf Thruster Test Data Summary	54
XIV	Results of Exhaust Gas Analysis	61

SECTION I

CONTRACT SCOPE

1.1 General

This program was conducted in three phases. Phase I involved conducting thermochemical calculations which provided theoretical data to assist in the selection of propellant systems for experimental evaluation. Phase II consisted of the determination of the physical properties of the selected propellants. Experimental delivered performance data was determined in Phase III.

This program was basically a propellant study and did not involve development of gas generator hardware, although a heavyweight experimental reactor was designed and fabricated for propellant evaluation purposes.

1.2 Thermochemical Calculations (Phase I)

Thermochemical calculations were performed on various compositions for the hydrazine-ammonia-water system. The effect of varying amounts of ammonia dissociation was investigated in addition to the effect of varying the chamber pressure.

1.3 Propellant Characterization (Phase II)

Seven different solutions composed of various concentrations of hydrazine, water and/or ammonia were selected for characterization studies. The selection of these propellants was based on the results of the thermochemical calculations and on preliminary physical property testing. The freezing point, density, vapor pressure and viscosity of each propellant was then measured.

1.4 Gas Generator Testing (Phase III)

A heavyweight experimental reactor was designed and fabricated. The reactor operated at a nominal chamber pressure of 250 psia and produced approximately 60 standard cubic feet of gas per minute. Each of the seven propellants was evaluated using this reactor.

SECTION II

THERMOCHEMICAL CALCULATIONS

2.1 Computer Program Description

The computer facilities of the Service Bureau Corporation, Palo Alto, California, were utilized for Phase I thermochemical equilibrium analyses. The NASA computational procedure was used for solution of the basic problem, as published in NASA Report No. 1037. The thermochemical data employed in this analysis was obtained from the joint Army, Navy, Air Force (JANAF) Interim Thermochemical Tables.

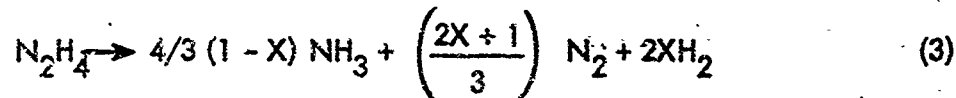
2.2 Chamber Conditions

The decomposition of hydrazine may be considered to take place according to the following consecutive reactions:



For the purpose of calculating the relative amounts of the reactants, it was assumed that equation (1) goes to completion. The extent to which reaction (2) takes place is determined by the efficiency of the catalyst used and the design details of the reaction chamber.

Reactions (1) and (2) may be combined as follows:



Where

X = fraction of NH_3 dissociated.

For the cases in which various concentrations of ammonia in hydrazine were considered, X represents only the fraction dissociation of the ammonia which was derived from the decomposing hydrazine, and Y represents the fraction of the added ammonia which has dissociated.

The input compositions were calculated in units of gram-atoms per 100 grams of reactant for hydrogen, oxygen, and nitrogen and gram-moles per 100 grams of reactant for ammonia by means of the following equations:

$$\frac{4(1-X)}{3} \left(\frac{P_h}{32.048} \right) + (1-Y) \left(\frac{P_{am}}{17.032} \right) = (NH_3) \quad (4)$$

$$\frac{2(1-X)}{3} \left(\frac{P_h}{32.048} \right) + Y \left(\frac{P_{am}}{17.032} \right) = (N) \quad (5)$$

$$\frac{2P_w}{18.016} + \frac{4P_h X}{32.048} + \frac{3P_{am} Y}{17.032} = (H) \quad (6)$$

$$\frac{P_w}{18.016} = (O) \quad (7)$$

Where:

P_h = weight percent hydrazine in reactants

P_{am} = weight percent ammonia in reactants

P_w = weight percent water in reactants

X = fraction ammonia (derived from hydrazine) dissociated

Y = fraction of added ammonia dissociated

Calculations were performed for numerous propellant compositions where arbitrary amounts of ammonia were impressed upon the reaction products in the chamber. In these cases, ammonia was not allowed to dissociate and the formation of additional ammonia was not permitted. For practical purposes this condition specified the composition of the chamber gases for these reactants. Numerous calculations were also performed in which complete chemical equilibrium was allowed to exist. Equilibrium conditions were applied whenever $X = Y = 1$.

All calculations were carried out under frozen flow conditions. Calculations under shifting-flow conditions were not necessary since the results would be identical to frozen flow conditions for all practical purposes.

2.3 Thermochemical Data

The heats of formation used in the thermochemical calculations are listed in Table I. These values were derived from the standard heat of formation of each component of the solutions and the heats of solution of ammonia and water in hydrazine.

TABLE I
HEAT OF FORMATION OF HYDRAZINE SOLUTIONS

Weight % N_2H_4	Weight % NH_3	Weight % H_2O	ΔH kcal/100 gm
100	0	0	+ 37.5998
90	0	10	- 5.5018
70	0	30	- 90.7060
65	0	35	-111.4167
60	0	40	-132.9876
55	0	45	-153.5183
50	0	50	-174.4393
45	0	55	-195.3601
40	0	60	-216.2509
30	0	70	-258.0026
95	5	0	+ 30.399
90	10	0	+ 24.508
80	20	0	+ 11.486
70	30	0	- 1.552
60	40	0	- 14.558
55	45	0	- 21.069
50	50	0	- 27.580
40	60	0	- 40.602
35	65	0	- 47.113
30	70	0	- 53.624
80	10	10	- 18.691

Values of the heat of solution for various concentrations of ammonia in hydrazine were obtained from the data given in Reference 1. After conversion to the appropriate units, this information was plotted as shown in Figure 1. This graph indicates that the heat of solution is essentially constant for concentrations greater than about 5%. The value -0.07 kcal/100 g was therefore applied as a correction in all cases involving ammonia solutions, even though a correction of this magnitude has very little influence on the results.

Corrections for the heat of solution for the various concentrations of water in hydrazine were obtained from Figure 2 (References 2 and 3).

For those solutions containing both ammonia and water in hydrazine, the heats of solution were estimated from values for the two component systems. The constant value of -0.07 kcal/100 g was applied to correct for the heat of solution of ammonia in hydrazine. The concentration of water in hydrazine was calculated as though no ammonia was in the solution and the corresponding heat of solution was then obtained from Figure 2.

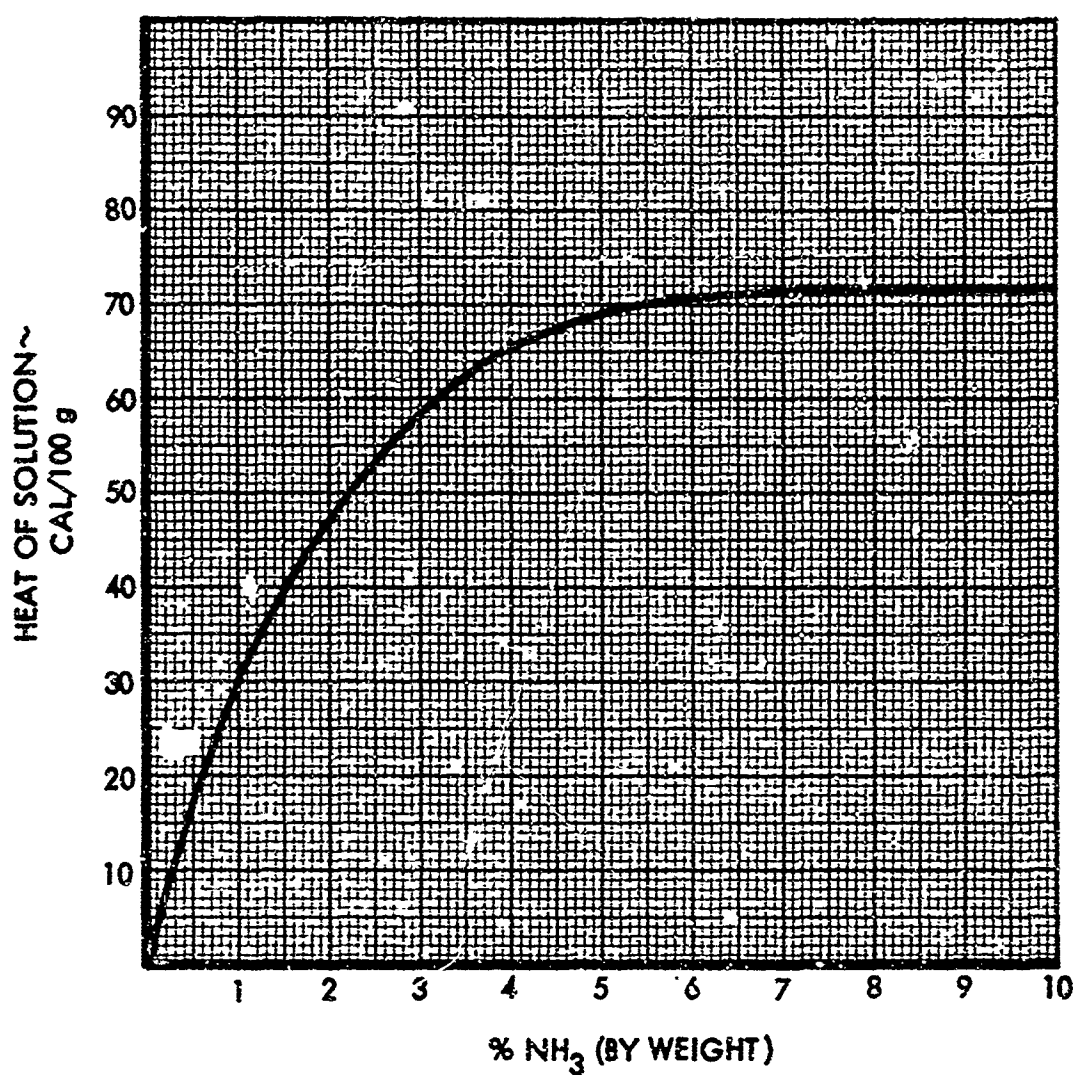
Thermochemical calculations were performed on a test case in an effort to determine the significance of the heat of solution corrections. The test case consisted of 30% ammonia and 70% hydrazine with $X = .4$ and $Y = 0$ and was calculated both with and without the heat of solution correction. When the correction was applied, the chamber temperature was 931.08°K and the characteristic exhaust velocity was $3,559 \text{ ft/sec}$. Without the correction, these values were 932.11°K and $3,561 \text{ ft/sec}$. From these values it was concluded that any errors which may have been introduced by the described methods of correcting for the heat of solution would not influence the results significantly.

2.4 Discussion of Results

The results of the Phase I thermochemical calculations are summarized in Tables II, III, and IV and in Figures 4 through 15 respectively, in the Appendix. These figures illustrate the wide ranges of chamber temperatures and performance which are theoretically possible through the use of mixtures of ammonia, water, and hydrazine.

During a later phase of the program, after the selection of the propellant compositions which were characterized and tested in the reactor, another series of calculations was performed. These calculations, summarized in Table V, provide a more direct comparison with the results of the reactor testing (Phase III) than was possible with the

HEAT OF SOLUTION
AMMONIA - HYDRAZINE SOLUTIONS



HEAT OF SOLUTION WATER - HYDRAZINE SOLUTIONS

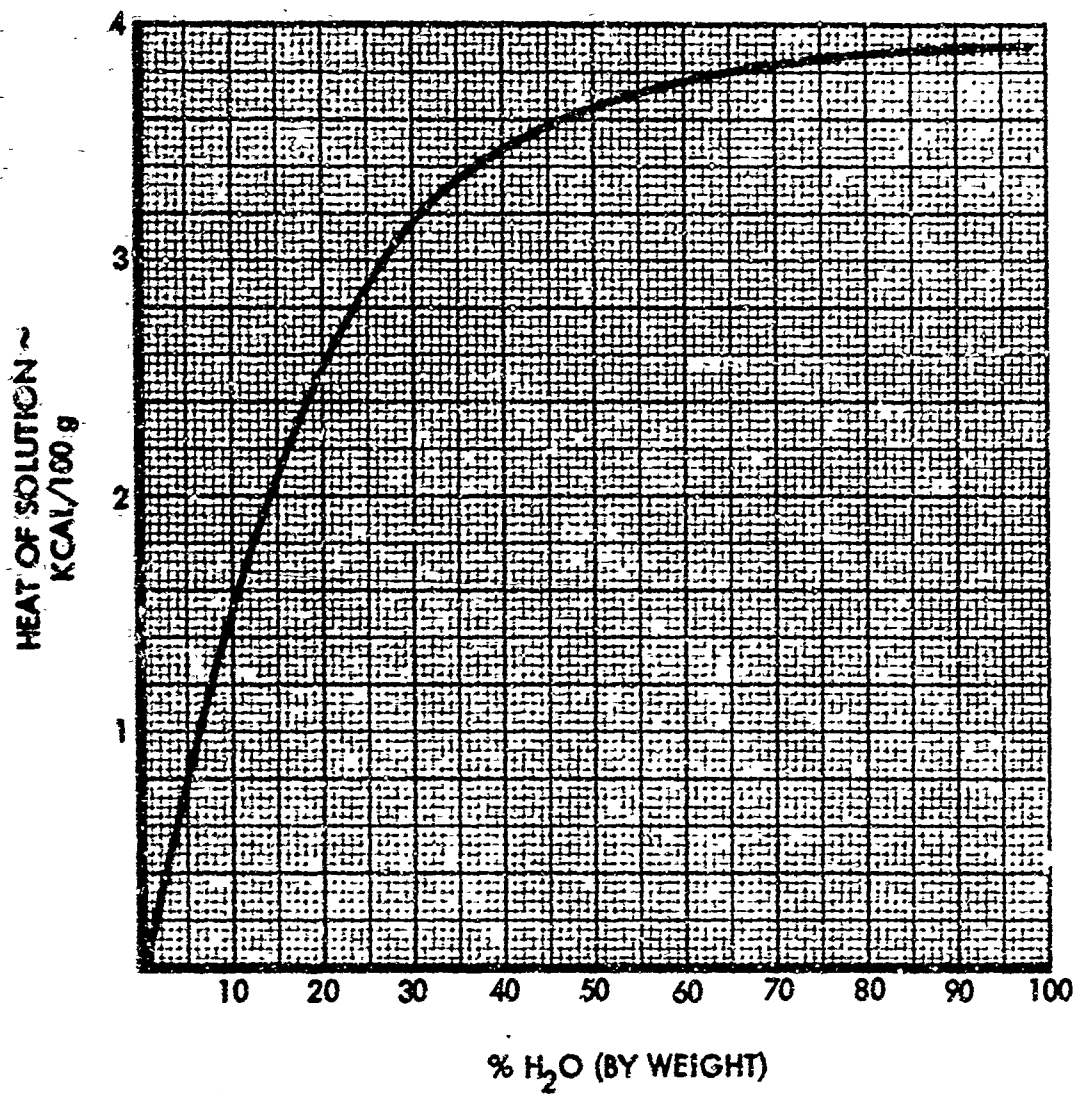


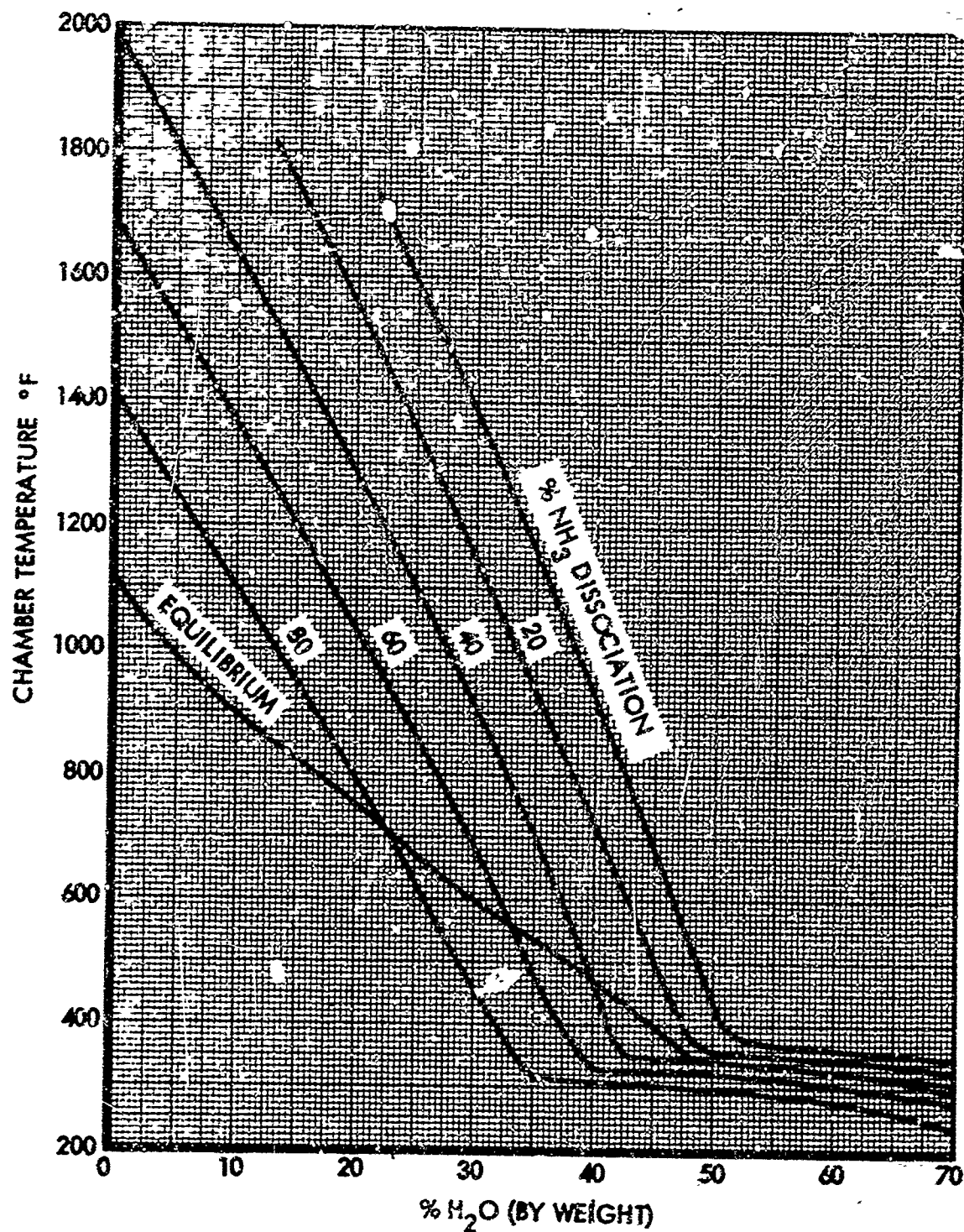
FIGURE 2

TABLE V
THEORETICAL PERFORMANCE
SELECTED HYDRAZINE-AMMONIA-WATER SYSTEMS
CHAMBER PRESSURE = 300 psia - EXHAUST PRESSURE = 14.7 psia

ΔH° Kcal/ 100g	Code No.	% N_2H_4	% NH_3	% H_2O	X	Y	T_c °K	T_c °F	c_p ft/sec	I_{sp} sec	ΔH° Kcal/ 100gm	M.W.	Frozen Gamma (Ch.)	Moles H_2	Moles N_2	Moles NH_3	Moles H_2O (Gm)	Moles H_2O (Liquid)
-93.520	3.307.00	69.3	--	30.7	0.0	--	1012	1362	3364	146.45	-24.469	18.839	1.2101	--	0.7208	2.3832	1.7040	--
-93.520	3.307.20	69.3	--	30.7	0.2	--	885	1133	3281	141.88	-22.965	16.945	1.2463	0.8630	0.9832	2.3065	1.7040	--
-93.520	3.307.40	69.3	--	30.7	0.4	--	756	901	3130	135.46	-20.782	15.373	1.2860	1.7300	1.2456	1.7299	1.7040	--
-170.261	3.49.00	51	--	49	0.0	--	527	489	2364	105.80	-12.864	18.615	1.2940	--	0.5305	2.1218	2.7198	--
-216.231	3.60.00	40	--	60	0.0	--	455	361	1996	88.4	-8.990	18.482	1.154	--	0.416	1.664	1.918	1.413
-216.231	3.60.20	40	--	60	0.2	--	447	344	1978	87.9	-8.985	17.411	1.139	0.699	0.582	1.331	1.554	1.776
-216.231	3.60.40	40	--	60	0.4	--	436	325	1957	87.2	-8.744	16.458	1.127	0.999	0.749	0.998	1.202	2.128
-53.624	4.70.00	30	70	--	0.0	--	410	278	2173	93.8	-10.122	17.636	1.232	--	0.312	5.358	--	--
-53.624	4.70.20	30	70	--	0.2	--	355	179	2062	86.7	-9.033	16.893	1.283	0.374	0.437	5.108	--	--
-53.624	4.70.40	30	70	--	0.4	--	302	084	1922	82.9	-7.892	16.205	1.320	0.749	0.562	4.859	--	--
-86.346	7.2625.675.00	65	26.25	8.75	0.0	--	944	1240	3260	141.80	-23.107	18.680	1.2118	--	0.6761	3.2180	1.4570	--
-86.346	7.2625.875.20	65	26.25	8.75	0.2	--	824	1024	3162	136.67	-21.467	16.972	1.2472	0.8114	0.9465	2.6771	1.4570	--
-86.346	7.2625.875.40	65	26.25	8.75	0.4	--	704	808	3021	129.93	-19.403	15.545	1.2862	1.6228	1.2169	2.1563	1.4570	--
-116.295	7.275.275.00	45	27.5	27.5	0.0	--	518	473	2395	105.65	-12.828	18.244	1.2823	--	0.4681	3.4868	1.3264	--
-116.295	7.275.275.20	45	27.5	27.5	0.2	--	418	293	2132	94.74	-15.184	19.522	1.3109	0.5617	2.3402	3.1121	1.4863	0.1001
-143.861	7.325.325.00	35	32.5	32.5	0.0	--	416	294	2064	92.14	-9.756	18.076	1.1945	--	0.3640	3.3643	0.9252	0.8787

previous calculations. It is interesting to note the abrupt changes in the slopes of the curves in Figures 3 and 3a. These changes are assumed to be due to the (theoretical) condensation of water in the chamber.

HYDRAZINE - WATER SYSTEM

CHAMBER TEMPERATURE VS % H_2O
FOR VARIOUS AMMONIA DISSOCIATION

HYDRAZINE - WATER SYSTEM

CHAMBER TEMPERATURE VS % H_2O FOR VARIOUS AMMONIA DISSOCIATION

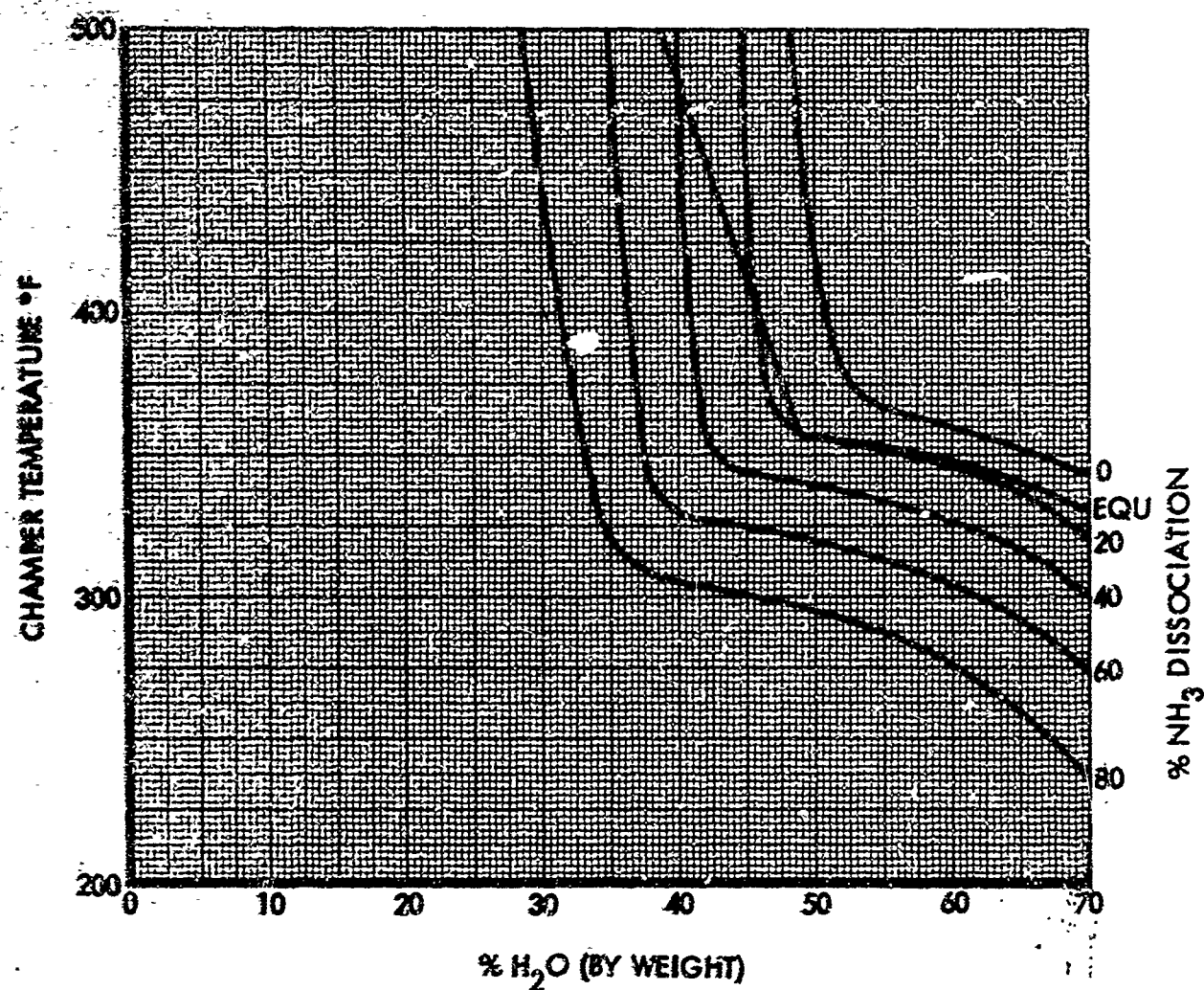


FIGURE 3c

SECTION III

PROPELLANT CHARACTERIZATION

3.1 Preliminary Evaluation

Preliminary testing was conducted to generate information required in the selection of solutions for further study.

Solutions with various concentrations of hydrazine, ammonia and water were sealed in heavy-wall, glass tubing and the freezing points of the solutions were determined. The compositions and freezing points of these solutions are listed in Table VI. Figure 16 illustrates this information and includes the freezing point curve for the hydrazine-water system taken from the work of Hill and Sumner (Reference 4).

It is interesting to note that solutions having a water to ammonia ratio (by weight) larger than one have lower freezing points than solutions containing only water and hydrazine at the same percent additive. Solution GT-5 would not freeze at -110°F although it was packed in dry ice overnight. This solution was also cooled in liquid nitrogen, but a glass-like material resulted and no freezing point was observed.

Although it was considered unlikely that any phase separation would occur, the samples numbered GT-1 through 5, 8, and 11, which were used for the freezing point determinations, were placed in individual lucite tubes and then placed in a temperature-controlled oven. The door of the oven was replaced by a lucite plate, and the temperature was increased in small increments up to 160°F . Each temperature was held constant for at least one-half hour, and the samples were held at 160°F overnight. A light was placed behind the samples to facilitate viewing. The samples were observed visually, and no evidence (such as opalescence or a second liquid layer) or the appearance of a second liquid phase was observed.

It may be concluded, therefore, that hydrazine, ammonia, and water are completely miscible at temperatures from the freezing point up to 160°F and over the concentration range of interest for this study.

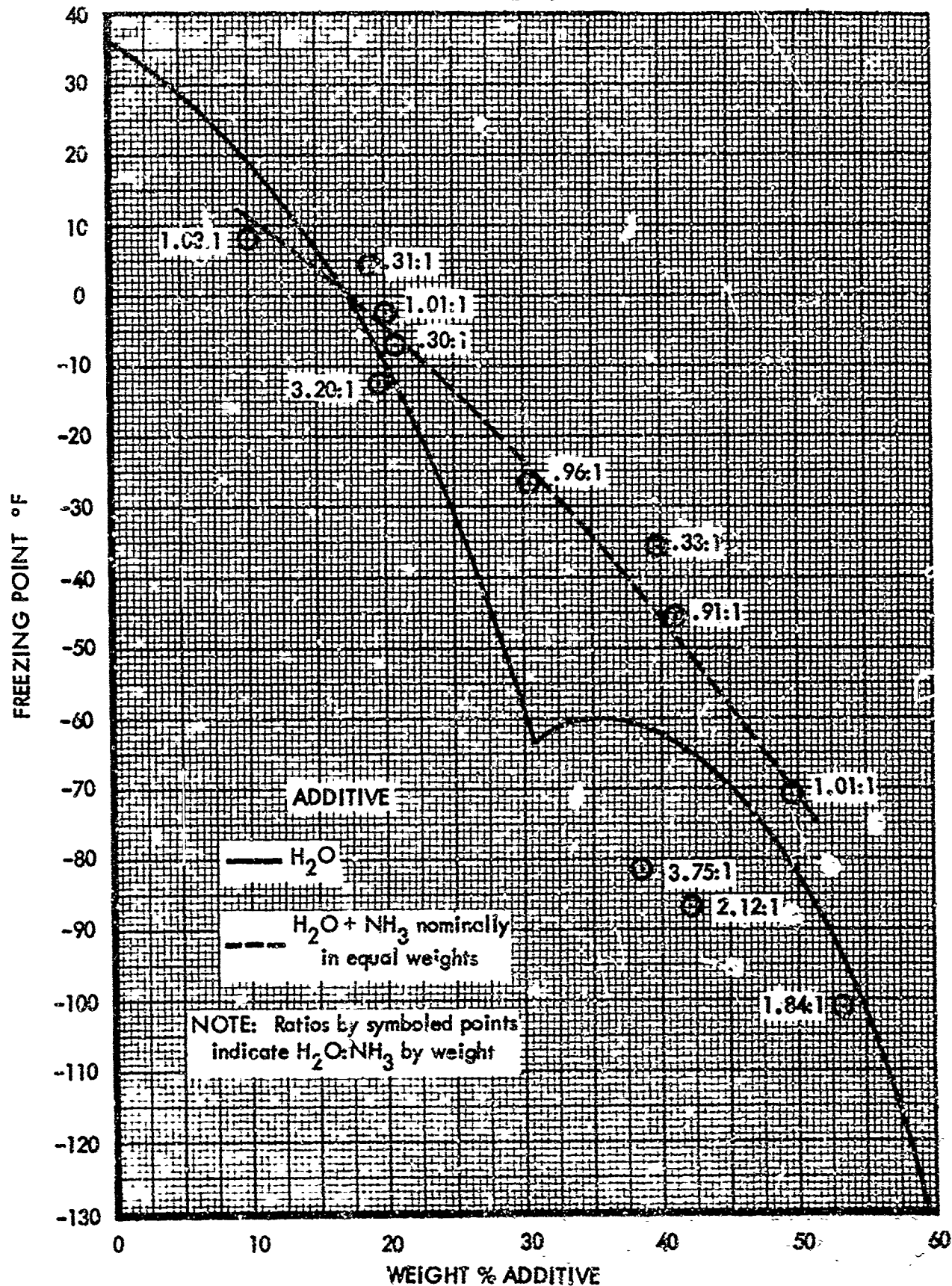
The vapor pressure of two hydrazine, water, and ammonia solutions was measured at various temperatures. This information is illustrated in Figures 17 and 18.

The methods used for these measurements is described in Paragraph 3.3.

TABLE VI
COMPOSITION AND FREEZING POINTS OF
HYDRAZINE-AMMONIA-WATER SOLUTIONS

Solution Designation	Weight Percent			Freezing Point °F
	H ₂ O	NH ₃	N ₂ H ₄	
GT-1	4.51	14.34	81.15	+4
GT-2	30.50	8.14	61.36	-82
GT-3	19.62	21.50	58.87	-46
GT-4	14.92	15.47	69.61	-27
GT-5	30.55	28.71	40.74	<-110
GT-6	5.03	4.87	90.10	+8
GT-7	10.01	9.92	80.07	-3
GT-8	25.08	24.76	50.16	-71
GT-9	34.70	13.82	46.48	-101
GT-10	28.71	13.53	57.76	-87
GT-11	4.78	15.97	79.25	-7
GT-12	14.89	4.66	80.45	-13
GT-13	9.88	29.96	60.16	-36

FREEZING POINT VS WEIGHT % ADDITIVE FOR VARIOUS N_2H_4 SOLUTIONS



VAPOR PRESSURE VS. TEMPERATURE
29.89% H₂O, 30.07% NH₃, 40.04% N₂H₄

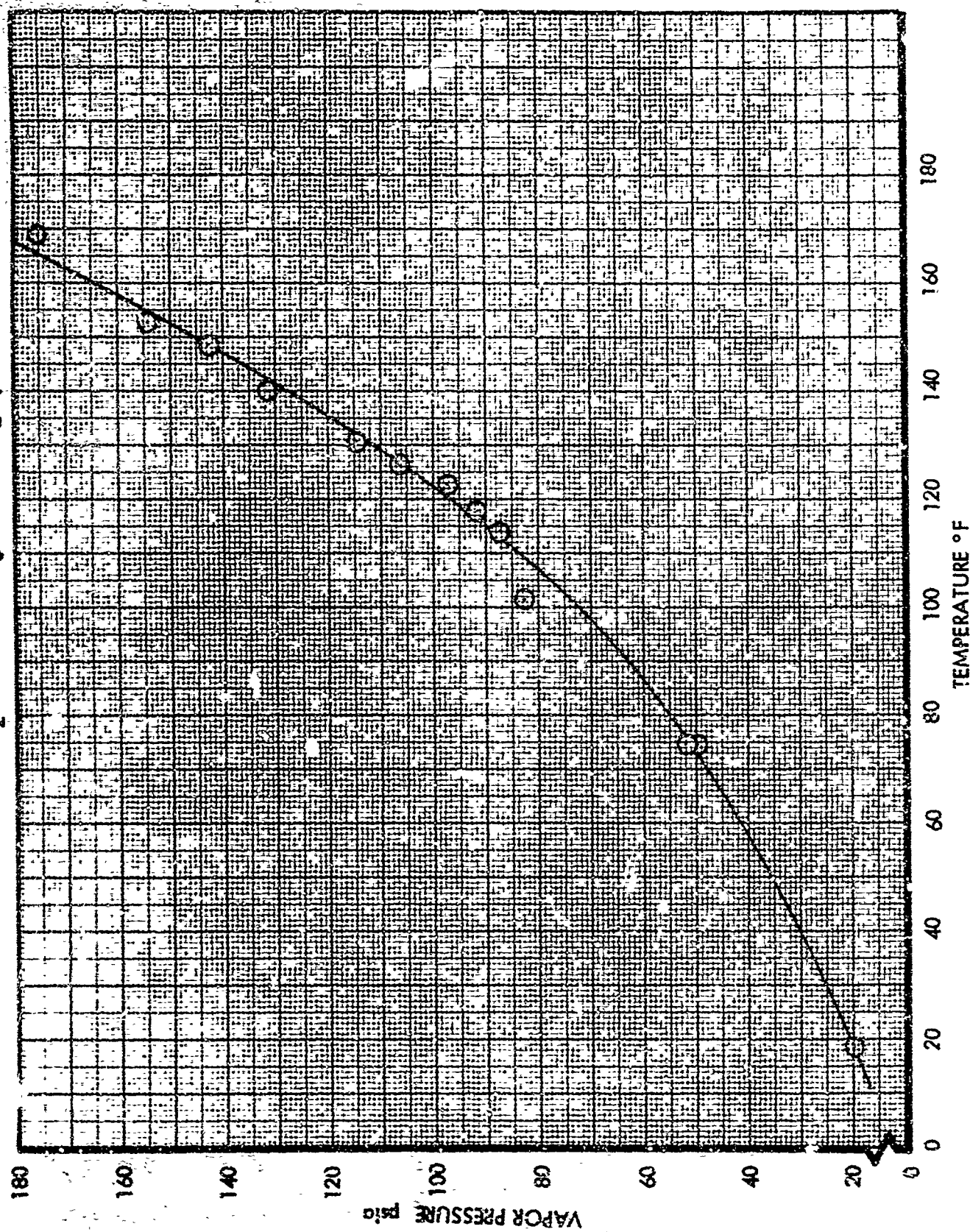
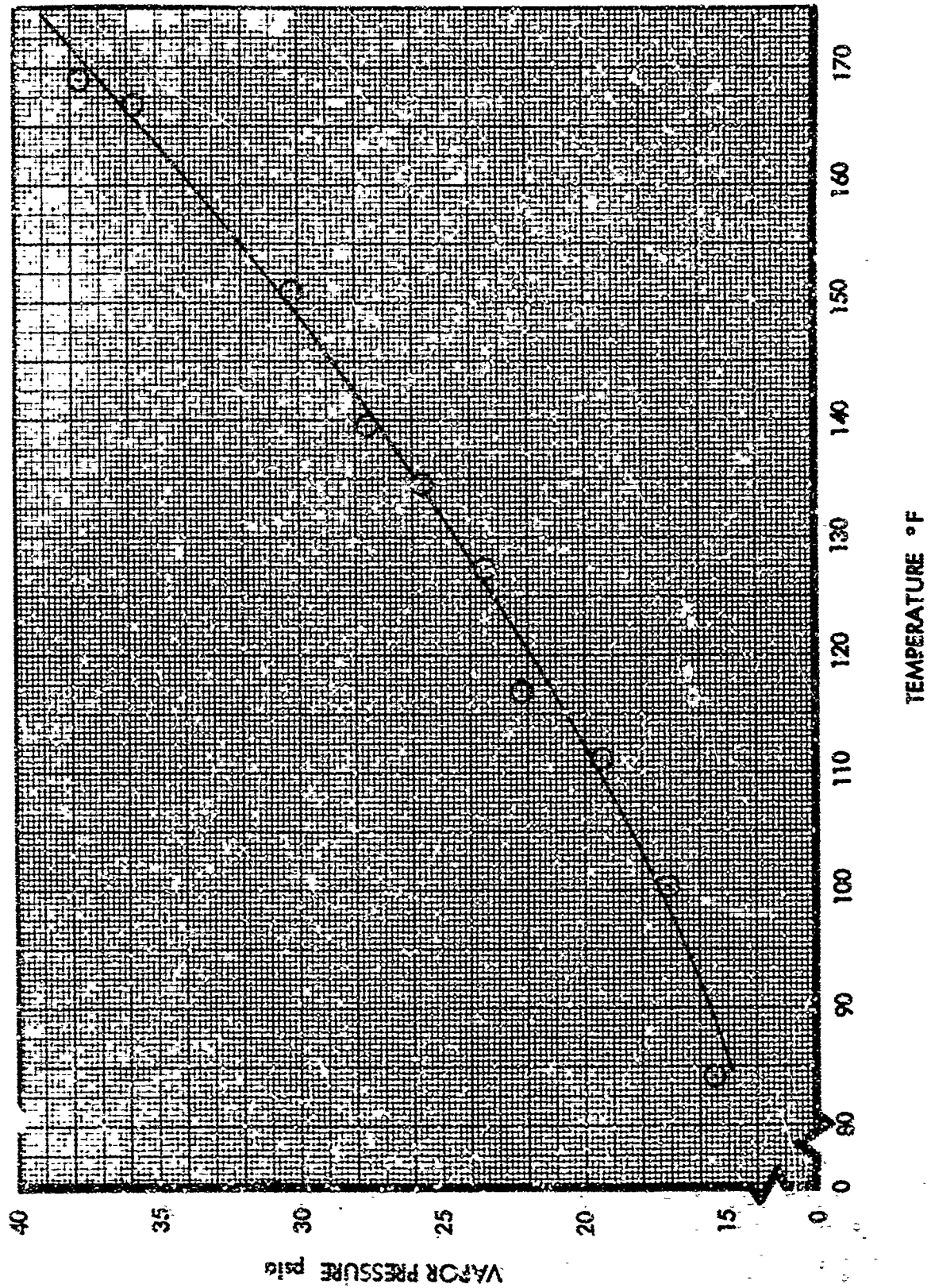


FIGURE 17

VAPOR PRESSURE VS TEMPERATURE
60.06% H₂O, 9.87% NH₃, 30.07% N₂H₄



3.2 Selection of Propellants

After consideration of the thermochemical calculations and the information described in Paragraph 3.1, seven low temperature gas generator propellants were selected for further evaluation. The physical properties of these propellants were measured as a function of temperature, and their performance was determined in reactor firings.

The compositions of the solutions were chosen in order to provide estimated chamber temperatures over the range of 275°F to 925°F, to have low freezing points, and to provide data on a variety of propellant compositions. The compositions, estimated chamber temperatures, and measured freezing points are listed in Table VII.

3.3 Physical Properties Determinations

3.3.1 Preparation of Propellants

Anhydrous hydrazine obtained from Olin Chemicals was analyzed by the J. M. Kniseley Engineering Company, Seattle, Washington, and the results of the analysis were utilized in calculating the concentration of water in the solutions which were mixed.

Ammonia, obtained from the J. T. Baker Chemical Company and specified as 99.99% ammonia, was used as received.

For the preparation of solutions to be used for freezing point determination, glass tubes approximately 10 inches long were prepared from tubing having an inside diameter of 8 mm and a wall thickness of 1.5 mm. The tubes were sealed on one end and a constriction was placed approximately two inches from the open end by heating the tube until the walls softened and collapsed, leaving a passageway of approximately 2 mm.

After weighing the empty glass tube on an analytical balance, the appropriate amount of hydrazine-water solution was placed in the lower part of the tube by means of a micropipet and the tube was then reweighed. The tube was then attached to the vacuum manifold by means of a short rubber vacuum tube. The hydrazine water solution was frozen by immersing the tube in liquid nitrogen and the tube was evacuated. Ammonia was then metered into the vacuum manifold to slightly less than atmospheric pressure as indicated by a mercury manometer. The vacuum manifold has two, one-liter flasks attached by stopcocks so that either one, or both, flasks

TABLE VII
COMPOSITIONS OF SELECTED LOW TEMPERATURE
GAS GENERATOR PROPELLANTS

Solution No.	Composition % by Weight			Estimated Chamber Temp. °F	Measured Freezing Point °F
	N ₂ H ₄	H ₂ O	NH ₃		
LT-1	69.3	30.7	---	925	-64
LT-2	45	27.5	27.5	500	-80
LT-3	35	32.5	32.5	275	-104
LT-4	40	60	---	350	-130
LT-5	51	49	---	500	-80
LT-6	30	---	70	300	-75
LT-7	65	26.25	8.75	900	-57

can be included in the volume of the manifold. The manifold volume was calibrated by absorbing ammonia in water and noting the increase in weight of the solution and the decrease in pressure within the manifold. The pressure change required to deliver the desired amount of ammonia was calculated, and the ammonia was then condensed into the glass tube by cooling with liquid nitrogen. The tube was then sealed off, and both parts were weighed after the tube warmed to room temperature. The actual amount of ammonia in the solution was, therefore, determined by weight.

Solutions which were mixed in larger quantities for vapor pressure, viscosity, and density measurements were prepared in stainless steel cylinders. The hydrazine-water solution was drawn into an evacuated, weighed cylinder which was then reweighed to determine the exact amount of solution. Slightly more than the calculated amount of ammonia required for the solution was then condensed into a separate cylinder. The exact weight of ammonia was then adjusted, after warming to room temperature, by alternately bleeding off ammonia and weighing the cylinder. The weighings were performed on a Mettler precision top-loading scale capable of weighing to ± 0.02 gm. The hydrazine-water solution was then frozen in liquid nitrogen and the ammonia was condensed into the solution cylinder. After warming to room temperature, the solution was mixed by vigorous shaking.

3.3.2 Freezing Point Determinations

The freezing points of the solutions containing ammonia were determined by the technique described below.

An acetone cold-bath was prepared in a large, clear-glass Dewar flask. A spark-proof stirrer provided the agitation necessary to keep an even temperature throughout the bath. The sample tube was handled by means of a small apparatus clamp with vinyl fingers. The sample was partly frozen by immersing in a separate dry ice bath and then was completely immersed in the large cold-bath. The tube was then rocked back and forth by hand and the crystals were viewed, with the aid of a strong light, through the walls of the clear Dewar flask. If the crystals melted, the bath was cooled by adding dry ice and the process was repeated. If the solution continued to freeze, the bath was warmed slightly by a small immersion heater. The freezing point was thus bracketed, and the process was repeated until the freezing point was determined as accurately as required. The freezing point is defined as the temperature at which

the last solid disappears upon slowly warming the solution. Due to the large volume of the acetone bath (approximately four gallons) the temperature changes very slowly when adding dry ice or heating and it is possible to control the temperature easily to a small range. The accuracy of freezing points determined by this method is believed to be about $\pm 0.5^{\circ}\text{F}$ for temperatures down to about -60°F and about $\pm 1.0^{\circ}\text{F}$ for lower temperatures. All thermometers used in these tests were certified to conform to ASTM Standards.

The solutions containing 27.5 and 32.5 per cent ammonia exhibited a marked tendency to supercool and considerable difficulty was experienced in freezing the solutions. Crystallization of both solutions was accomplished, however, and the freezing points were obtained by observing the disappearance of the last crystals upon slowly warming the solutions.

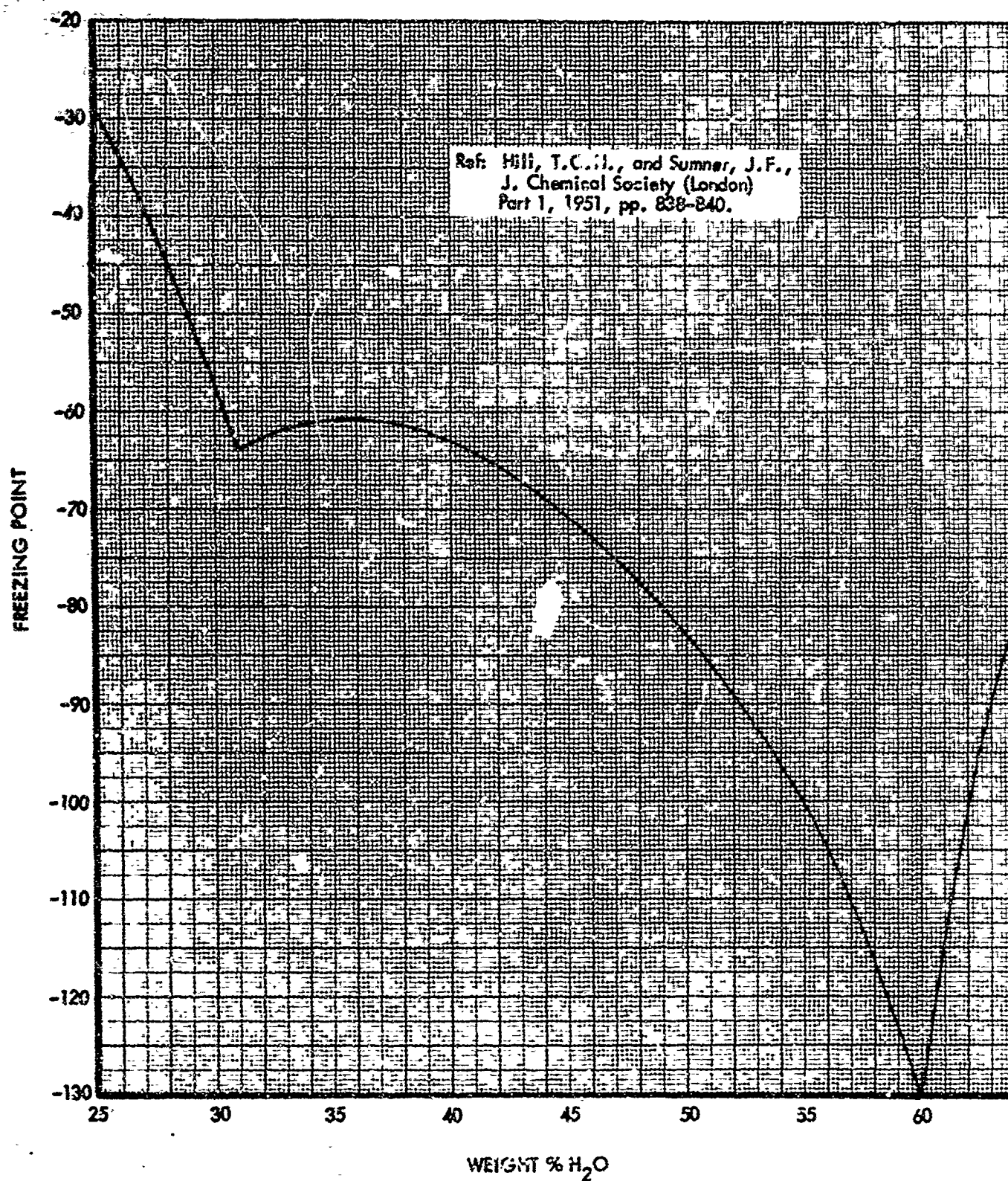
Freezing points of the solutions containing only hydrazine and water were taken from the data of Hill and Sumner (Reference 4). A part of their data was plotted on an expanded scale as shown in Figure 19, and the freezing points were taken from this graph.

3.3.3 Vapor Pressure Measurements

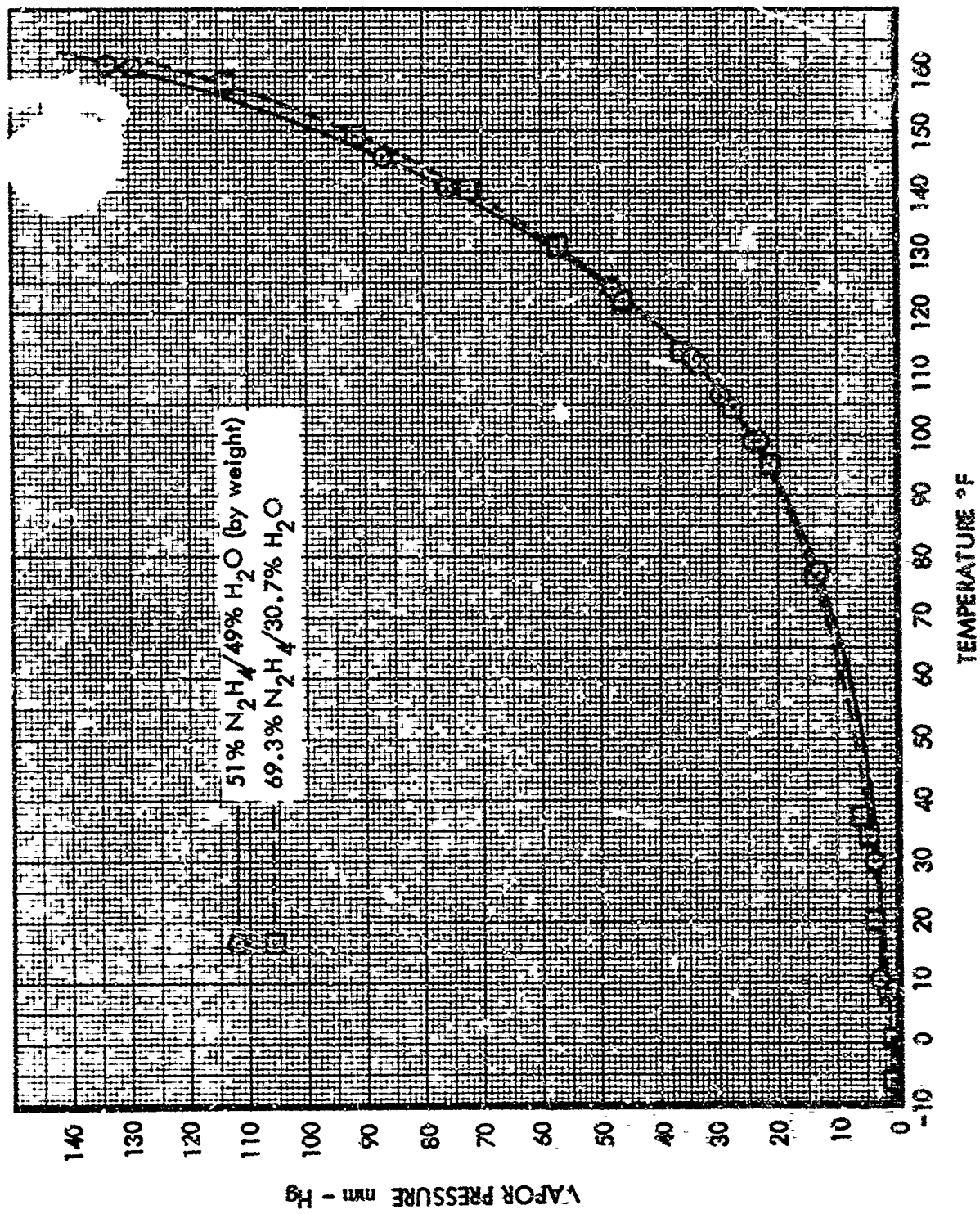
The vapor pressures of the solutions containing only hydrazine and water were measured in an all-glass apparatus consisting of a glass bulb, which holds the solution, connected to a short mercury manometer. The mercury was degassed by heating with a hand torch while evacuating the system. The solution was then added to the bulb and degassed by a freeze-evacuate-thaw-procedure which was repeated three times; the apparatus was then sealed while being evacuated. The complete apparatus was then immersed in a controlled temperature bath, and the mercury level was read by means of a cathetometer. The results of these measurements are shown in Figures 20 and 21.

The vapor pressures of the solutions containing ammonia were measured by means of a 0-300 psi, temperature compensated, Heise pressure gauge. The stainless steel cylinder containing the solution was connected to the pressure gauge through a 0.25 inch stainless tube and tee. The other end of the tee was closed by a small valve through which the apparatus, except for the cylinder, was evacuated. For temperatures below ambient, the cylinder was immersed in a cold bath and, at

FREEZING POINT VS WEIGHT % H_2O
FOR $N_2H_4 + H_2O$ SOLUTIONS



TEMPERATURE EFFECT ON VAPOR PRESSURE
OF $N_2H_4 + H_2O$ SOLUTIONS



TEMPERATURE EFFECT ON VAPOR PRESSURE
OF 40% N_2H_4 /60% H_2O

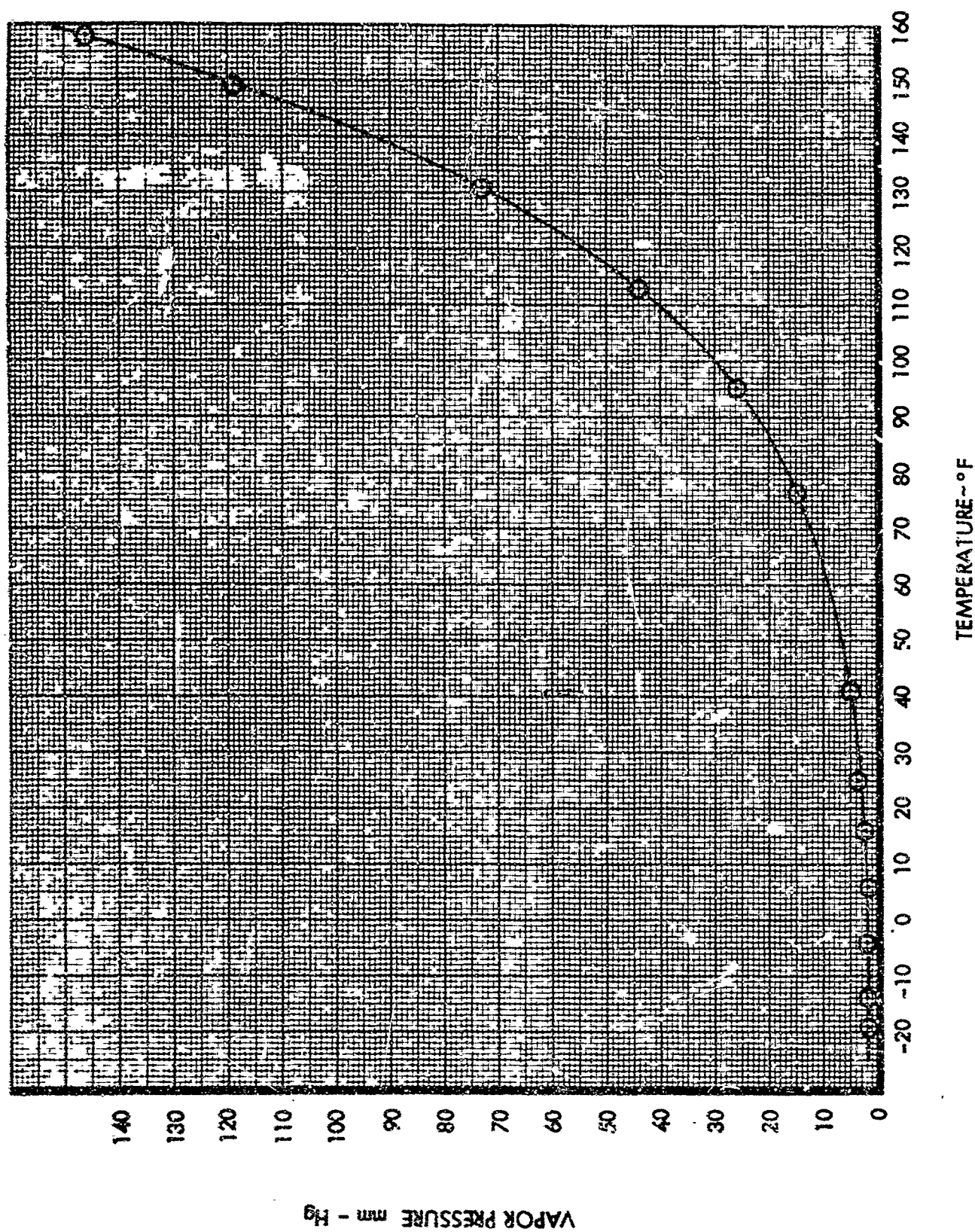


FIGURE 21

each temperature, was shaken until the pressure remained constant. For temperatures above ambient, the cylinder and pressure gauge were placed in a temperature controlled oven which is capable of maintaining the temperature constant to within $\pm 1^\circ\text{C}$. The temperature was increased in increments and was held constant at each temperature until the pressure remained constant for at least 15 minutes. The vapor pressures of the solutions containing ammonia are illustrated in Figures 22 and 23.

3.3.4 Viscosity Measurements

Viscosity measurements were performed on solutions containing only hydrazine and water by using Cannon-Fenske glass capillary viscometers. The measurements were conducted according to ASTM Standard Test Method D445-64-IP71. The viscometers were calibrated by the Cannon Instrument Company, State College, Pennsylvania.

The above method is not adequate for measuring the viscosity of solutions containing ammonia because of the higher vapor pressures which necessitated devising a new technique for these measurements. The apparatus, shown schematically in Figure 24, is an adaptation of the conventional rolling-ball viscometer. The viscometer consists, essentially, of a heavy-wall glass capillary tube with a small steel sphere which rolls down the inclined tube. The sphere is pulled to the top of the tube by means of a small magnet and then released. The time of travel of the sphere between two marks on the tube is measured by a stopwatch. The tube is held at a reproducible angle by a special clamp. This viscometer was calibrated with distilled water and a standard oil obtained from the Cannon Instrument Company.

The viscometer is loaded by a gravity flow arrangement shown schematically in Figure 25. The viscosities of the various solutions are illustrated in Figures 26, 27, and 28.

3.3.5 Density Measurements

Density measurements were run on the solutions containing only hydrazine and water by using the Lipkin Bicapillary pycnometer as specified in ASTM Standard Test Method D941-55. This method is not adequate for the solutions containing ammonia due to the higher vapor pressures and another technique was used.

A new pycnometer was fabricated which is similar to the Lipkin Bicapillary pycnometer except that heavy-wall glass capillary tubing was used and the ends of

TEMPERATURE EFFECT ON VAPOR PRESSURE
OF 65.0% N_2H_4 , 26.25% H_2O , 8.75% NH_3

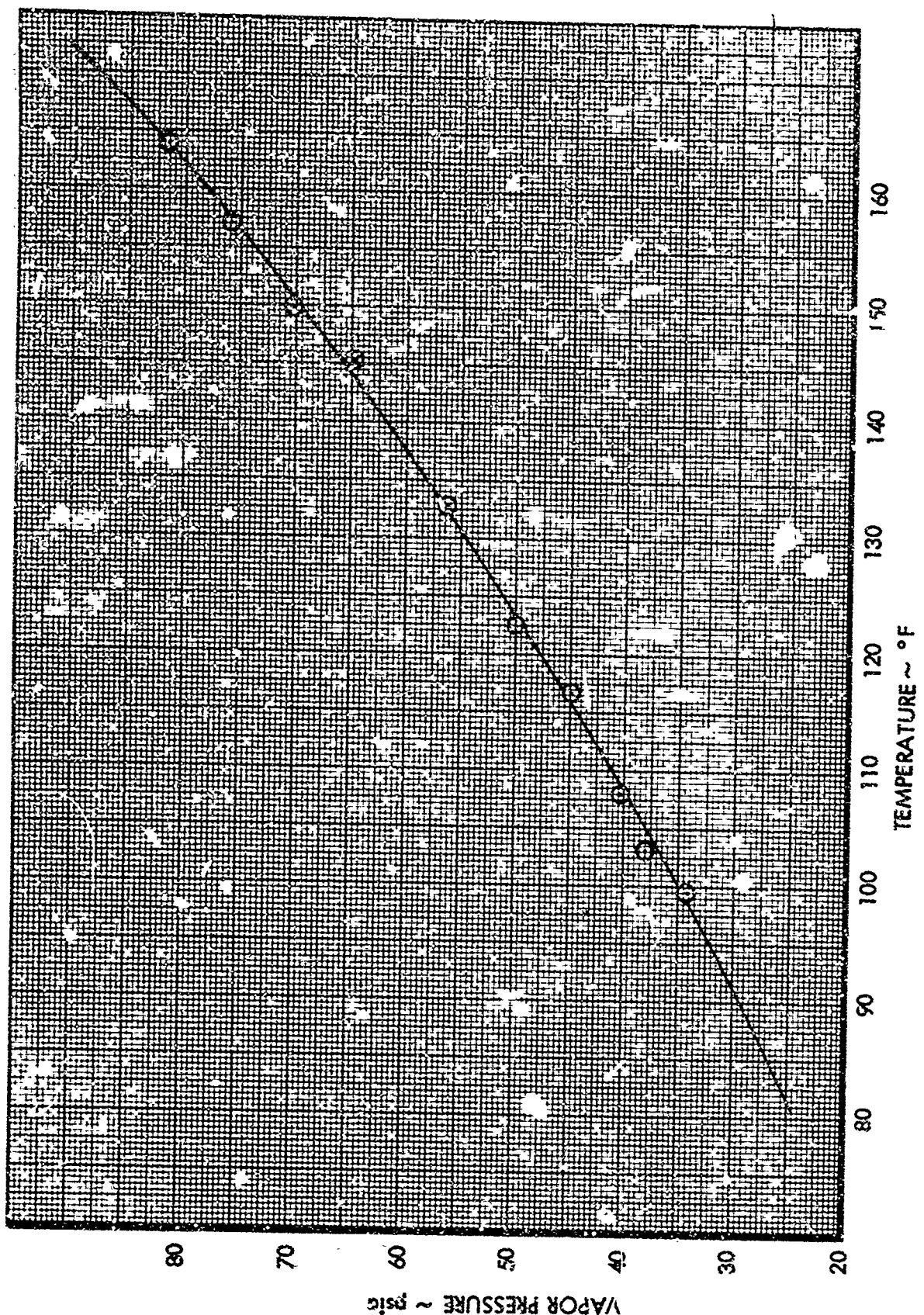
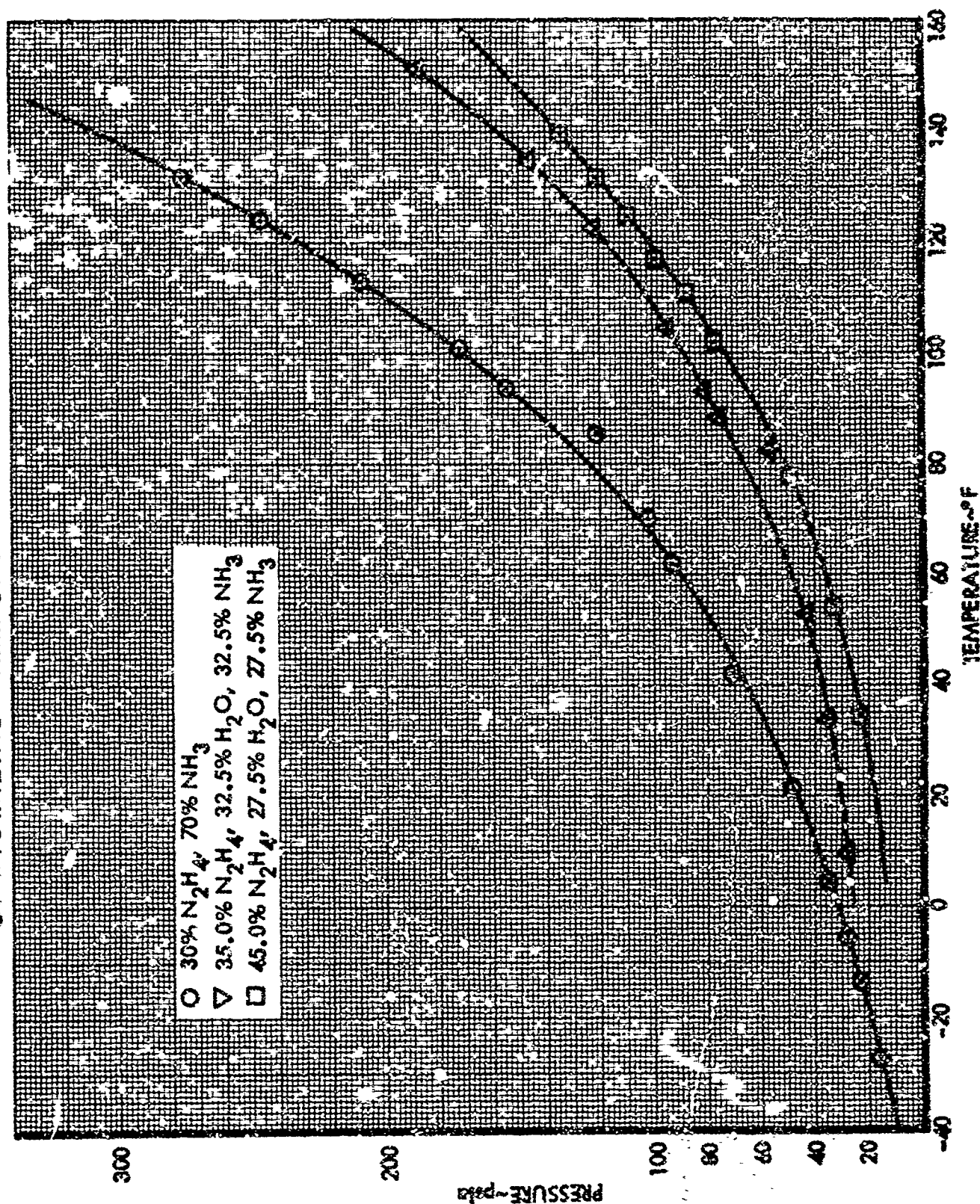


FIGURE 22

TEMPERATURE EFFECT ON VAPOR PRESSURE
OF HYDRAZINE - AMMONIA - WATER SOLUTIONS



ROLLING BALL VISCOMETER

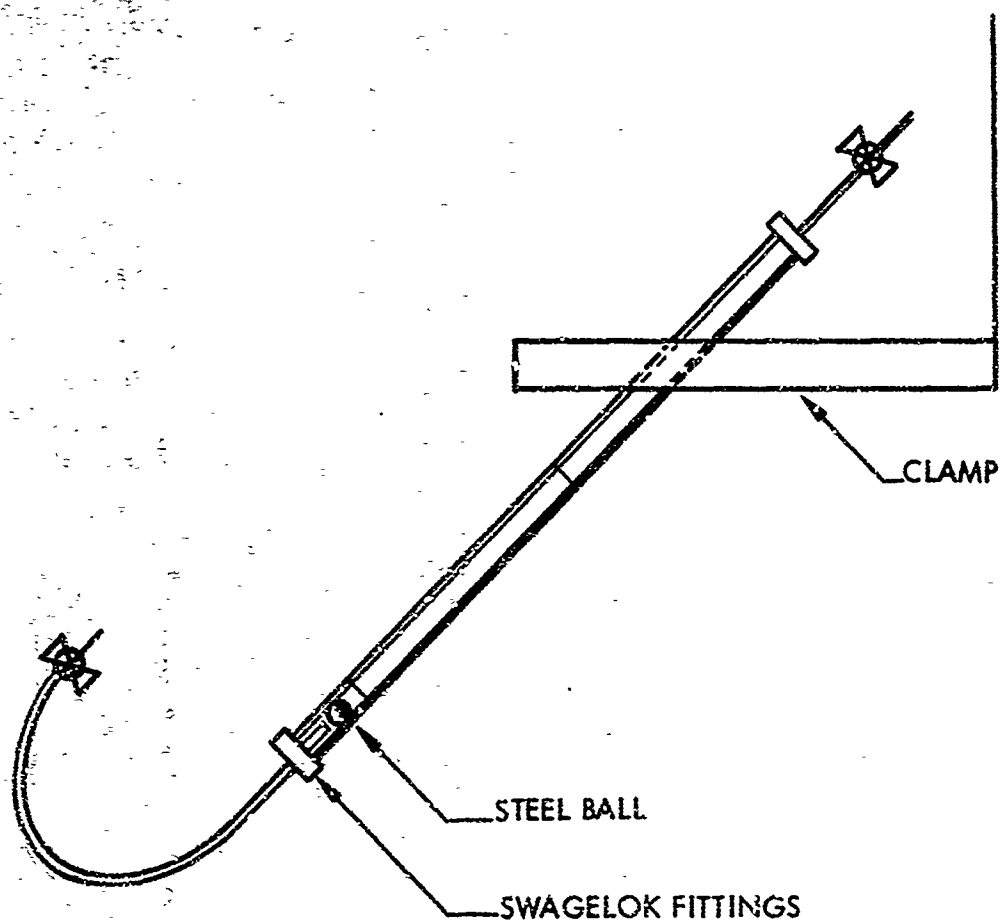
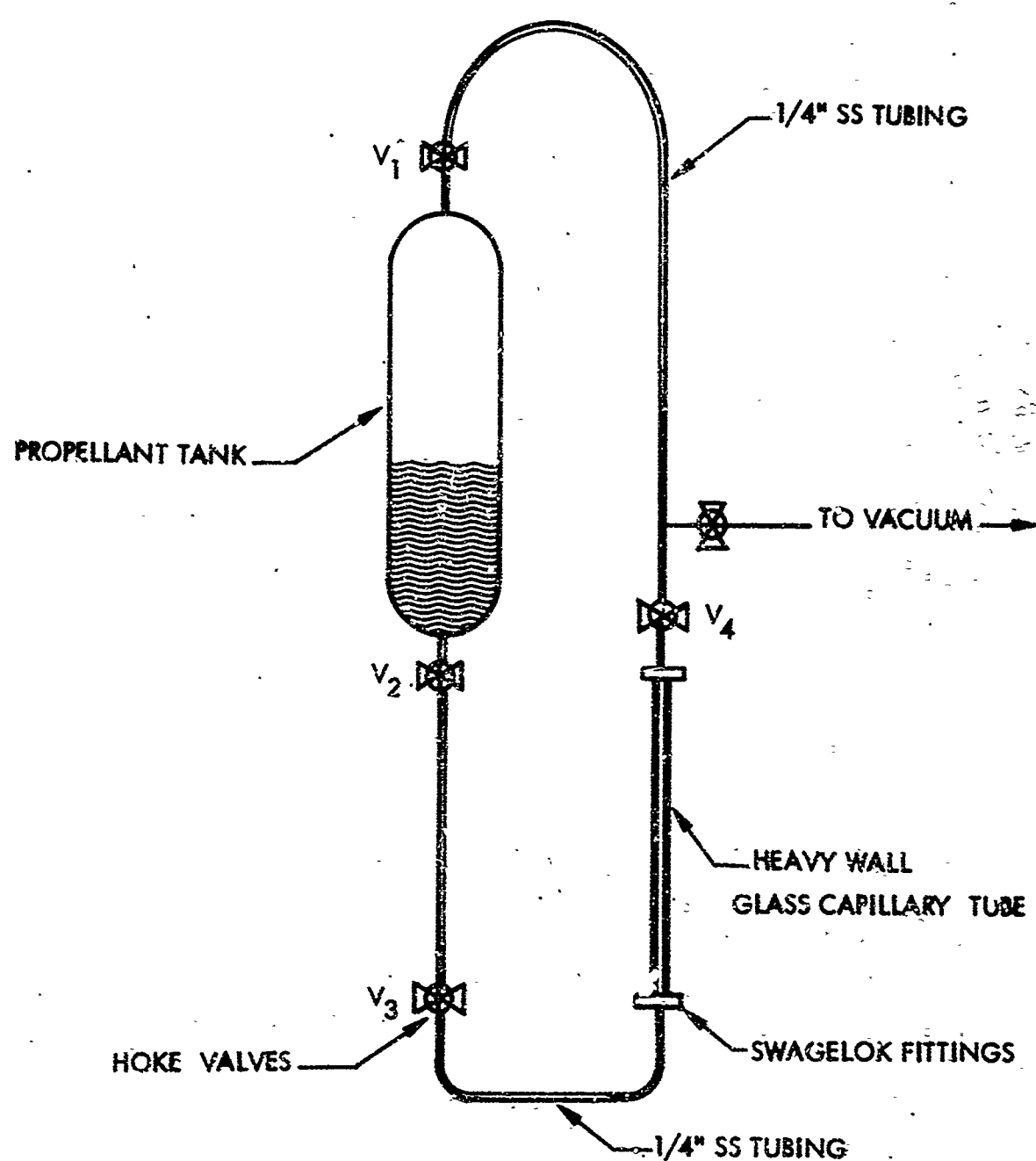


FIGURE 24

VISCOMETER LOADING SCHEMATIC



TEMPERATURE EFFECT ON VISCOSITY OF $N_2H_4 + H_2O$ SOLUTIONS

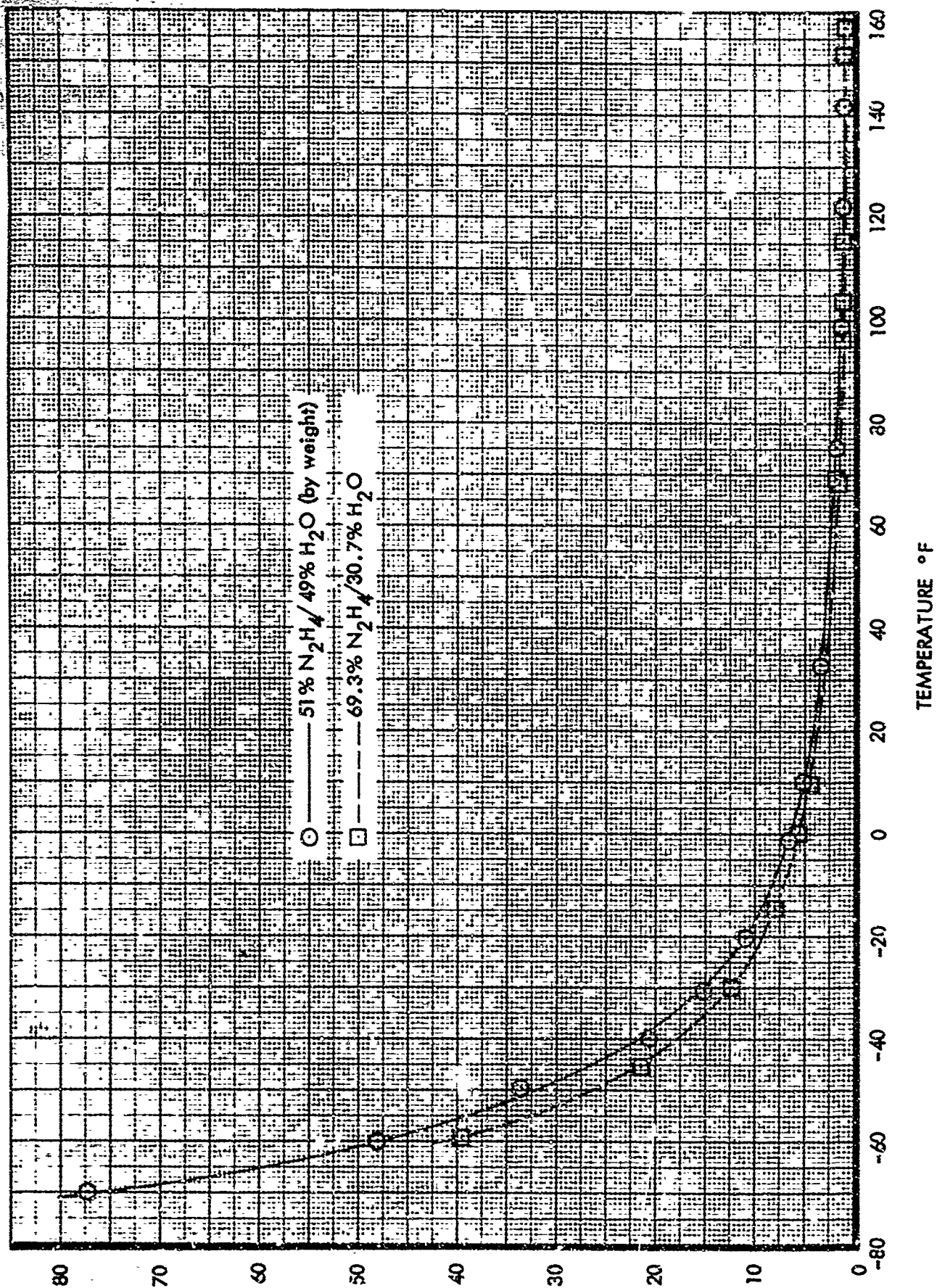


FIGURE 26

30 -
VISCOSITY CENTISTOKES

TEMPERATURE EFFECT ON VISCOSITY OF HYDRAZINE - AMMONIA - WATER SOLUTIONS

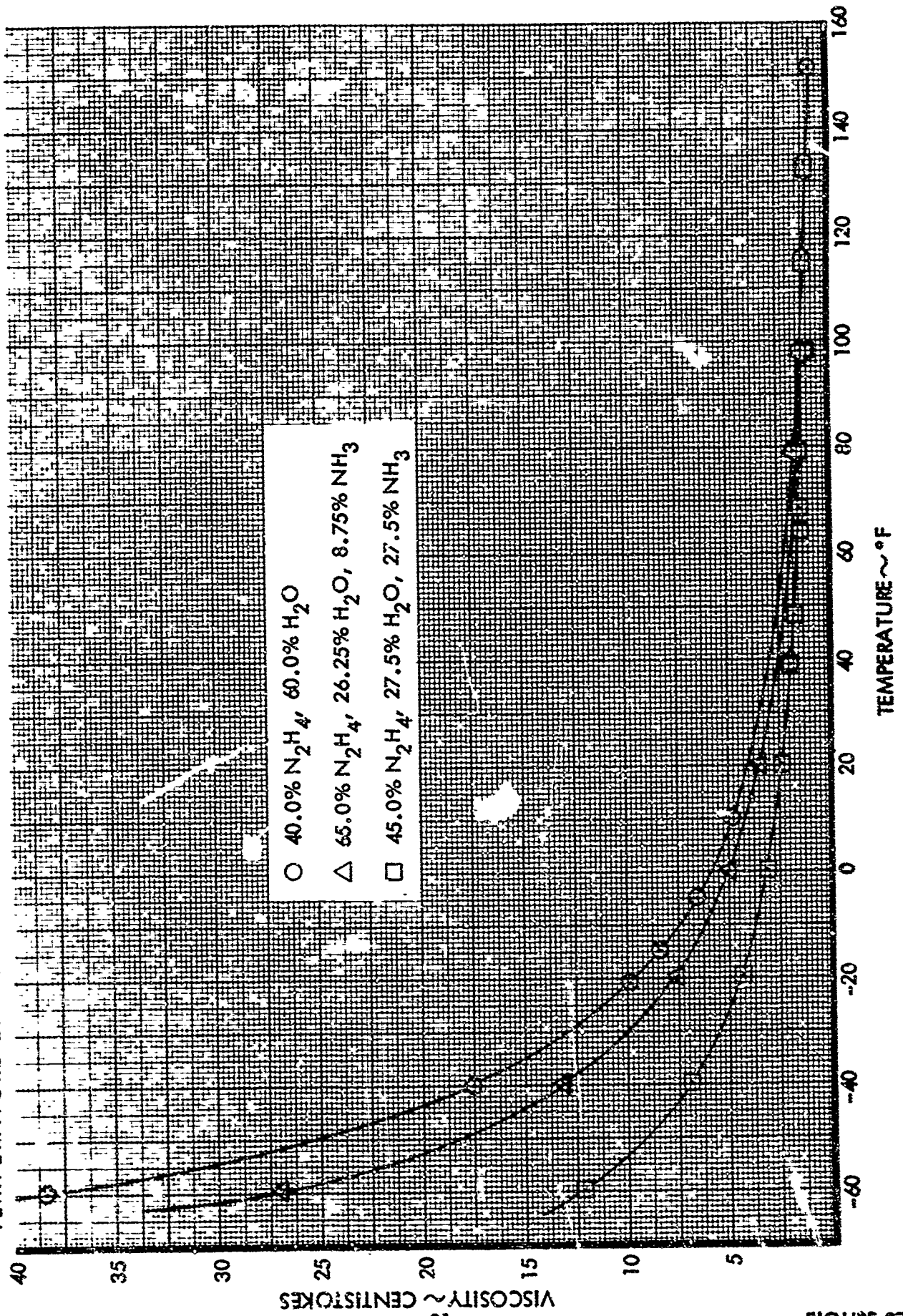


FIGURE 27

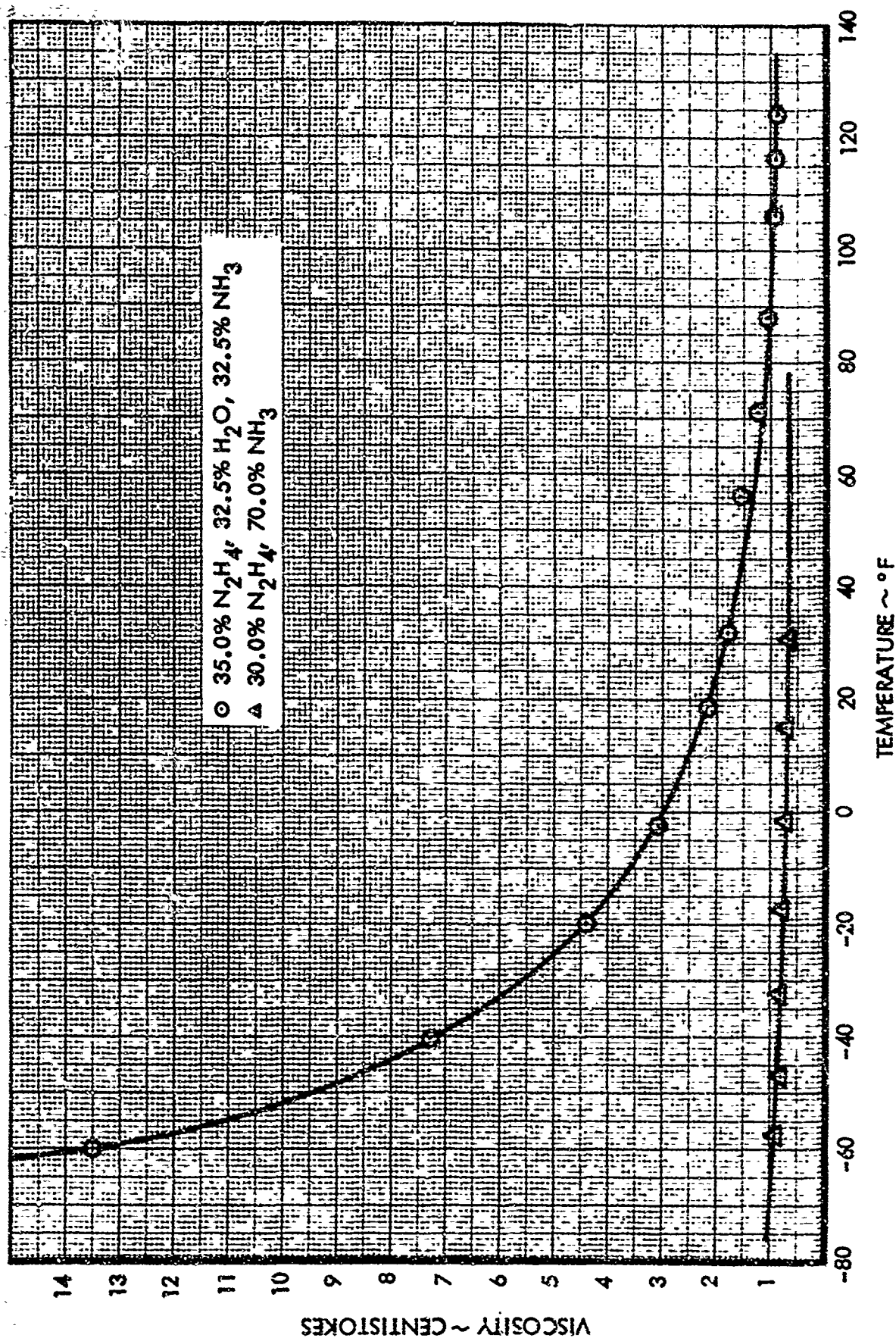
TEMPERATURE EFFECT ON VISCOSITY
OF HYDRAZINE - AMMONIA - WATER SOLUTIONS

FIGURE 28

the capillary tubes were closed by pressure stopcocks. This pycnometer was loaded by the same technique used for the rolling-ball viscometer. The pycnometer was weighed before and after loading and, after thermal equilibrium was established, the liquid level in each arm of the pycnometer was determined by a cathetometer. The pycnometer was calibrated with both mercury and distilled water. This pycnometer was used for the solutions containing 8.75% and 27.5% ammonia. On the latter solution, however, the pressure stopcocks developed leaks at the higher temperatures and the use of this pycnometer was discontinued.

In order to accurately measure the density of the solutions containing 27.5%, 32.5% and 70% ammonia, individual pycnometers were blown from heavy wall glass tubing, and each pycnometer was calibrated with freshly boiled distilled water. The sample was loaded into the pycnometer as before, and after freezing the sample in liquid nitrogen, each arm of the pycnometer was sealed off with a hand torch. As a safety precaution, the pycnometer was then warmed slowly to slightly above room temperature and then cooled to room temperature before weighing. The pycnometers were then immersed in a controlled temperature bath and the liquid level in each arm was determined by means of a cathetometer. It is believed the possible error associated with this method is less than 0.1%. The measured densities are shown in Figures 29 through 33 as a function of temperature.

3.4 Summary of Propellant Physical Properties

The compositions and measured physical properties of the seven selected propellants are summarized in Table VIII.

TEMPERATURE EFFECT ON DENSITY
OF $N_2H_4 + H_2O$ SOLUTIONS

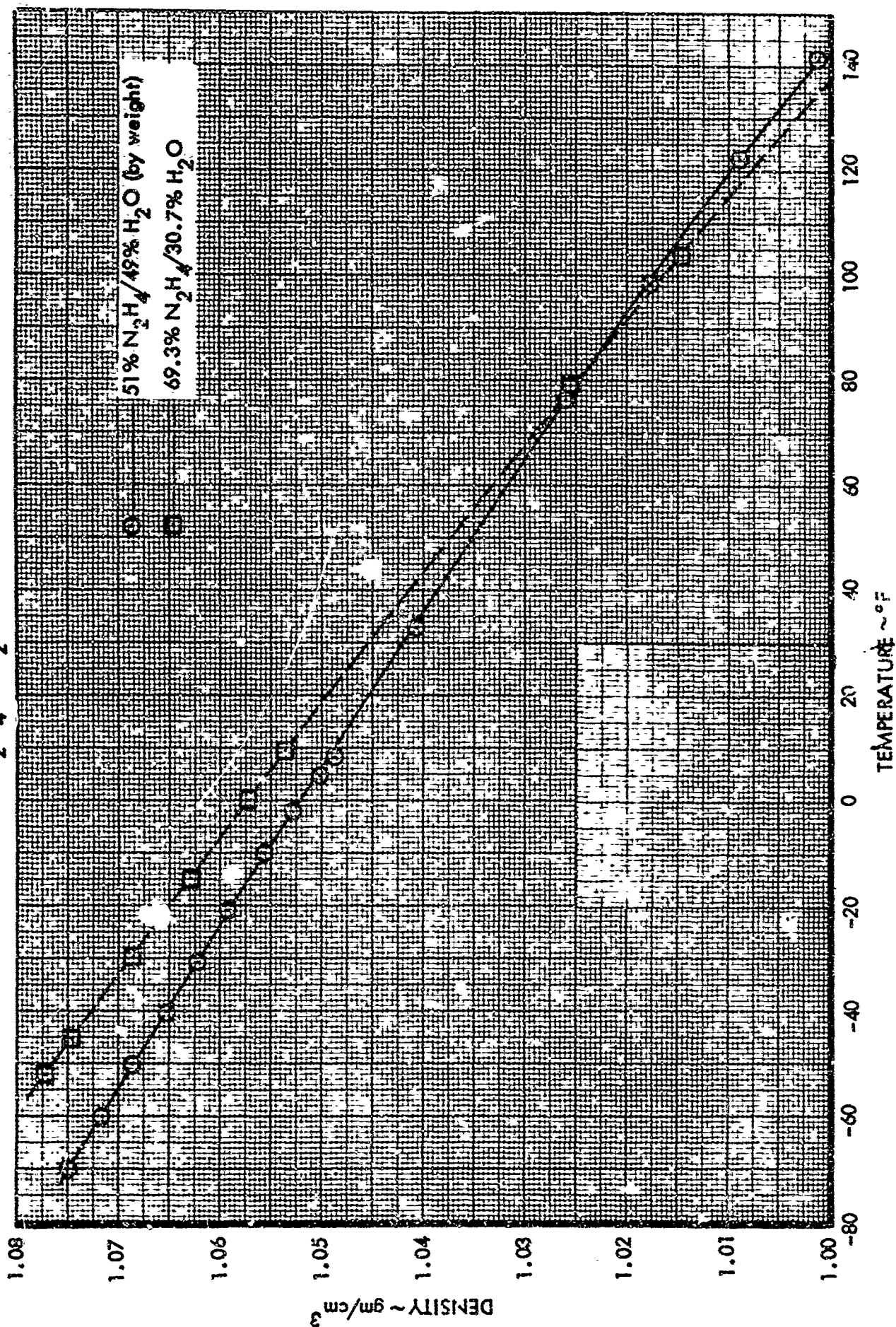
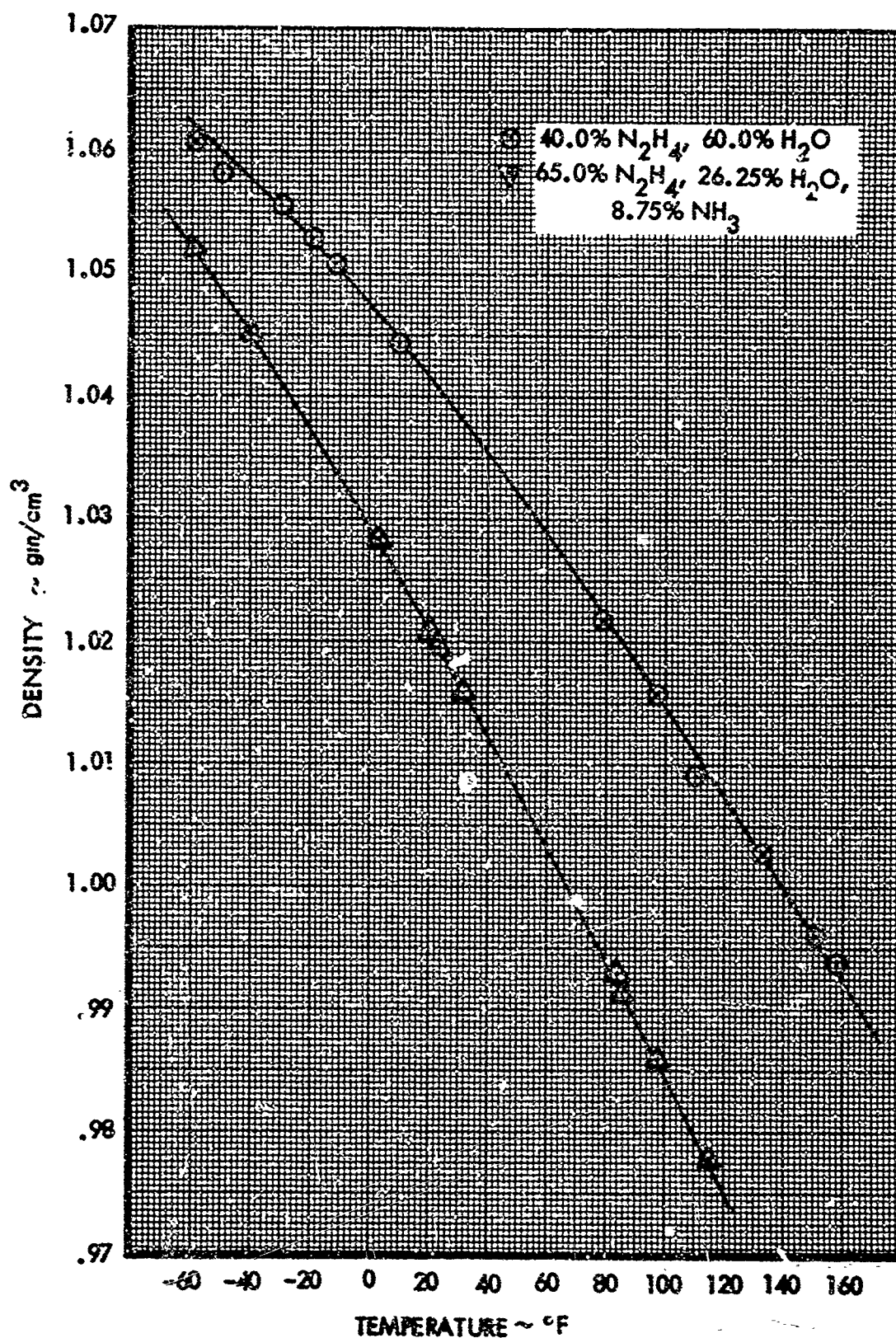


FIGURE 29

TEMPERATURE EFFECT ON DENSITY

40.0% N_2H_4 , 60% H_2O AND 65.0% N_2H_4 , 26.25% H_2O , 8.75% NH_3 

TEMPERATURE EFFECT ON DENSITY
45.0% N_2H_4 , 27.5% H_2O , 27.5% NH_3

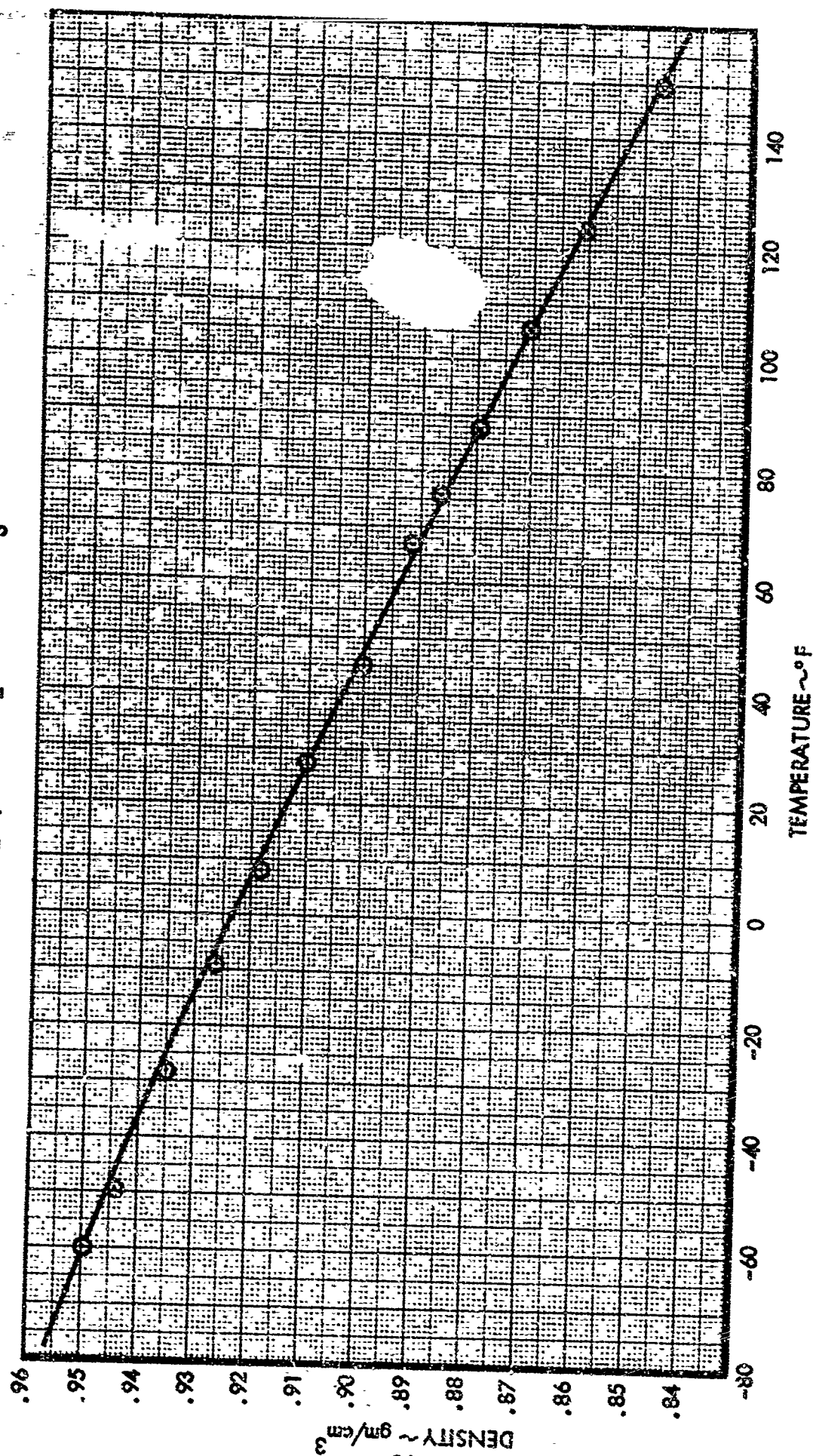
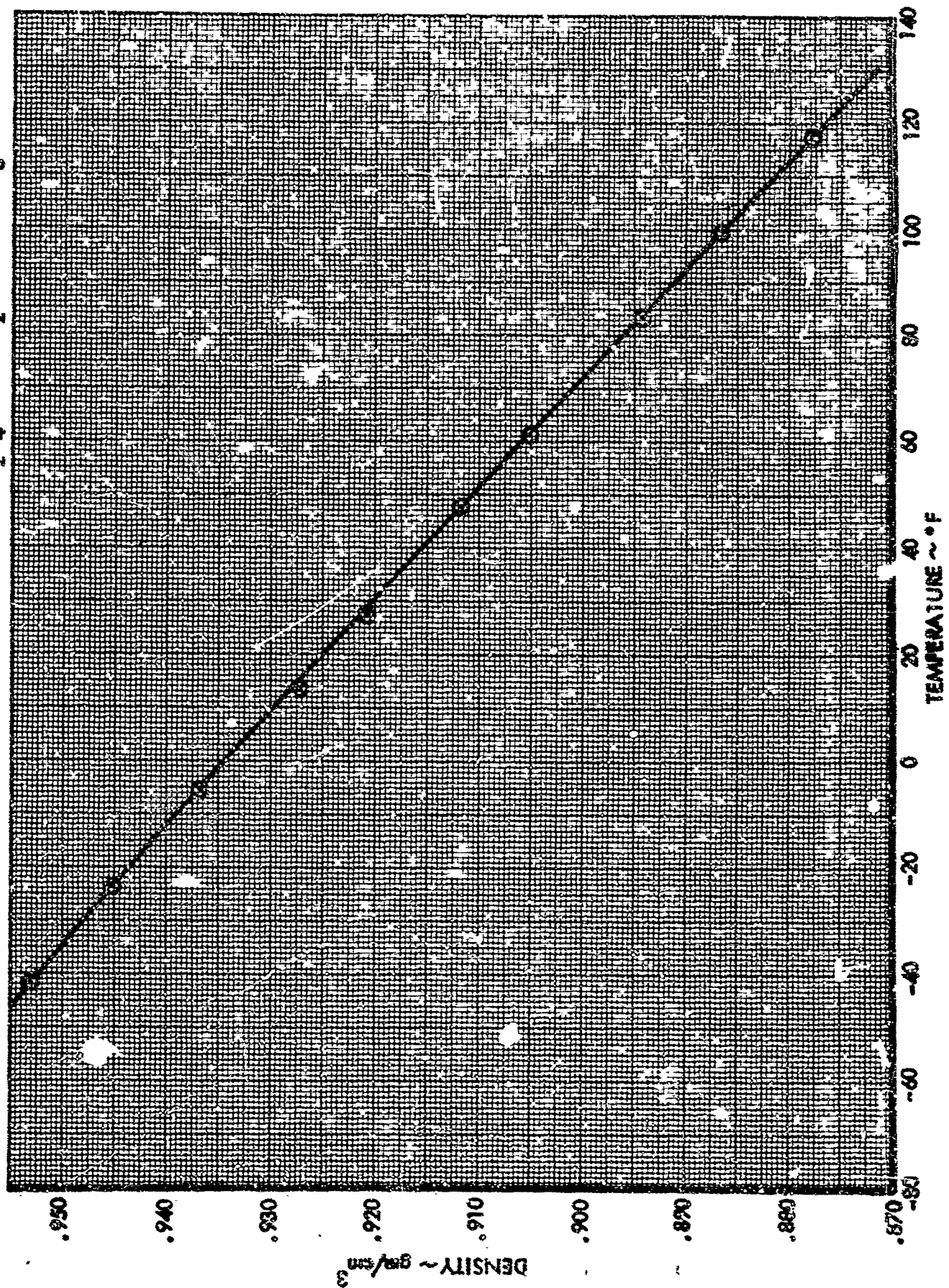


FIGURE 31

TEMPERATURE EFFECT ON DENSITY 35.0% N_2H_4 , 32.5% H_2O , 32.5% NH_3 

TEMPERATURE EFFECT ON DENSITY
30.0% N_2H_4 70% NH_3

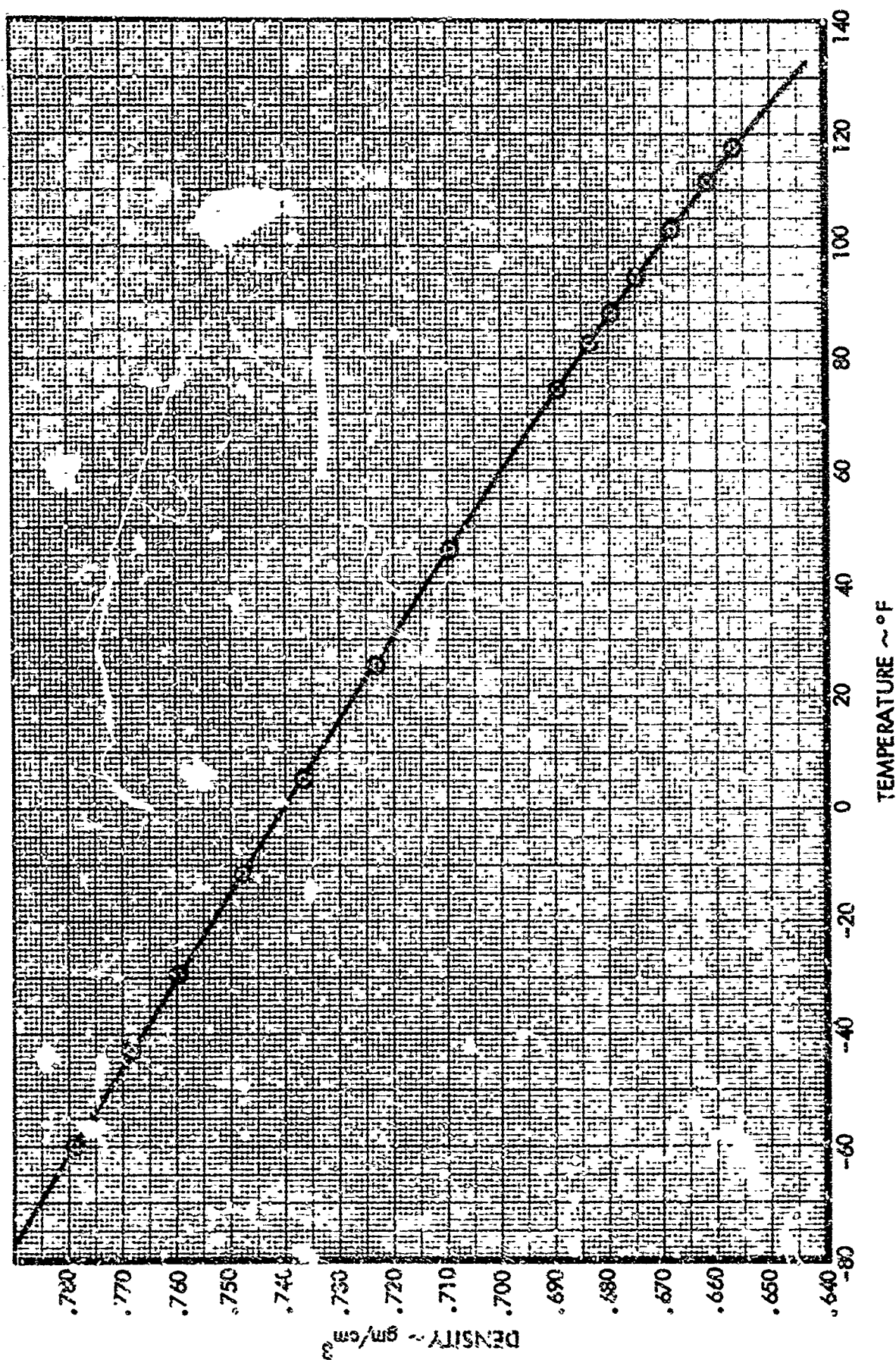


FIGURE 33

TABLE VIII
PHYSICAL PROPERTIES OF LOW TEMPERATURE GAS GENERATOR PROPELLANTS

Wt. % N_2H_4	Wt. % H_2O	Wt. % NH_3	Freezing pt °F	Viscosity Centistokes at °F			Density gm/cm ³ at °F			Vapor Pressure psig at °F		
				120	+70	-60	120	+70	-60	120	+70	-60
69.3	30.7	--	-64	1.0	1.8	40.0	1.008	1.029	1.082	.83	.24	~0
45.0	27.5	27.5	-80	0.9	1.2	12.0	.863	.889	.949	87	28	~0
.0	32.5	32.5	-104	0.9	1.2	13.5	.876	0.901	0.960	103	42	~0
40.0	60.0	--	-130	0.9	1.5	38.3	1.008	1.025	1.064	1.0	.25	~0
51.0	49.0	--	-80	1.0	1.8	48.2	1.010	1.028	1.072	.83	.22	~0
30.0	--	70.0	-75	0.6	0.7	0.9	0.654	0.692	0.779	218	91	~0
65.0	26.25	8.75	-57	1.0	1.5	26.9	.975	.999	1.052	33	7	~0

SECTION IV

REACTOR TEST PHASE

4.1 General

Phase III of this program provided for the design and fabrication of a heavyweight gas generator reactor to be used to evaluate the low temperature gas generator propellants which were selected during Phases I and II. The propellant evaluation firings were to consist of two, sixty-second steady state firings for each propellant. These tasks were completed as described in detail in later sections of this report.

Due to the completion of another contract (NAS 9-5617) by Rocket Research Corporation coincident with the start of Phase III of this contract, it was possible to obtain much more performance data than provided for by the minimum requirements of the contract. In addition to the two steady state firings using the Low Temperature Gas Generator (LTGG) reactor, many firings were made using a 1 lbf thruster unit developed under the NASA contract. The 1 lbf thruster was operated for 70 pulses of varying pulse width and duty cycle on the seven selected propellant mixes, thereby providing much valuable information on the operating characteristics of the low temperature propellants.

4.2 Gas Generator Design

An assembly drawing of the gas generator is shown in Figure 34. The gas generator consists of three basic parts:

- a. An orificed showerhead injector utilized to distribute the propellant onto the catalyst bed
- b. A cylindrical chamber which contains the catalyst bed
- c. A convergent section which has the capability of replacement of sonic orifices used to control the flow of the gas generator.

The design assumptions and calculations upon which the gas generator is based are described in the ensuing paragraphs.

The gas generator is designed to decompose selected mixtures of hydrazine, water, and/or ammonia as tabulated in Table VIII. The basic design parameters for the engine are: a chamber pressure of 300 psia, a volumetric flow rate of 60 scfm, and an ammonia dissociation with neat hydrazine of 80%. The design of the gas generator is based on

LOW TEMPERATURE GAS GENERATOR ASSEMBLY

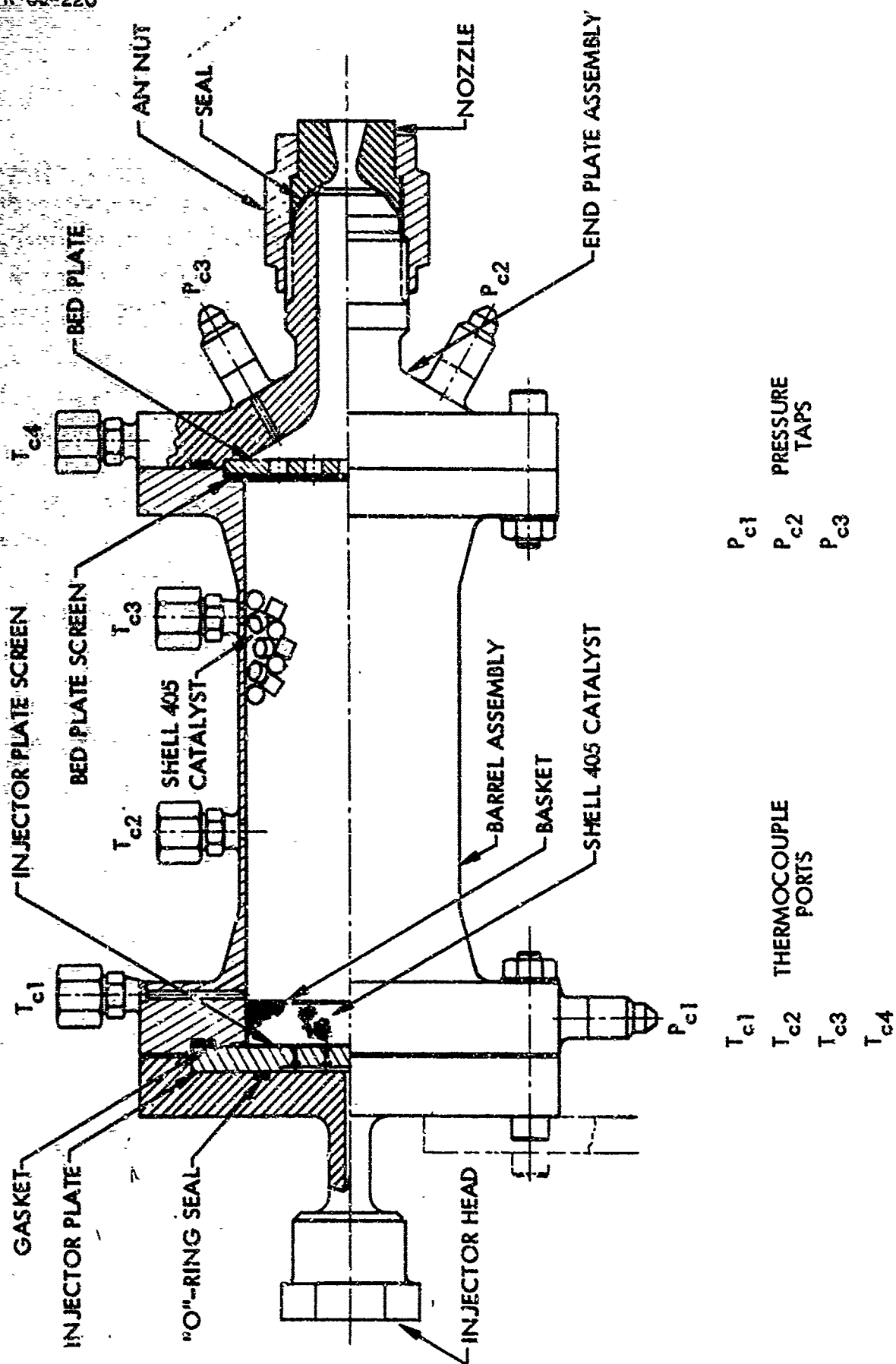


FIGURE 34

design criteria developed by Rocket Research Corporation under NASA Contracts NAS 7-372 and NAS 9-5617.

Under NASA Contract NAS 7-372, it was shown that a layer of fine mesh catalyst (25 - 30 mesh) approximately 0.2 to 0.3 inches in thickness is required at the top of the catalyst bed to insure smooth and stable operation. The remainder of the catalyst bed is composed of larger size catalyst such that the ratio of chamber diameter to particle size diameter is at least 8:1. A bed loading of 0.0274 was selected for the gas generator. From the definition of bed loading, the chamber diameter is calculated to be 1.50 inches. The catalyst size in the lower portion of the bed is 1/8" x 1/8" pellets (largest size manufactured by Shell Development Company).

The average molecular weight of the gas products from the hydrazine mixtures is 18.72 if it is assumed no ammonia dissociation occurs as a result of the high water content in the mixtures. Using the perfect gas law, the reactor flow rate is then calculated as:

$$\dot{w} = \frac{P_s \bar{M}}{RT_s} \dot{V}$$

Where:

$\dot{w}$ = Propellant flow rate, lbm/sec

R = Universal gas constant

P_s = Standard Atmospheric Pressure, lbf/ft²

T_s = Standard Temperature, °R

$\bar{M}$ = Average Gas Product molecular weight, lb/lb mole

$\dot{V}$ = Volumetric flow rate, scfs

Thus:

$$\dot{w} = \frac{(2116)(18.7)(1)}{(1544)(530)} = 0.0483 \text{ lbm/sec}$$

Under NASA Contract NAS 7-372, the following equation was developed to predict ammonia dissociation in the catalyst bed with neat hydrazine and using 1/8" x 1/8" cylindrical catalyst pellets:

$$\ln(1 - X) = - 0.472 + 910 \frac{G^{0.71} t}{P}$$

Where:

X = Fractional ammonia dissociation

G = Bed loading, $\text{lbm/in}^2\text{-sec}$

t = Residence time of propellant in catalyst bed, ms

P = Chamber pressure, psia

The residence time is given by:

$$t = \frac{\epsilon L M P}{G R T} (1000)$$

where previously undefined parameters are:

ϵ = Fractional catalyst bed porosity

L = Catalyst bed length, in.

Thus, for the design conditions of the gas generator, the catalyst bed length is calculated as:

$$\ln(1 - 0.8) = - \left[0.472 + 910 \frac{(0.0274)^{0.71} (0.340)(13.8)(1000)L}{(0.0274)(1544)(12)(2260)} \right]$$

$$1.6094 = 0.472 + 0.289L$$

$$L = 3.94 \text{ inches}$$

A catalyst bed of 4.0 inches was used for the design. It should be noted that the gas generator was designed for 80% ammonia dissociation with neat hydrazine and that when operated with the propellant mixtures, the ammonia dissociation will be less because of the flame temperature reduction from diluent addition.

The injector design is based on criteria developed under NASA Contract NAS 7-372. This criteria for a showerhead injector is:

- a. Use a pressure drop across the injector of 15% of steady state chamber pressure
- b. Use an orifice density of 6 orifices per square inch of catalyst bed cross-sectional area.

Thus the injector utilizes 12 orifices with a pressure drop of 45 psid. Table IX summarizes the gas generator design parameters.

4.3 Reactor Testing

Schematic drawings of the LTGG and the 1 lbf thruster are shown in Figures 35 and 36. The test set-up is illustrated schematically in Figure 37. The various instrumentation parameters are listed in Table X. A typical run sequence involved the following steps.

- a. Propellant was loaded into the precleaned and nitrogen dried run tank through a 10 micron filter.
- b. Flowmeters were calibrated.
- c. Two 60-second steady state firings were carried out with the LTGG at a nominal chamber pressure of 300 psia. An exhaust gas sample was taken during each firing in a pre-evacuated sample bottle. The gas sample flow was initiated approximately 40 seconds after ignition and sampling was continued until a sample pressure of approximately 50 psig was obtained.
- d. After the second LTGG firing on each fuel mix, the gas generator was removed from the system and oven purged at 250°F for 15 minutes with dry, filtered (10 micron) gaseous nitrogen.
- e. A single 30-second steady state firing of the 1 lbf thruster was conducted at a nominal chamber pressure of 70 psia followed as soon as possible by the pulse mode firing sequence listed in Table XI.
- f. Upon completion of the firing sequence, the 1 lbf thruster was removed from the system and oven purged as described in Step d.

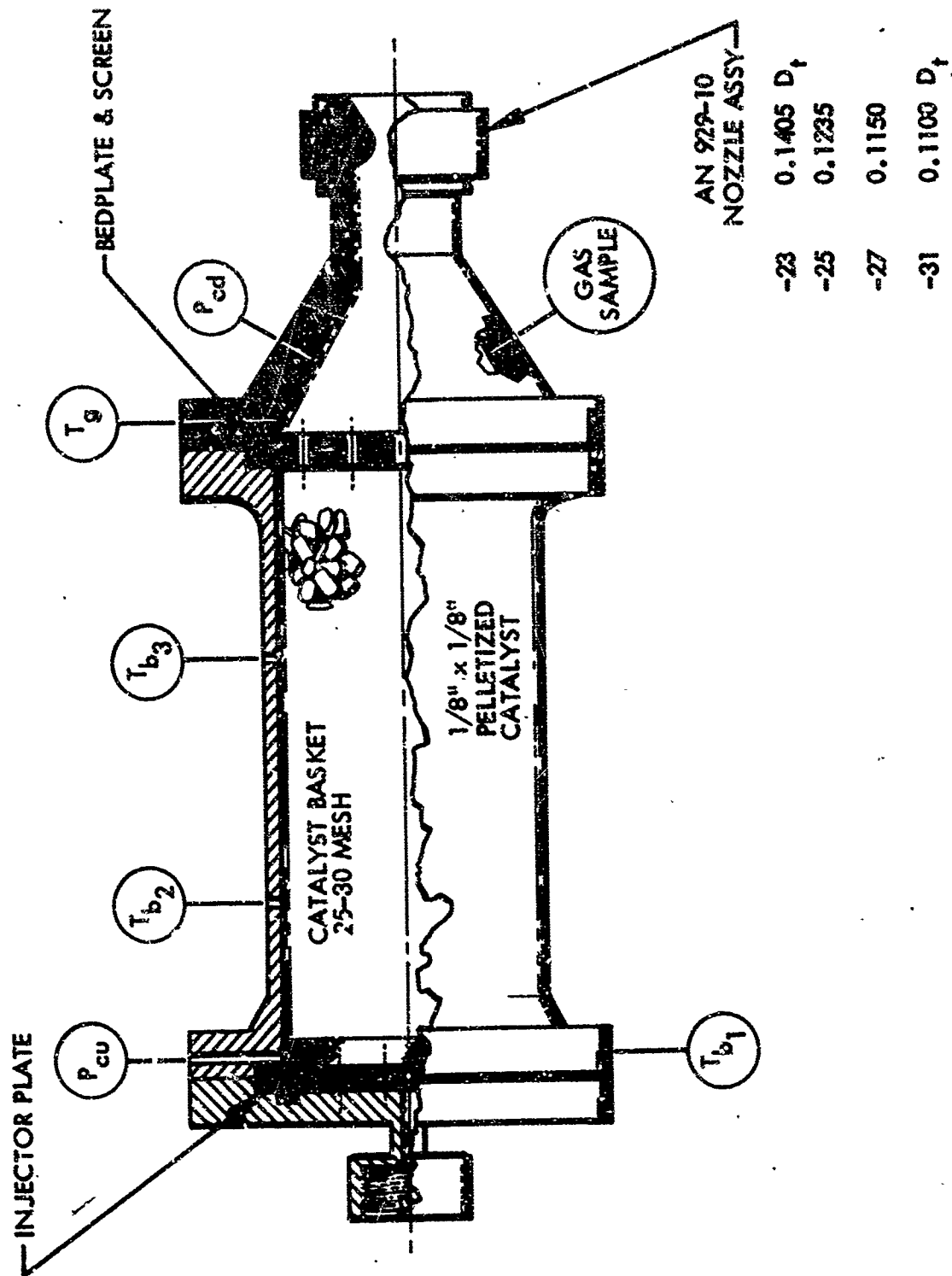
4.3.1 Propellant Preparation

The propellant was prepared by weighing the required amount of water in a polyethylene carboy and adding anhydrous hydrazine by pressurizing the storage

TABLE IX
GAS GENERATOR DESIGN PARAMETERS

Chamber Pressure	300 psia
Volumetric Flow Rate	60 scfm
Propellant Flow Rate	0.0483 lbm/sec
Predicted Ammonia Dissociation (Neat Hydrazine)	80%
Catalyst Bed Diameter	1.5 inches
Catalyst Bed Length	4.0 inches
Catalyst Size	0.3 inches 25-30 Mesh 3.7 inches 1/8" x 1/8" pellets
Injector Type	Showerhead
Number of Orifices	12
Injector Pressure Drop	45 psid
Catalyst Bed Pressure Drop	~ 4 psid

LTGG REACTOR INSTRUMENTATION



1 lbf THRUSTER INSTRUMENTATION

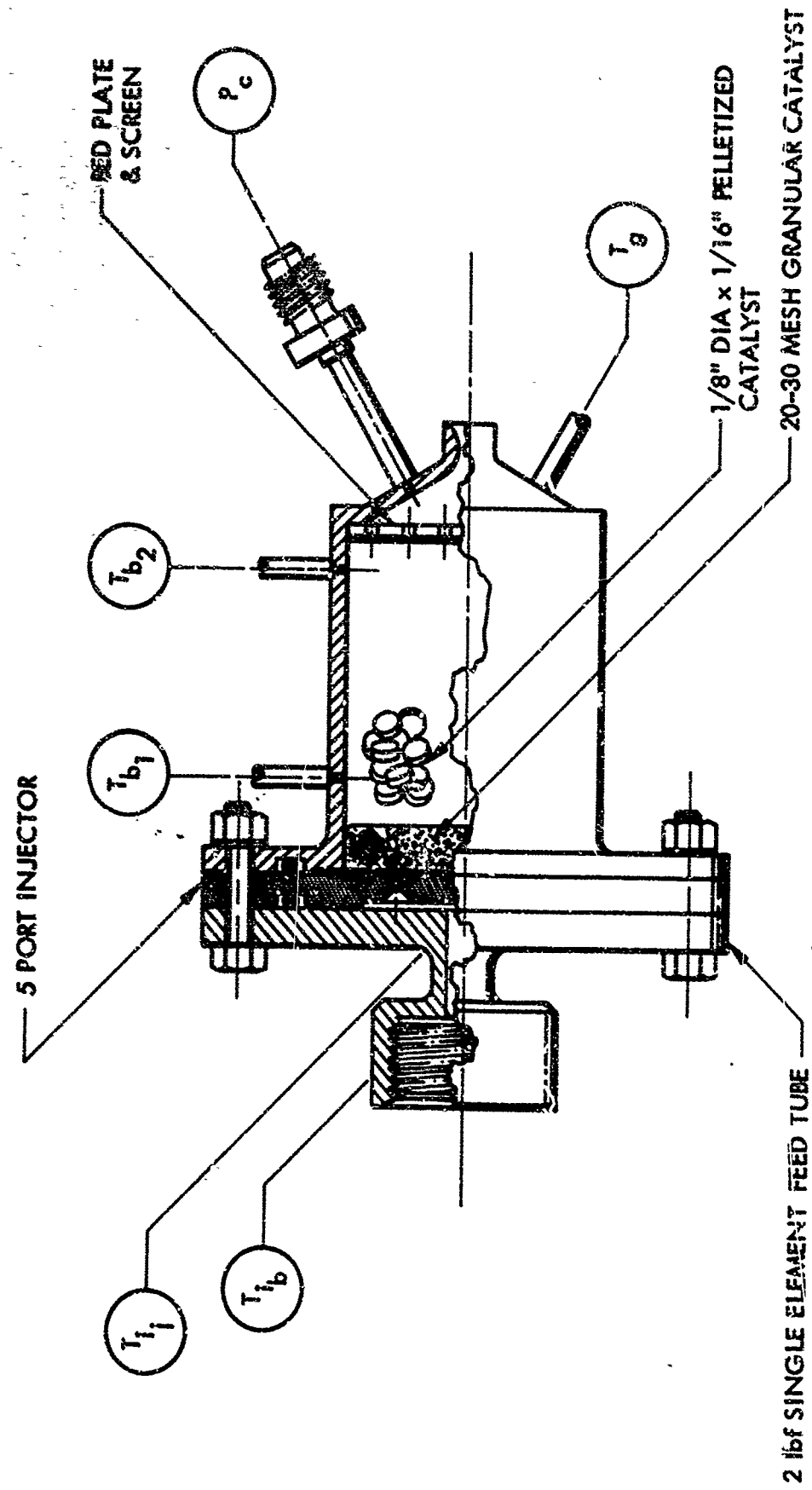


FIGURE 36

REACTOR TEST SCHEMATIC

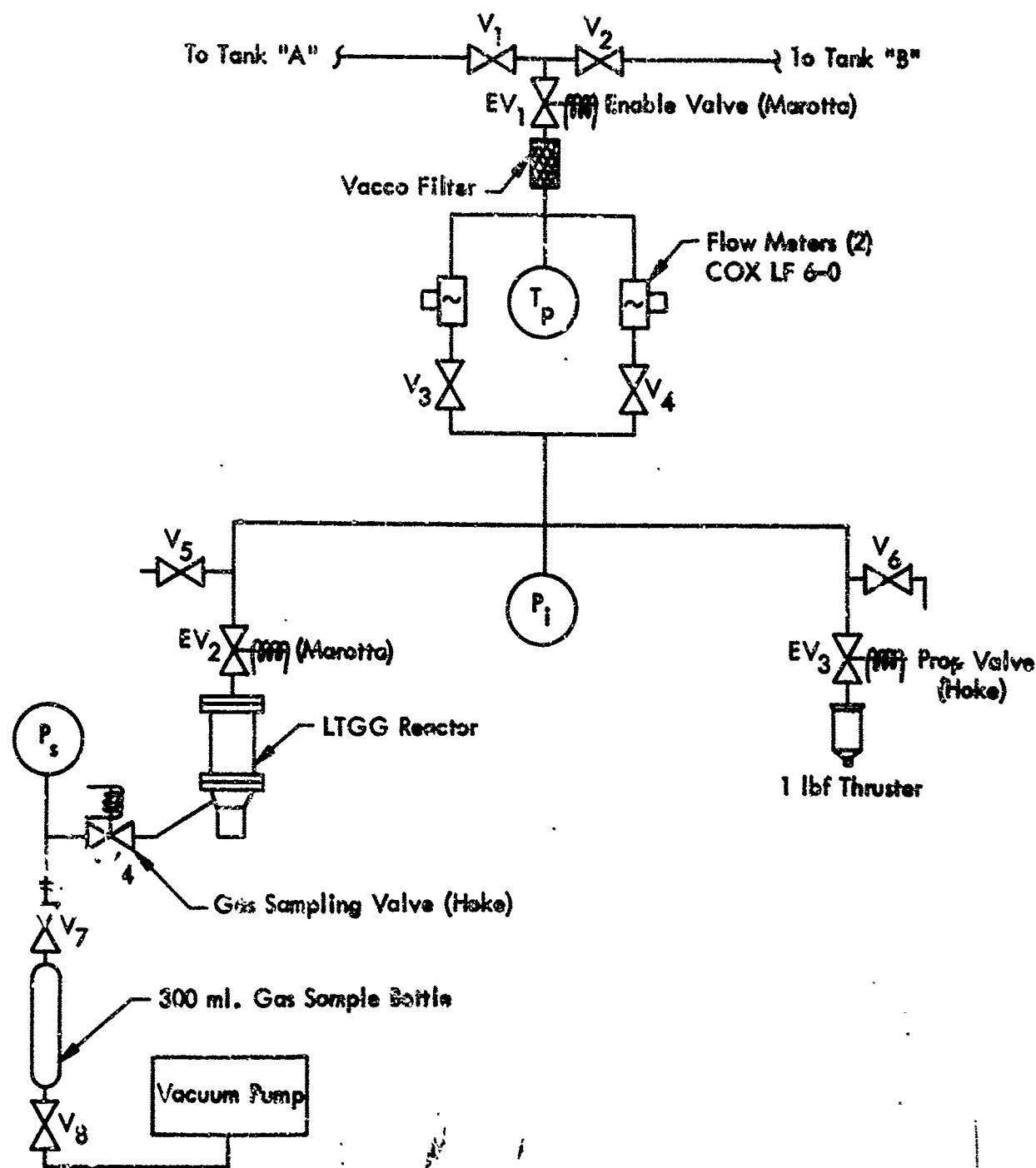


TABLE X
INSTRUMENTATION PARAMETERS

<u>Parameter Symbol</u>	<u>Parameter Identification</u>
P_i System	Injector Pressure
T_p System	Propellant Temperature
P_s (LTGG)	Gas Sample Pressure
P_{cd} (LTGG)	Chamber Pressure (Downstream)
P_{cu} (LTGG)	Chamber Pressure (Upstream)
T_{b1} (LTGG)	Bed Temperature (Top)
T_{b2} (LTGG)	Bed Temperature (Mid)
T_{b3} (LTGG)	Bed Temperature (Bottom)
T_g (LTGG)	Gas Temperature
w_{p1} (LTGG)	Propellant Flow Rate
w_{p2} (LTGG)	Propellant Flow Rate
V_{p1} (LTGG)	Propellant Valve Position
P_e (1 lbf)	Chamber Pressure
T_g (1 lbf)	Gas Temperature
T_{ib} (1 lbf)	Injector Gas Temperature
T_{ig} (1 lbf)	Injector Temperature
T_{b1} (1 lbf)	Bed Temperature (Top)
T_{b2} (1 lbf)	Bed Temperature (Bottom)
w_{p1} (1 lbf)	Propellant Flow Rate
V_{p2} (1 lbf)	Propellant Valve Position

TABLE XI
PULSE MODE FIRING SEQUENCE

<u>No. of Pulses</u>	<u>On Time (seconds)</u>	<u>Off Time (seconds)</u>	<u>Duty Cycle %</u>
50	0.25	0.25	50
50	0.25	0.25	10
50	1.0	1.0	50
50	1.0	9.0	10
25	3.0	3.0	50
25	3.0	27.0	10
20	7.0	7.0	50
20	7.0	63.0	10

container with nitrogen and forcing the hydrazine through a transfer tube into the mixing container until the proper total weight was obtained. The hydrazine was analyzed for water content and the results of the analysis were used in calculating the required weight of hydrazine and water.

The propellants containing ammonia were prepared in the same way to obtain the required hydrazine-water solution. The ammonia (liquid) was then added through a "flexible" line until the required total weight was obtained plus a slight excess. The line was then removed and the excess ammonia was bled off slowly until the required total weight was obtained. Any possible error in weighing due to the influence of the line was therefore eliminated.

4.3.2 Flowmeter Calibration

Calibration of the turbine flowmeters was attempted by flowing the propellant from one pressurized tank to another with both tanks pressurized to above the vapor pressure of the propellant. A constant flow rate could not be maintained by this method, however, and the accuracy of the resultant data was questionable. The propellant flow rate was therefore estimated by utilizing a universal calibration curve* which can be readily developed by water calibration. The accuracy of this approach is estimated to be within $\pm 2\%$ and in all probability is better than this value due to the small changes in viscosity of the NH_2 mixes as compared to the viscosity of water.

4.4 Results of Test Firings

The results of the LTGG evaluation tests are shown in Table XII, while the results of the 1 lbf thruster test firings are summarized in Table XIII. The theoretical range listed is based on temperatures possible for different percentages of ammonia dissociation. For the LTGG reactor, agreement among the three catalyst bed temperatures and exhaust temperature was reasonably good with the exception of the mixture containing 60% water. In this case, the exhaust gas temperature was from 60 to 100 degrees lower than the three bed temperatures and the theoretical temperature.

The chamber pressure of the LTGG reactor was within 7 psia of the nominal 300 psia except for the two mixtures containing less than 40% hydrazine. These mixtures operated

* Plot of cycles per gallon vs. cycles per second/viscosity.

15646 AGOSTON TERN EGG
3382 27701014

[illegible]

2. Valve full open to 150 degrees pressure rise. 3. Valve full open signal to 900 standard pressure rise.

TABLE XIB
ENGINE TEST DATA SUMMARY

Propellant Composition % by Weight	Time on Test Seconds	1 Dry Cycle	2 Chamber Pressure P_c - psia	3 Chamber Pressure Amplitude % of P_c	Exhaust Gas Temperature T_g - $^{\circ}$ F	4 Propellant Supply Temperature T_p - $^{\circ}$ F	5 Upper Chamber Stagnant Temp. T_{sc} - $^{\circ}$ F	6 Lower Chamber Stagnant Temp. T_{lc} - $^{\circ}$ F	7 Ignition Delay Microseconds	8 Response Time Microseconds	9 Chamber Exit Velocity C^* - ft/sec	Comments
N_2H_4 -57% H_2O -43%	25 25 1.00 1.00 1.00 2.00 3.00 7.00 7.00	50 50 50 50 50 50 50 50 50	71 67 75 49 70 70 66 66 66	-1% -1% -1% -1% -1% -1% -1% -1% -1%	N/A N/A N/A N/A N/A N/A N/A N/A N/A	57* 60 63 66 77 75 75 75 75	50 50 50 50 50 50 50 50 50	50 50 50 50 50 50 50 50 50	— 10 5 5 15 N/A 5 5	— 10 20 20 20 20 20 20 20 20	2286 2216 2254 2420 2440 — 2475 2474 2284 ft/sec	NO combustion - stable operation, good running rate.
N_2H_4 -43% H_2O -57%	25 25 1.00 1.00 1.00 2.00 3.00 7.00 7.00	50 50 50 50 50 50 50 50 50	66 66 66 66 66 66 66 66 66	-1% -1% -1% -1% -1% -1% -1% -1% -1%	247 247 253 254 255 256 256 256 256	73 77 80 80 73 62 66 69 66	25 25 25 25 25 25 25 25 25	25 25 25 25 25 25 25 25 25	— 10 10 10 10 10 10 10 10 10	— 10 20 20 20 20 20 20 20 20	2286 1690 1576 1579 1572 — 1577 1575-1580 ft/sec	No combustion - stable operation, very wet exhaust.
N_2H_4 -57% H_2O -43%	25 25 1.00 1.00 2.00 3.00 7.00 7.00	50 50 50 50 50 50 50 50	71 71 71 71 71 71 71 71	-1% -1% -1% -1% -1% -1% -1% -1%	N/A N/A N/A N/A N/A N/A N/A N/A	73 77 73 80 70 70 66 66	1265 1023 1080 1085 1116 1112 1116 1116	1265 1023 1080 1085 1116 1112 1116 1116	— 5 5 10 5 10 10 10 5	— 50 50 50 50 50 50 50 50	1582 3423 3755 3293 3255 3299 3351 3250 3135-3204 ft/sec	No combustion - stable operation on start. Stable operation.

1. % On Test 2. Maximum Value Measured 3. Minimum Value Measured 4. Value Open Signal to 1% Chamber Pressure Rise 5. Value Open Signal to 90% Chamber Pressure Rise

[illegible][illegible]

1. % On Farm
2. Maximum Value of Income
3. Maximum Value of Income
4. Value Open Sped to 1% Capital Feature as a
5. Value Open Sped to 97% Capital Feature as a

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Reaction Conditions (g by weight)	Reaction Conditions Summary	Dist. Cyls	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
Reaction Conditions (g by weight)	Reaction Conditions Summary	Dist. Cyls	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
Reaction Conditions (g by weight)	Reaction Conditions Summary	Dist. Cyls	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100

1. *A. A. Kozlov*
2. *Moscow State University Bulletin*
3. *Moscow State University Bulletin*
4. *U.S.S.R. Journal of Mathematics*
5. *U.S.S.R. Journal of Mathematics*

poorly and had low and decaying chamber pressures. The five mixtures which sustained reactor operation were very smooth running with chamber pressure roughness factors of within $\pm 1\%$ on both reactors except for the mixture containing 65% N_2H_4 . The operation of this mixture was somewhat rougher in the pulse mode tests.

The calculated c^* values were in the range of 100 to 106.5% of theoretical for the LTCG reactor. The fact that the temperatures recorded were near the theoretical upper limit, and the small nozzle orifices used do not make the high c^* values too surprising.

The calculated c^* values are shown in Figure 38 as a function of weight percent hydrazine. The theoretical curves for hydrazine-ammonia solutions and hydrazine-water solutions are also illustrated for comparison purposes. It is believed that the dip in the theoretical curve for hydrazine-water solutions is a result of the theoretical condensation of water in the chamber with a resultant decrease in the amount of working gas.

The c^* values obtained during pulse mode operation of the 1 lbf thruster are shown in Figure 39 as a function of pulse width and duty cycle. It may be observed that for pulse widths as short as 1 second, the performance approximately equals the steady state values but falls off rapidly for shorter pulses.

The 40% hydrazine-60% water mixture operated smoothly in both steady state and pulse mode operation although very long response times were observed. The propellants containing 30% and 35% hydrazine would not sustain pulse mode operation although the 35% hydrazine mixture could be forced to operate for several pulses by reheating the reactor externally to ambient temperature.

Exhaust gas samples were collected near the end of each 60-second firing of the propellant mixtures. The samples were collected in Hoke stainless steel cylinders of 300 ml capacity which were connected to the reactor (near the nozzle) through a solenoid valve and stainless steel tubing. A pressure transducer was also in the system between the valve and the cylinder to monitor the pressure in the sample cylinder. Collection of the gas sample was initiated approximately 40 seconds after ignition and continued until a sample pressure of approximately 50 psig was obtained. The chemical analysis, performed by an independent laboratory, involved heating the sample cylinder to ensure complete vaporization of the sample which was then injected into a gas chromatograph through a heated valve. The results of the initial analyses were not satisfactory, and considerable effort was expended in checking both the analysis and the sampling procedures.

PERFORMANCE AS A FUNCTION OF HYDRAZINE CONTENT

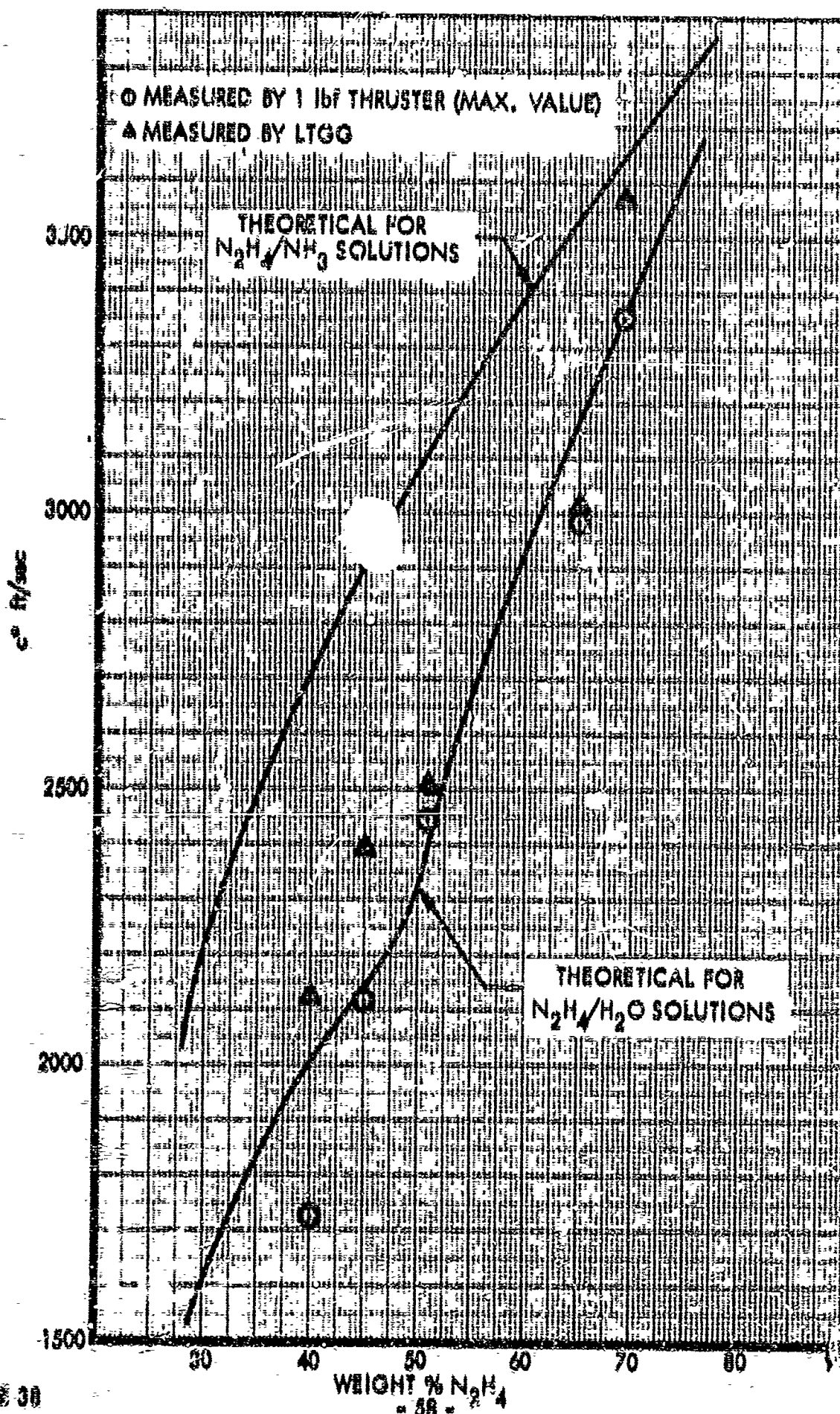
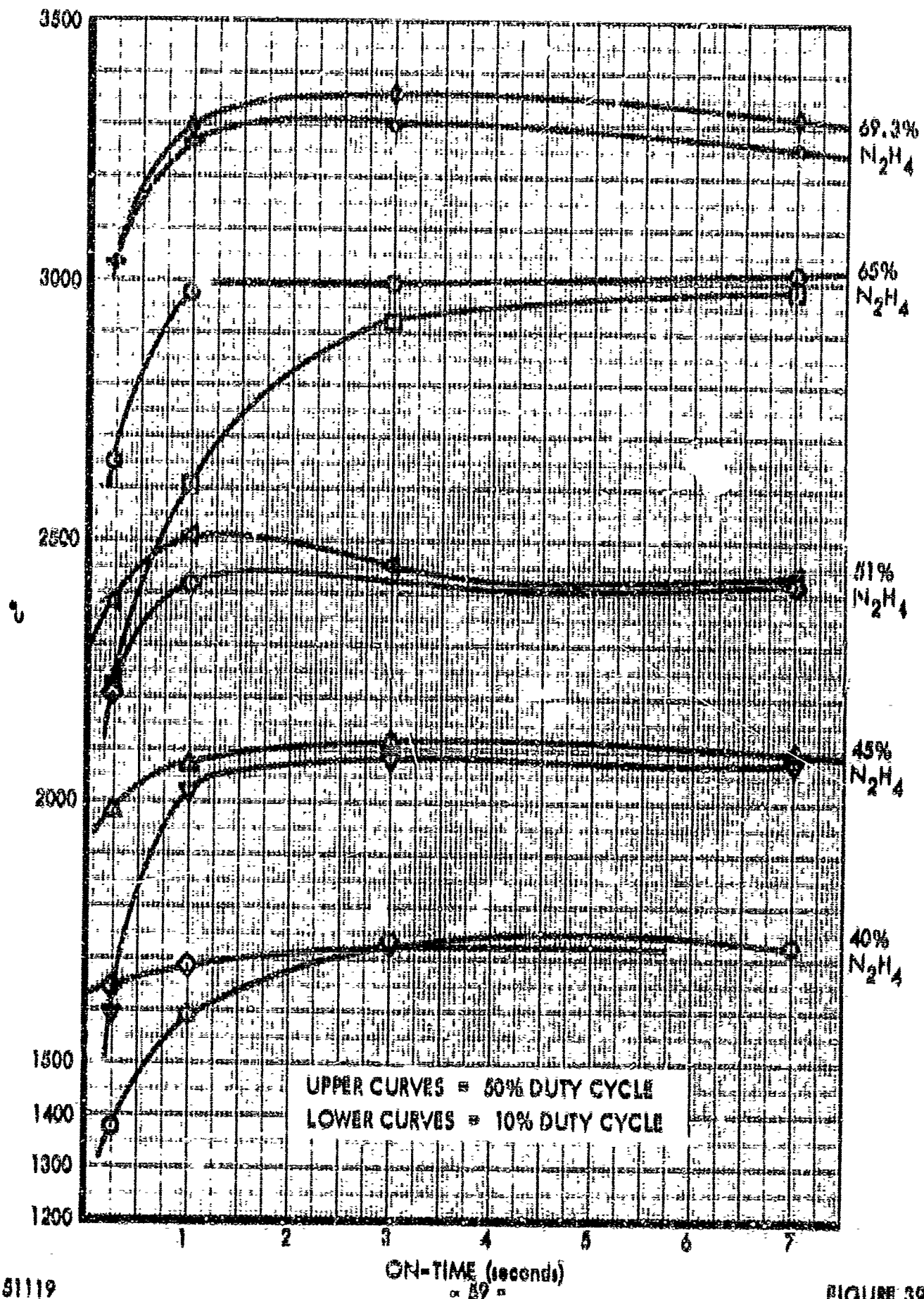


FIGURE 38

CHARACTERISTIC EXHAUST VELOCITY DURING PULSE MODE OPERATION



It was not determined whether the sampling technique or the gas analysis was at fault. The results of the analyses which were run are shown in Table XIV. These results, while not quantitatively accurate, show the presence of small amounts of hydrogen in the exhaust gases of the higher temperature propellants. The absence of hydrogen in the exhaust gases of the lower temperature propellants demonstrates that these propellants are operating with no ammonia dissociation as was expected. Additionally, the recorded temperatures and measured characteristic velocities (c^*) also confirm these results.

4.5 Summary and Conclusions

Thermochemical calculations have been performed over a wide range of compositions for the system hydrazine-ammonia-water. Experimental reactor firings have been conducted on seven specific monopropellants containing hydrazine, water and/or ammonia. These firings have proven that stable operation is possible over a wide range of propellant compositions. The propellant decomposition products are clean, noncorrosive gases in the temperature range of 362°F to 1,160°F. Lower temperatures have been recorded but are still questionable as to repeatability. Two of the seven monopropellants, both containing less than 40% by weight hydrazine, were shown to provide unsatisfactory operation both in steady state and pulse mode systems. The freezing points of the propellants were determined and their densities, viscosities, and vapor pressures were measured over a wide temperature range. The ammonia and water diluents are excellent freezing point depressants for hydrazine and the propellants exhibited freezing points in the temperature range from -57°F to -130°F.

TABLE XIV
RESULTS OF EXHAUST GAS ANALYSIS

Initial Propellant Composition (Weight %)			Reported Composition* of Exhaust Gases (Weight %)			
N_2H_4	H_2O	NH_3	N_2	H_2O	NH_3	H_2
69.3	30.7	---	38.7	11.4	49.1	0.8
69.3	30.7	---	39.5	11.4	48.4	0.7
65.0	26.25	8.75	32.8	6.3	60.7	0.2
63.0	26.25	8.75	32.3	6.6	61.8	0.1
40.0	60.0	---	14.5	50.7	34.8	---
40.0	60.0	---	18.4	43.9	37.7	---
51.0	49.0	---	56.5	16.8	27.0	---
51.0	49.0	---	29.1	35.5	35.4	---
51.0	49.0	---	12.1	60.3	27.5	---
51.0	49.0	---	13.6	45.1	41.3	---

*Results are known to be in error due to sampling and/or analysis techniques.
See text.

APPENDIX
SUMMARY OF PHASE I THERMOCHEMICAL CALCULATIONS

TABLE II
DESIGN PERFORMANCE
STRESS-STRAIN - TENSILE
CHARACTERISTICS - 100 PSI - 1000 PSI - 10000 PSI

Stress psi	Strain in/in	Modulus psi	Yield psi	Ultimate psi	Elongation %	Reduction Area %	Charpy ft-lb	Impact ft-lb	Temp °F	Notes
100	0.001	100000	10000	10000	0.1	0.1	100	100	100	
200	0.002	200000	20000	20000	0.2	0.2	200	200	200	
300	0.003	300000	30000	30000	0.3	0.3	300	300	300	
400	0.004	400000	40000	40000	0.4	0.4	400	400	400	
500	0.005	500000	50000	50000	0.5	0.5	500	500	500	
600	0.006	600000	60000	60000	0.6	0.6	600	600	600	
700	0.007	700000	70000	70000	0.7	0.7	700	700	700	
800	0.008	800000	80000	80000	0.8	0.8	800	800	800	
900	0.009	900000	90000	90000	0.9	0.9	900	900	900	
1000	0.010	1000000	100000	100000	1.0	1.0	1000	1000	1000	
1100	0.011	1100000	110000	110000	1.1	1.1	1100	1100	1100	
1200	0.012	1200000	120000	120000	1.2	1.2	1200	1200	1200	
1300	0.013	1300000	130000	130000	1.3	1.3	1300	1300	1300	
1400	0.014	1400000	140000	140000	1.4	1.4	1400	1400	1400	
1500	0.015	1500000	150000	150000	1.5	1.5	1500	1500	1500	
1600	0.016	1600000	160000	160000	1.6	1.6	1600	1600	1600	
1700	0.017	1700000	170000	170000	1.7	1.7	1700	1700	1700	
1800	0.018	1800000	180000	180000	1.8	1.8	1800	1800	1800	
1900	0.019	1900000	190000	190000	1.9	1.9	1900	1900	1900	
2000	0.020	2000000	200000	200000	2.0	2.0	2000	2000	2000	
2100	0.021	2100000	210000	210000	2.1	2.1	2100	2100	2100	
2200	0.022	2200000	220000	220000	2.2	2.2	2200	2200	2200	
2300	0.023	2300000	230000	230000	2.3	2.3	2300	2300	2300	
2400	0.024	2400000	240000	240000	2.4	2.4	2400	2400	2400	
2500	0.025	2500000	250000	250000	2.5	2.5	2500	2500	2500	
2600	0.026	2600000	260000	260000	2.6	2.6	2600	2600	2600	
2700	0.027	2700000	270000	270000	2.7	2.7	2700	2700	2700	
2800	0.028	2800000	280000	280000	2.8	2.8	2800	2800	2800	
2900	0.029	2900000	290000	290000	2.9	2.9	2900	2900	2900	
3000	0.030	3000000	300000	300000	3.0	3.0	3000	3000	3000	
3100	0.031	3100000	310000	310000	3.1	3.1	3100	3100	3100	
3200	0.032	3200000	320000	320000	3.2	3.2	3200	3200	3200	
3300	0.033	3300000	330000	330000	3.3	3.3	3300	3300	3300	
3400	0.034	3400000	340000	340000	3.4	3.4	3400	3400	3400	
3500	0.035	3500000	350000	350000	3.5	3.5	3500	3500	3500	
3600	0.036	3600000	360000	360000	3.6	3.6	3600	3600	3600	
3700	0.037	3700000	370000	370000	3.7	3.7	3700	3700	3700	
3800	0.038	3800000	380000	380000	3.8	3.8	3800	3800	3800	
3900	0.039	3900000	390000	390000	3.9	3.9	3900	3900	3900	
4000	0.040	4000000	400000	400000	4.0	4.0	4000	4000	4000	
4100	0.041	4100000	410000	410000	4.1	4.1	4100	4100	4100	
4200	0.042	4200000	420000	420000	4.2	4.2	4200	4200	4200	
4300	0.043	4300000	430000	430000	4.3	4.3	4300	4300	4300	
4400	0.044	4400000	440000	440000	4.4	4.4	4400	4400	4400	
4500	0.045	4500000	450000	450000	4.5	4.5	4500	4500	4500	
4600	0.046	4600000	460000	460000	4.6	4.6	4600	4600	4600	
4700	0.047	4700000	470000	470000	4.7	4.7	4700	4700	4700	
4800	0.048	4800000	480000	480000	4.8	4.8	4800	4800	4800	
4900	0.049	4900000	490000	490000	4.9	4.9	4900	4900	4900	
5000	0.050	5000000	500000	500000	5.0	5.0	5000	5000	5000	
5100	0.051	5100000	510000	510000	5.1	5.1	5100	5100	5100	
5200	0.052	5200000	520000	520000	5.2	5.2	5200	5200	5200	
5300	0.053	5300000	530000	530000	5.3	5.3	5300	5300	5300	
5400	0.054	5400000	540000	540000	5.4	5.4	5400	5400	5400	
5500	0.055	5500000	550000	550000	5.5	5.5	5500	5500	5500	
5600	0.056	5600000	560000	560000	5.6	5.6	5600	5600	5600	
5700	0.057	5700000	570000	570000	5.7	5.7	5700	5700	5700	
5800	0.058	5800000	580000	580000	5.8	5.8	5800	5800	5800	
5900	0.059	5900000	590000	590000	5.9	5.9	5900	5900	5900	
6000	0.060	6000000	600000	600000	6.0	6.0	6000	6000	6000	
6100	0.061	6100000	610000	610000	6.1	6.1	6100	6100	6100	
6200	0.062	6200000	620000	620000	6.2	6.2	6200	6200	6200	
6300	0.063	6300000	630000	630000	6.3	6.3	6300	6300	6300	
6400	0.064	6400000	640000	640000	6.4	6.4	6400	6400	6400	
6500	0.065	6500000	650000	650000	6.5	6.5	6500	6500	6500	
6600	0.066	6600000	660000	660000	6.6	6.6	6600	6600	6600	
6700	0.067	6700000	670000	670000	6.7	6.7	6700	6700	6700	
6800	0.068	6800000	680000	680000	6.8	6.8	6800	6800	6800	
6900	0.069	6900000	690000	690000	6.9	6.9	6900	6900	6900	
7000	0.070	7000000	700000	700000	7.0	7.0	7000	7000	7000	
7100	0.071	7100000	710000	710000	7.1	7.1	7100	7100	7100	
7200	0.072	7200000	720000	720000	7.2	7.2	7200	7200	7200	
7300	0.073	7300000	730000	730000	7.3	7.3	7300	7300	7300	
7400	0.074	7400000	740000	740000	7.4	7.4	7400	7400	7400	
7500	0.075	7500000	750000	750000	7.5	7.5	7500	7500	7500	
7600	0.076	7600000	760000	760000	7.6	7.6	7600	7600	7600	
7700	0.077	7700000	770000	770000	7.7	7.7	7700	7700	7700	
7800	0.078	7800000	780000	780000	7.8	7.8	7800	7800	7800	
7900	0.079	7900000	790000	790000	7.9	7.9	7900	7900	7900	
8000	0.080	8000000	800000	800000	8.0	8.0	8000	8000	8000	
8100	0.081	8100000	810000	810000	8.1	8.1	8100	8100	8100	
8200	0.082	8200000	820000	820000	8.2	8.2	8200	8200	8200	
8300	0.083	8300000	830000	830000	8.3	8.3	8300	8300	8300	
8400	0.084	8400000	840000	840000	8.4	8.4	8400	8400	8400	
8500	0.085	8500000	850000	850000	8.5	8.5	8500	8500	8500	
8600	0.086	8600000	860000	860000	8.6	8.6	8600	8600	8600	
8700	0.087	8700000	870000	870000	8.7	8.7	8700	8700	8700	
8800	0.088	8800000	880000	880000	8.8	8.8	8800	8800	8800	
8900	0.089	8900000	890000	890000	8.9	8.9	8900	8900	8900	
9000	0.090	9000000	900000	900000	9.0	9.0	9000	9000	9000	
9100	0.091	9100000	910000	910000	9.1	9.1	9100	9100	9100	
9200	0.092	9200000	920000	920000	9.2	9.2	9200	9200	9200	
9300	0.093	9300000	930000	930000	9.3	9.3	9300	9300	9300	
9400	0.094	9400000	940000	940000	9.4	9.4	9400	9400	9400	
9500	0.095	9500000	950000	950000	9.5	9.5	9500	9500	9500	
9600	0.096	9600000	960000	960000	9.6	9.6	9600	9600	9600	
9700	0.097	9700000	970000	970000	9.7	9.7	9700	9700	9700	
9800	0.098	9800000	980000	980000	9.8	9.8	9800	9800	9800	
9900	0.099	9900000	990000	990000	9.9	9.9	9900	9900	9900	
10000	0.100	10000000	1000000	1000000	10.0	10.0	10000	10000	10000	

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TABLE III
MECHANICAL PERFORMANCE
HYPERBOLIC - AMMONIUM NITRATE
CHAMBER PRESSURE = 300 psig - GRAIN SIZE PRESSURE = 14.7 psig

P _c psi	Grain No.	Mass, % H ₂ O	Mass, % NH ₃	Mass, % H ₂ O	x	y	T _c , °C	T _c , °F	c	ρ _p	ΔH _f	Av. W.	From Grain, %	H ₂	NH ₃	Water H ₂ O (Grain)	Water H ₂ O (Grain)
300	4.105, 10.10	95	5	—	1.10	0	310	590	3.798	162.4	-35.250	10.800	1.367	5.975	2.944	0.254	—
	4.110, 10.10	90	10	—	0	0	300	570	4.143	162.2	-35.184	10.700	1.104	—	0.900	4.730	—
	4.115, 10.10	—	—	—	1	0	300	570	4.146	162.0	-35.184	10.600	1.100	0.900	0.900	3.900	—
	4.120, 10.10	90	10	—	1	0	300	570	4.150	162.0	-35.184	10.500	1.100	0.900	0.900	3.900	—
	4.125, 10.10	90	10	—	1	0	300	570	4.154	162.0	-35.184	10.400	1.100	0.900	0.900	3.900	—
	4.130, 10.10	90	10	—	1	0	300	570	4.158	162.0	-35.184	10.300	1.100	0.900	0.900	3.900	—
	4.135, 10.10	90	10	—	1	0	300	570	4.162	162.0	-35.184	10.200	1.100	0.900	0.900	3.900	—
	4.140, 10.10	90	10	—	1	0	300	570	4.166	162.0	-35.184	10.100	1.100	0.900	0.900	3.900	—
	4.145, 10.10	90	10	—	1	0	300	570	4.170	162.0	-35.184	10.000	1.100	0.900	0.900	3.900	—
	4.150, 10.10	90	10	—	1	0	300	570	4.174	162.0	-35.184	9.900	1.100	0.900	0.900	3.900	—
	4.155, 10.10	90	10	—	1	0	300	570	4.178	162.0	-35.184	9.800	1.100	0.900	0.900	3.900	—
	4.160, 10.10	90	10	—	1	0	300	570	4.182	162.0	-35.184	9.700	1.100	0.900	0.900	3.900	—
	4.165, 10.10	90	10	—	1	0	300	570	4.186	162.0	-35.184	9.600	1.100	0.900	0.900	3.900	—
	4.170, 10.10	90	10	—	1	0	300	570	4.190	162.0	-35.184	9.500	1.100	0.900	0.900	3.900	—
	4.175, 10.10	90	10	—	1	0	300	570	4.194	162.0	-35.184	9.400	1.100	0.900	0.900	3.900	—
	4.180, 10.10	90	10	—	1	0	300	570	4.198	162.0	-35.184	9.300	1.100	0.900	0.900	3.900	—
	4.185, 10.10	90	10	—	1	0	300	570	4.202	162.0	-35.184	9.200	1.100	0.900	0.900	3.900	—
	4.190, 10.10	90	10	—	1	0	300	570	4.206	162.0	-35.184	9.100	1.100	0.900	0.900	3.900	—
	4.195, 10.10	90	10	—	1	0	300	570	4.210	162.0	-35.184	9.000	1.100	0.900	0.900	3.900	—
	4.200, 10.10	90	10	—	1	0	300	570	4.214	162.0	-35.184	8.900	1.100	0.900	0.900	3.900	—
	4.205, 10.10	90	10	—	1	0	300	570	4.218	162.0	-35.184	8.800	1.100	0.900	0.900	3.900	—
	4.210, 10.10	90	10	—	1	0	300	570	4.222	162.0	-35.184	8.700	1.100	0.900	0.900	3.900	—
	4.215, 10.10	90	10	—	1	0	300	570	4.226	162.0	-35.184	8.600	1.100	0.900	0.900	3.900	—
	4.220, 10.10	90	10	—	1	0	300	570	4.230	162.0	-35.184	8.500	1.100	0.900	0.900	3.900	—
	4.225, 10.10	90	10	—	1	0	300	570	4.234	162.0	-35.184	8.400	1.100	0.900	0.900	3.900	—
	4.230, 10.10	90	10	—	1	0	300	570	4.238	162.0	-35.184	8.300	1.100	0.900	0.900	3.900	—
	4.235, 10.10	90	10	—	1	0	300	570	4.242	162.0	-35.184	8.200	1.100	0.900	0.900	3.900	—
	4.240, 10.10	90	10	—	1	0	300	570	4.246	162.0	-35.184	8.100	1.100	0.900	0.900	3.900	—
	4.245, 10.10	90	10	—	1	0	300	570	4.250	162.0	-35.184	8.000	1.100	0.900	0.900	3.900	—
	4.250, 10.10	90	10	—	1	0	300	570	4.254	162.0	-35.184	7.900	1.100	0.900	0.900	3.900	—
	4.255, 10.10	90	10	—	1	0	300	570	4.258	162.0	-35.184	7.800	1.100	0.900	0.900	3.900	—
	4.260, 10.10	90	10	—	1	0	300	570	4.262	162.0	-35.184	7.700	1.100	0.900	0.900	3.900	—
	4.265, 10.10	90	10	—	1	0	300	570	4.266	162.0	-35.184	7.600	1.100	0.900	0.900	3.900	—
	4.270, 10.10	90	10	—	1	0	300	570	4.270	162.0	-35.184	7.500	1.100	0.900	0.900	3.900	—
	4.275, 10.10	90	10	—	1	0	300	570	4.274	162.0	-35.184	7.400	1.100	0.900	0.900	3.900	—
	4.280, 10.10	90	10	—	1	0	300	570	4.278	162.0	-35.184	7.300	1.100	0.900	0.900	3.900	—
	4.285, 10.10	90	10	—	1	0	300	570	4.282	162.0	-35.184	7.200	1.100	0.900	0.900	3.900	—
	4.290, 10.10	90	10	—	1	0	300	570	4.286	162.0	-35.184	7.100	1.100	0.900	0.900	3.900	—
	4.295, 10.10	90	10	—	1	0	300	570	4.290	162.0	-35.184	7.000	1.100	0.900	0.900	3.900	—
	4.300, 10.10	90	10	—	1	0	300	570	4.294	162.0	-35.184	6.900	1.100	0.900	0.900	3.900	—
	4.305, 10.10	90	10	—	1	0	300	570	4.298	162.0	-35.184	6.800	1.100	0.900	0.900	3.900	—
	4.310, 10.10	90	10	—	1	0	300	570	4.302	162.0	-35.184	6.700	1.100	0.900	0.900	3.900	—
	4.315, 10.10	90	10	—	1	0	300	570	4.306	162.0	-35.184	6.600	1.100	0.900	0.900	3.900	—
	4.320, 10.10	90	10	—	1	0	300	570	4.310	162.0	-35.184	6.500	1.100	0.900	0.900	3.900	—
	4.325, 10.10	90	10	—	1	0	300	570	4.314	162.0	-35.184	6.400	1.100	0.900	0.900	3.900	—
	4.330, 10.10	90	10	—	1	0	300	570	4.318	162.0	-35.184	6.300	1.100	0.900	0.900	3.900	—
	4.335, 10.10	90	10	—	1	0	300	570	4.322	162.0	-35.184	6.200	1.100	0.900	0.900	3.900	—
	4.340, 10.10	90	10	—	1	0	300	570	4.326	162.0	-35.184	6.100	1.100	0.900	0.900	3.900	—
	4.345, 10.10	90	10	—	1	0	300	570	4.330	162.0	-35.184	6.000	1.100	0.900	0.900	3.900	—
	4.350, 10.10	90	10	—	1	0	300	570	4.334	162.0	-35.184	5.900	1.100	0.900	0.900	3.900	—
	4.355, 10.10	90	10	—	1	0	300	570	4.338	162.0	-35.184	5.800	1.100	0.900	0.900	3.900	—
	4.360, 10.10	90	10	—	1	0	300	570	4.342	162.0	-35.184	5.700	1.100	0.900	0.900	3.900	—
	4.365, 10.10	90	10	—	1	0	300	570	4.346	162.0	-35.184	5.600	1.100	0.900	0.900	3.900	—
	4.370, 10.10	90	10	—	1	0	300	570	4.350	162.0	-35.184	5.500	1.100	0.900	0.900	3.900	—
	4.375, 10.10	90	10	—	1	0	300	570	4.354	162.0	-35.184	5.400	1.100	0.900	0.900	3.900	—
	4.380, 10.10	90	10	—	1	0	300	570	4.358	162.0	-35.184	5.300	1.100	0.900	0.900	3.900	—
	4.385, 10.10	90	10	—	1	0	300	570	4.362	162.0	-35.184	5.200	1.100	0.900	0.900	3.900	—
	4.390, 10.10	90	10	—	1	0	300	570	4.366	162.0	-35.184	5.100	1.100	0.900	0.900	3.900	—
	4.395, 10.10	90	10	—	1	0	300	570	4.370	162.0	-35.184	5.000	1.100	0.900	0.900	3.900	—
	4.400, 10.10	90	10	—	1	0	300	570	4.374	162.0	-35.184	4.900	1.100	0.900	0.900	3.900	—
	4.405, 10.10	90	10	—	1	0	300	570	4.378	162.0	-35.184	4.800	1.100	0.900	0.900	3.900	—
	4.410, 10.10	90	10	—	1	0	300	570	4.382	162.0	-35.184	4.700	1.100	0.900	0.900	3.900	—
	4.415, 10.10	90	10	—	1	0	300	570	4.386	162.0	-35.184	4.600	1.100	0.900	0.900	3.900	—
	4.420, 10.10	90	10	—	1	0	300	570	4.390	162.0	-35.184	4.500	1.100	0.900	0.900	3.900	—
	4.425, 10.10	90	10	—	1	0	300	570	4.394	162.0	-35.184	4.400	1.100	0.900	0.900	3.900	—
	4.430, 10.10	90	10	—	1	0	300	570	4.398	162.0	-35.184	4.300	1.100	0.900	0.900	3.900	—
	4.435, 10.10	90	10	—	1	0	300	570	4.402	162.0	-35.184	4.200	1.100	0.900	0.900	3.900	—
	4.440, 10.10	90	10	—	1	0	300	570	4.406	162.0	-35.184	4.100	1.100	0.900	0.900	3.900	—
	4.445, 10.10	90	10	—	1	0	300	570	4.410	162.0	-35.184	4.000	1.100	0.900	0.900	3.900	—
	4.450, 10.10	90	10	—	1	0	300	570	4.414	162.0	-35.184	3.900	1.100	0.900	0.900	3.900	—
	4.455, 10.10	90	10	—	1	0	300	570	4.418	162.0	-35.184	3.800	1.100	0.900	0.900	3.900	—
	4.460, 10.10	90	10	—	1	0	300	570	4.422	162.0	-35.184	3.700	1.100	0.900	0.900	3.900	—
	4.465, 10.10	90	10	—	1	0	300	570	4.426	162.0	-35.184	3.600	1.100	0.900	0.900	3.900	—
	4.470, 10.10	90	10	—	1	0	300	570	4.430	162.0	-35.184	3.500	1.100	0.900	0.900	3.900	—

TABLE III (Cont'd)
THEORETICAL PERFORMANCE
HYDROGEN - AMMONIA SYSTEM
CHAMBER PRESSURE = 200 psia - EXHAUST PRESSURE = 14.7 psia

Case No.	SAF ₂	SAF ₃	SAF ₂	X	Y	V _c - K	V _c - K	C _p	I _{sp}	BP _h	Wt. Wt.	Formic Gases (DCJ)	Ratio H ₂	Ratio N ₂	Ratio H ₂ O (Feed)	Ratio H ₂ O (Exhaust)
100	10.15	70	30	1	0	700	800	3.203	140.9	-27.004	12.928	1.301	3.465	1.893	2.343	-
	11.25	70	30	1	0	614	675	3.134	134.5	-26.006	12.207	1.289	4.105	2.113	1.904	-
	11.50	70	30	1	0	529	493	2.974	127.5	-18.072	11.611	1.263	4.246	2.303	1.463	-
	10.00	70	30	1	0	504	504	3.006	132.4	-20.104	12.008	1.340	4.208	2.004	1.266	-
	10.25	70	30	1	0	572	465	2.978	125.8	-17.960	11.401	1.289	5.029	2.406	1.229	-
	10.50	70	30	1	0	472	301	2.706	110.1	-15.709	12.878	1.262	5.889	2.625	0.981	-
	10.75	70	30	1	0	376	596	3.006	122.4	-20.303	12.019	1.340	4.369	2.304	1.252	-
	4.00, 10.75	70	30	1	0	248	213	2.488	103.7	-10.003	12.510	1.261	3.737	1.818	2.429	-
	4.00, 10.25	70	30	1	0	217	039	2.169	92.1	-9.750	11.555	1.279	4.723	2.148	1.209	-
	11.50	70	30	1	0	93	107	3.105	148.7	-25.200	10.205	1.289	-	0.404	4.845	-
	4.00, 10.00	70	30	1	0	88	108	3.105	144.8	-24.008	10.706	1.277	0.709	0.854	4.245	-
	2.0	60	40	2	0	700	929	3.120	139.9	-23.488	15.462	1.248	1.486	1.123	1.806	-
	4.0	60	40	2	0	640	745	3.002	132.6	-20.199	14.105	1.288	2.173	1.427	1.259	-
	4.25	60	40	2	0	575	532	2.880	123.8	-17.105	13.086	1.259	3.229	1.710	2.672	-
	4.50	60	40	2	0	489	777	3.109	132.8	-20.503	14.234	1.282	2.247	1.573	2.307	-
	4.75	60	40	2	0	398	943	2.912	125.2	-18.010	13.238	1.204	3.137	1.573	2.760	-
	4.90	60	40	2	0	453	705	2.882	115.1	-15.206	12.204	1.255	4.106	1.960	2.143	-
	5.0	60	40	2	0	546	595	2.940	128.4	-18.409	13.304	1.219	2.946	1.823	2.808	-
	5.25	60	40	2	0	470	386	2.718	124.7	-15.153	12.418	1.252	2.876	1.549	2.361	-
	5.50	60	40	2	0	361	146	2.459	120.3	-12.310	11.574	1.244	1.575	2.310	1.614	-
	5.75	60	40	2	0	275	27	2.912	107.1	-12.102	11.673	1.263	4.626	2.214	1.781	-
	5.90	60	40	2	0	215	025	2.975	94.0	-10.145	10.942	1.288	5.926	2.409	1.024	-
	6.0	60	40	2	0	121.1	517	2.865	121.1	-17.401	13.018	1.27	3.129	1.730	2.612	-
	4.5, 10.0	50	50	0	0	810	908	3.077	133.7	-20.503	12.244	1.207	-	0.539	5.006	-
	2.0	50	50	0	0	724	844	2.941	129.3	-19.215	16.801	1.235	0.634	0.775	4.680	-
	4.0	50	50	0	0	628	689	2.875	124.0	-17.607	15.704	1.267	1.208	0.736	4.104	-
	4.25	50	50	0	0	472	472	2.816	102.4	-14.514	14.200	1.213	2.249	1.213	2.403	-

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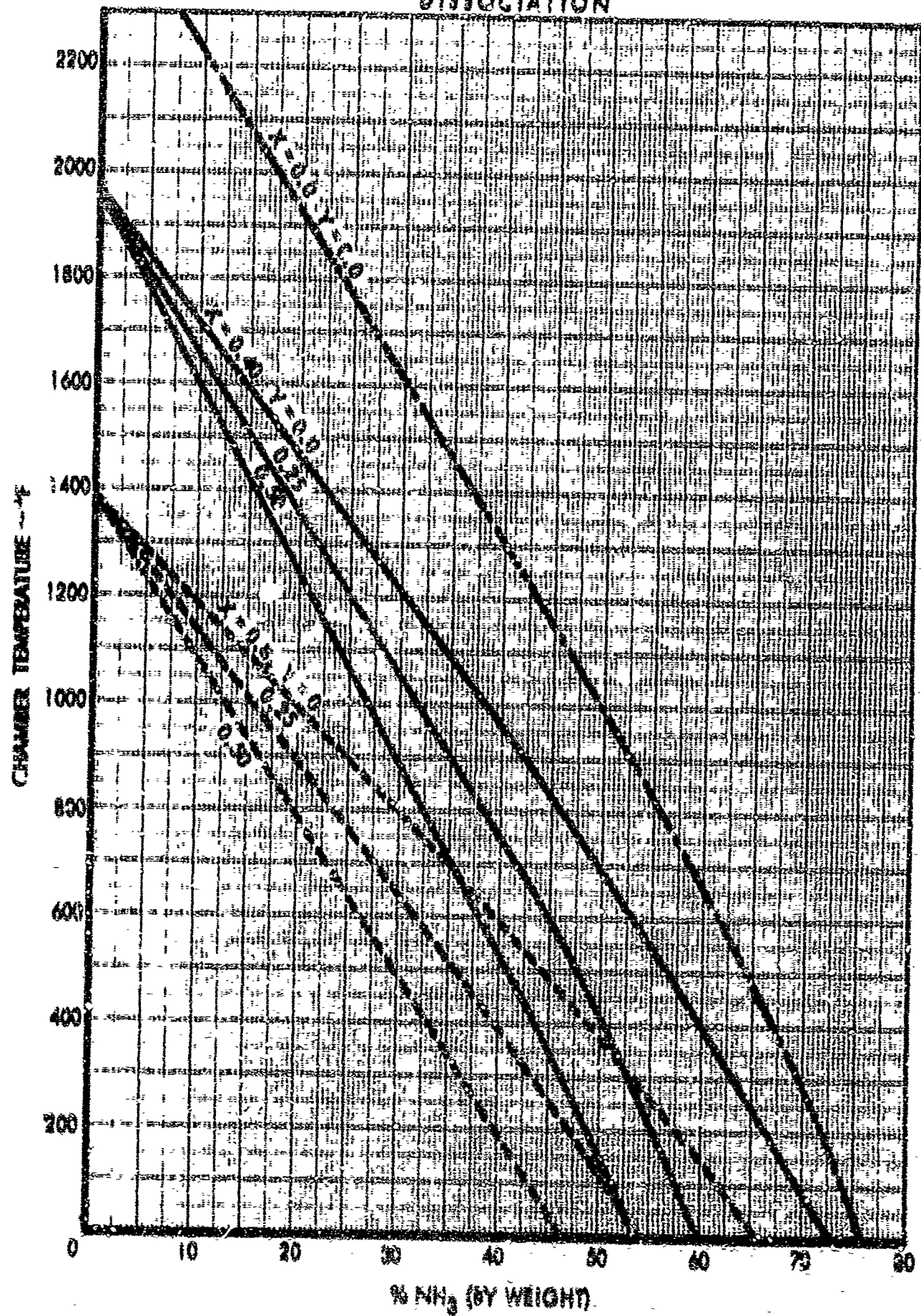
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HYDRAZINE - AMMONIA SYSTEM AFRPL-TR-66-226
 CHAMBER TEMPERATURE VS % NH_3 FOR VARYING AMMONIA
 DISSOCIATION



HYDRAZINE - AMMONIA SYSTEM CHAMBER TEMPERATURE VS % NH_3 FOR VARYING AMMONIA DISSOCIATION

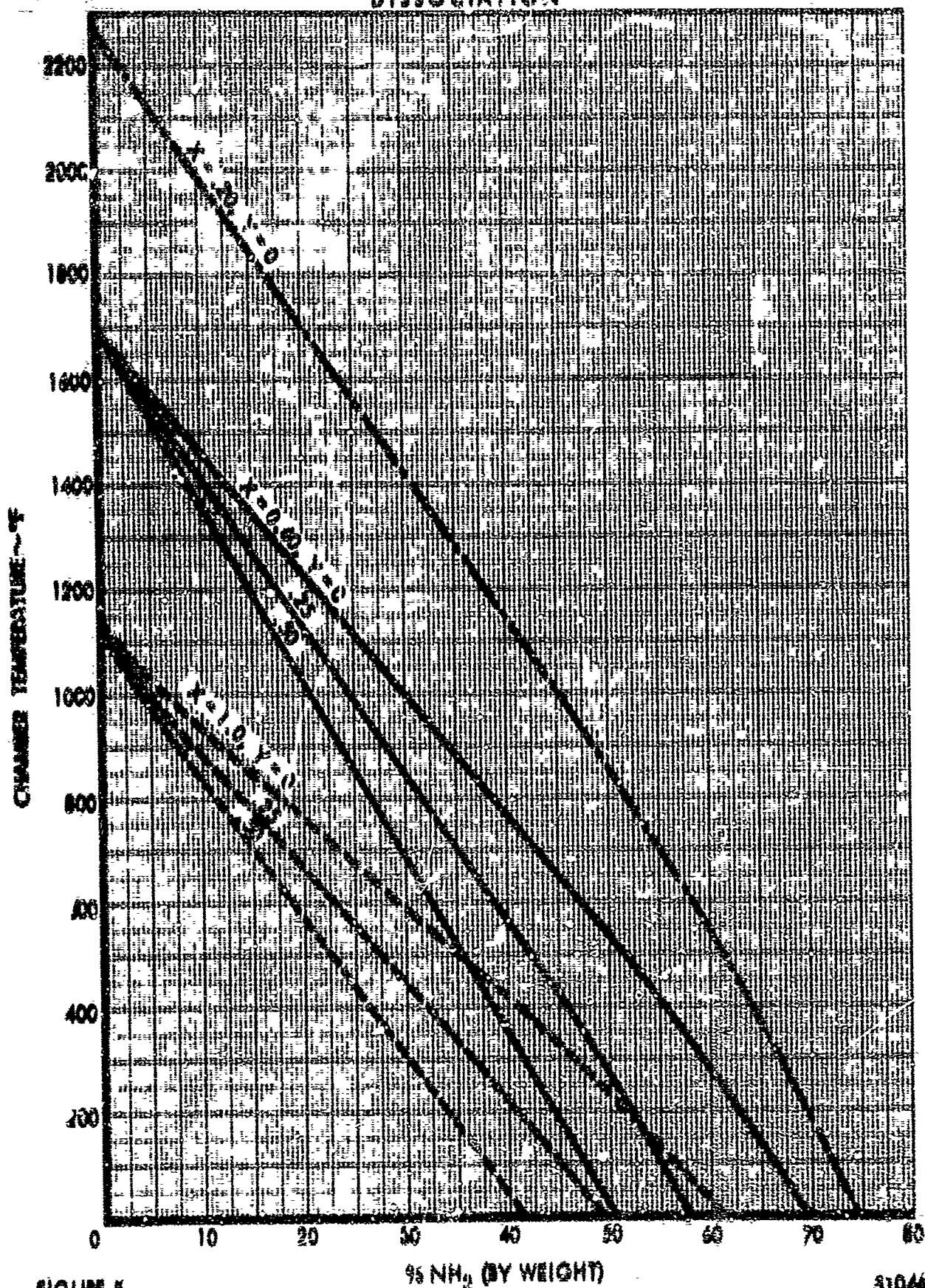
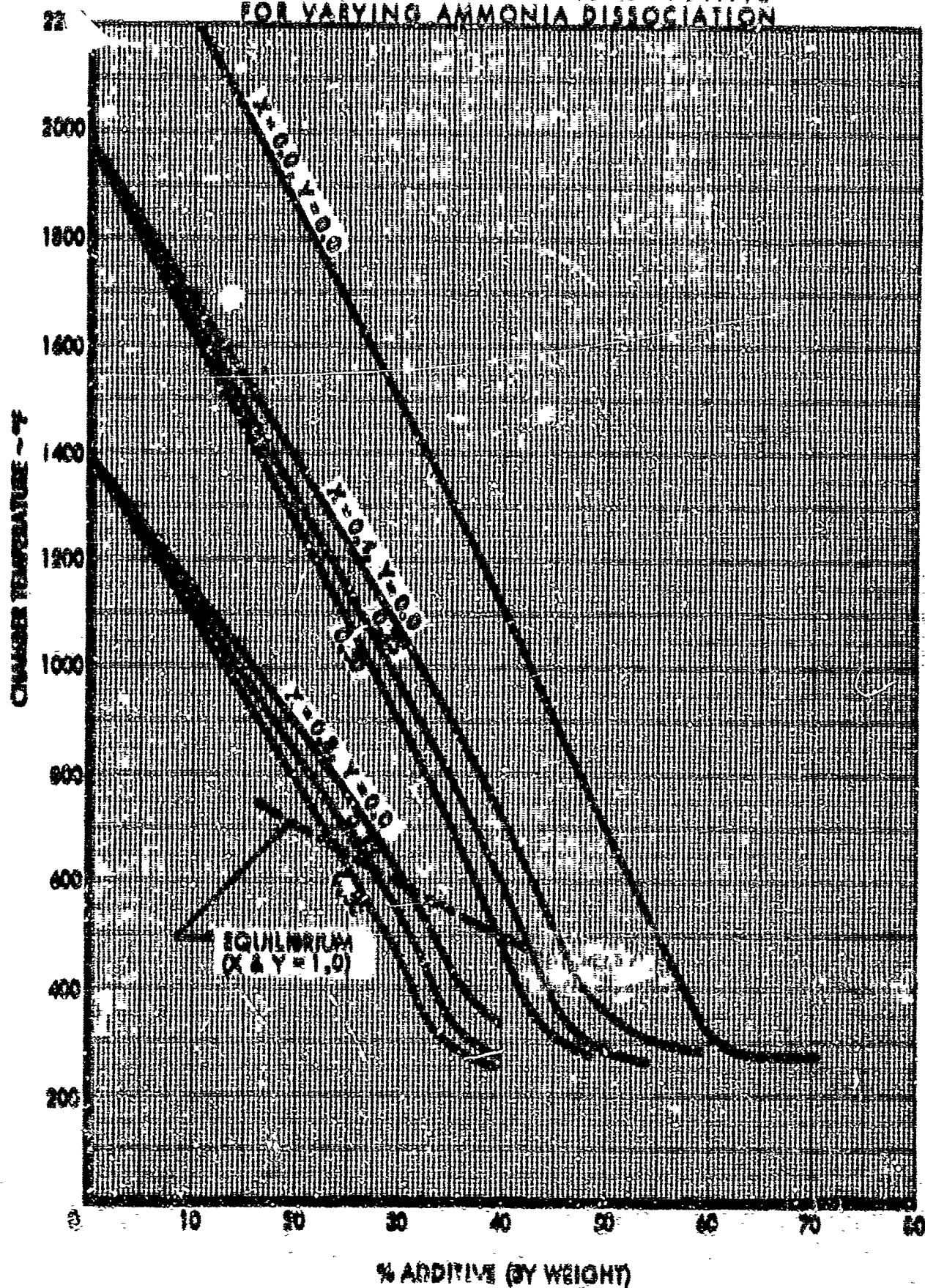


FIGURE 5

HYDRAZINE - EQUAL WEIGHT % H_2O AND NH_3 SYSTEM
CHAMBER TEMPERATURE VS % ADDITIVE
FOR VARYING AMMONIA DISSOCIATION



HYDRAZINE-EQUAL WEIGHT % H_2O AND NH_3 SYSTEM
CHAMBER TEMPERATURE VS % ADDITIVE
FOR VARYING AMMONIA DISSOCIATION

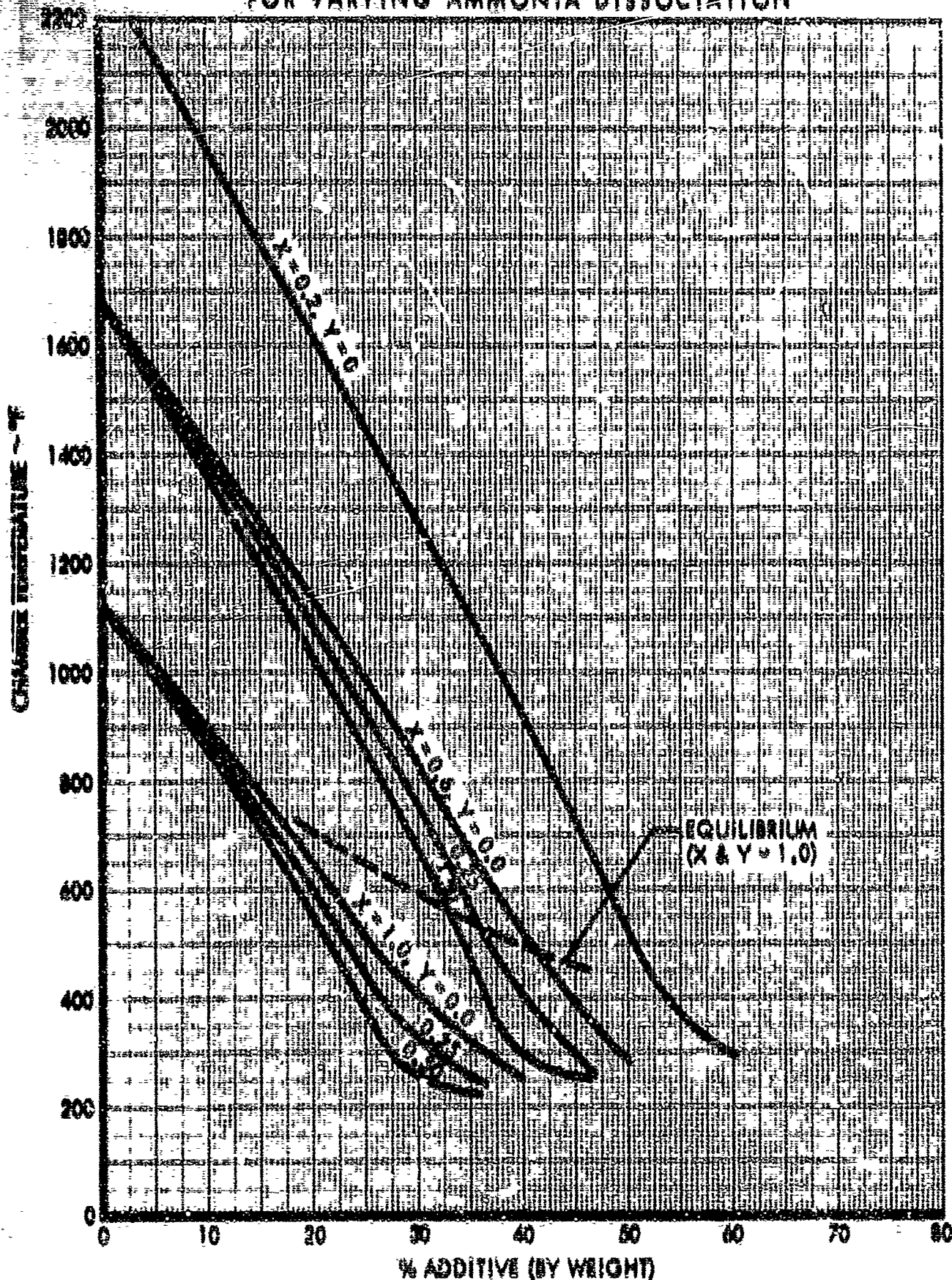
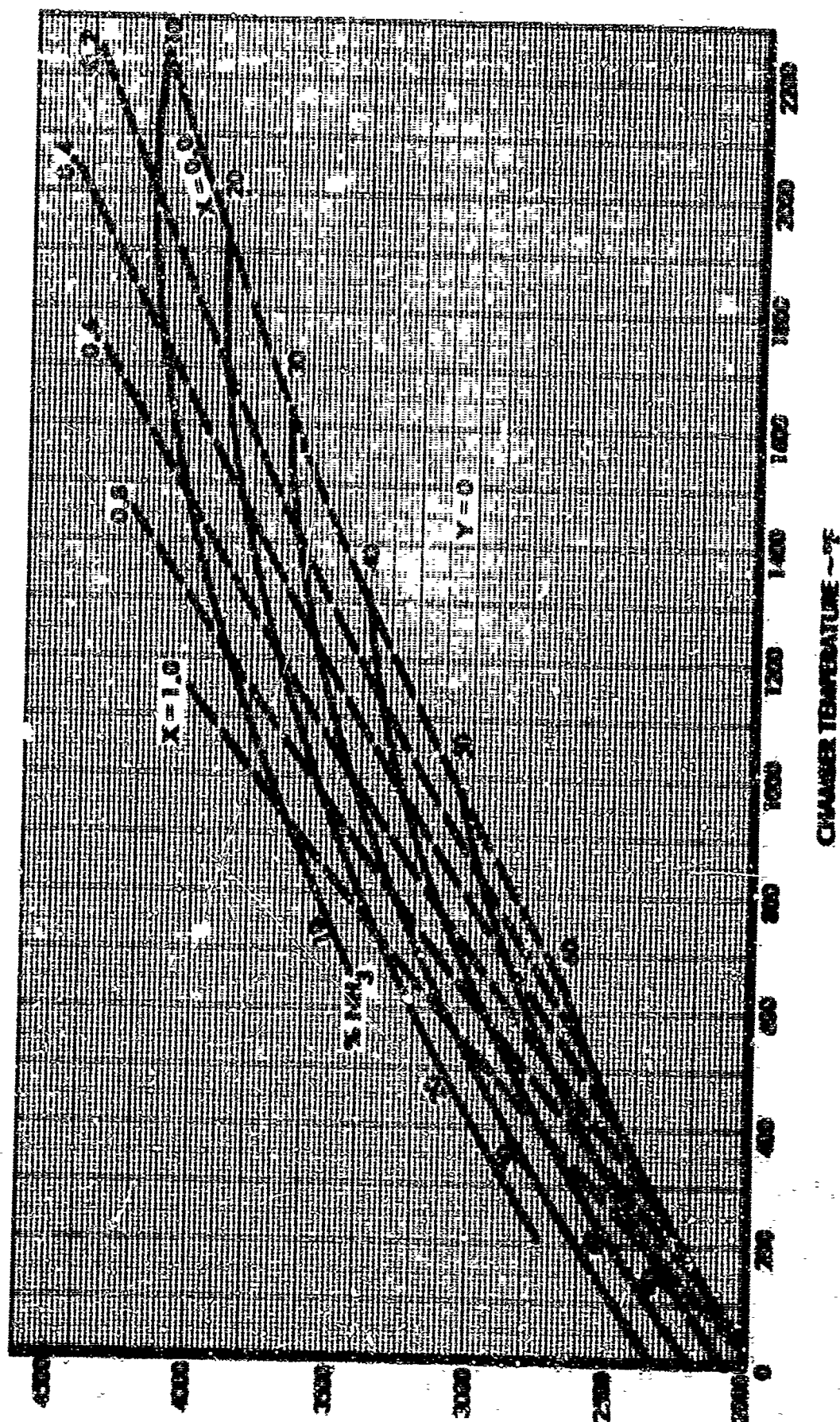


FIGURE 7

PERFORMANCE OF THE HYDRAZINE - AMMONIA SYSTEM AS A FUNCTION
OF TEMPERATURE (BE AND NH_3 DISSOCIATION)



PERFORMANCE OF THE HYDRAZINE - H_2O SYSTEM AS A FUNCTION OF
TEMPERATURE AND NH_3 DISSOCIATION

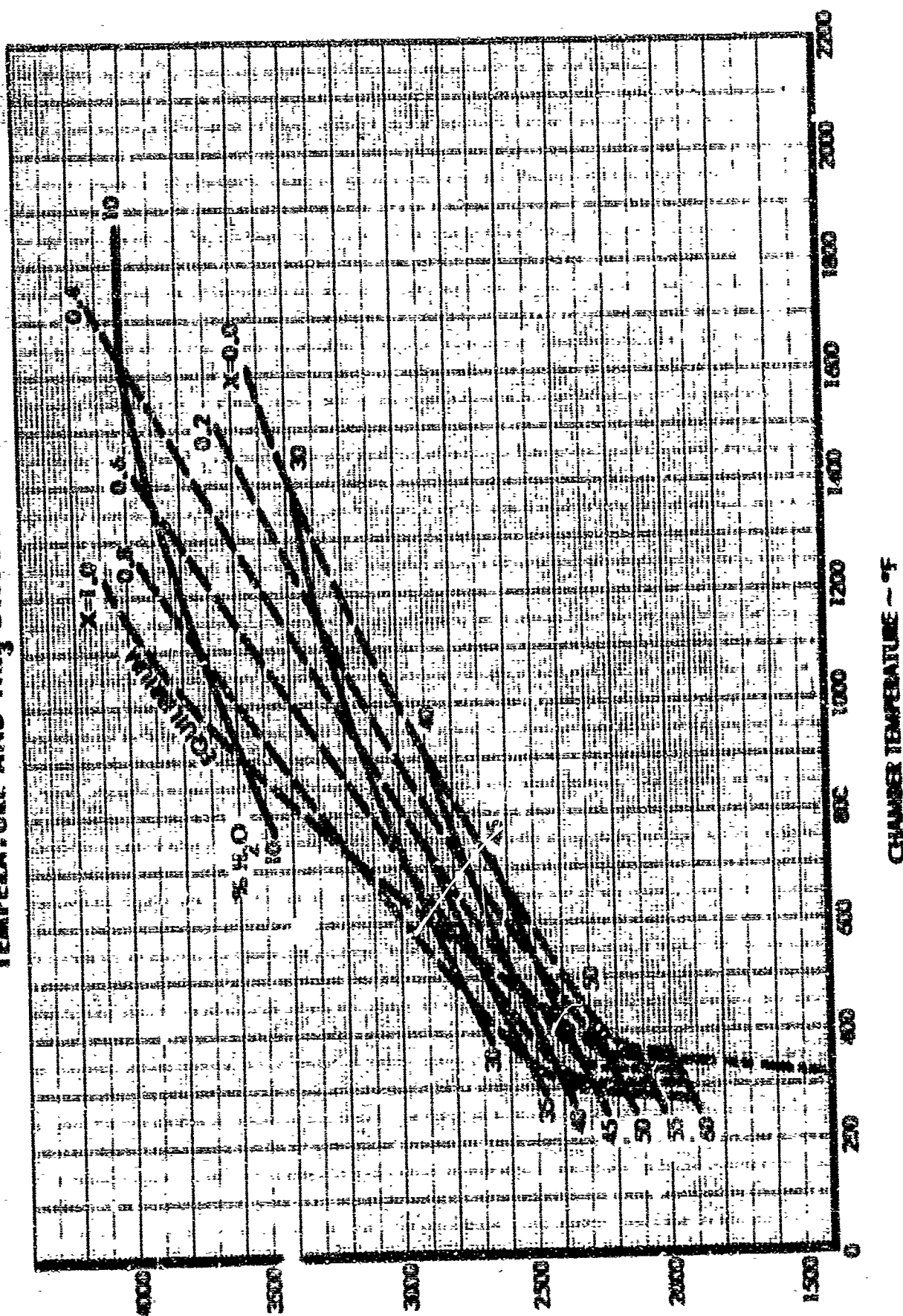
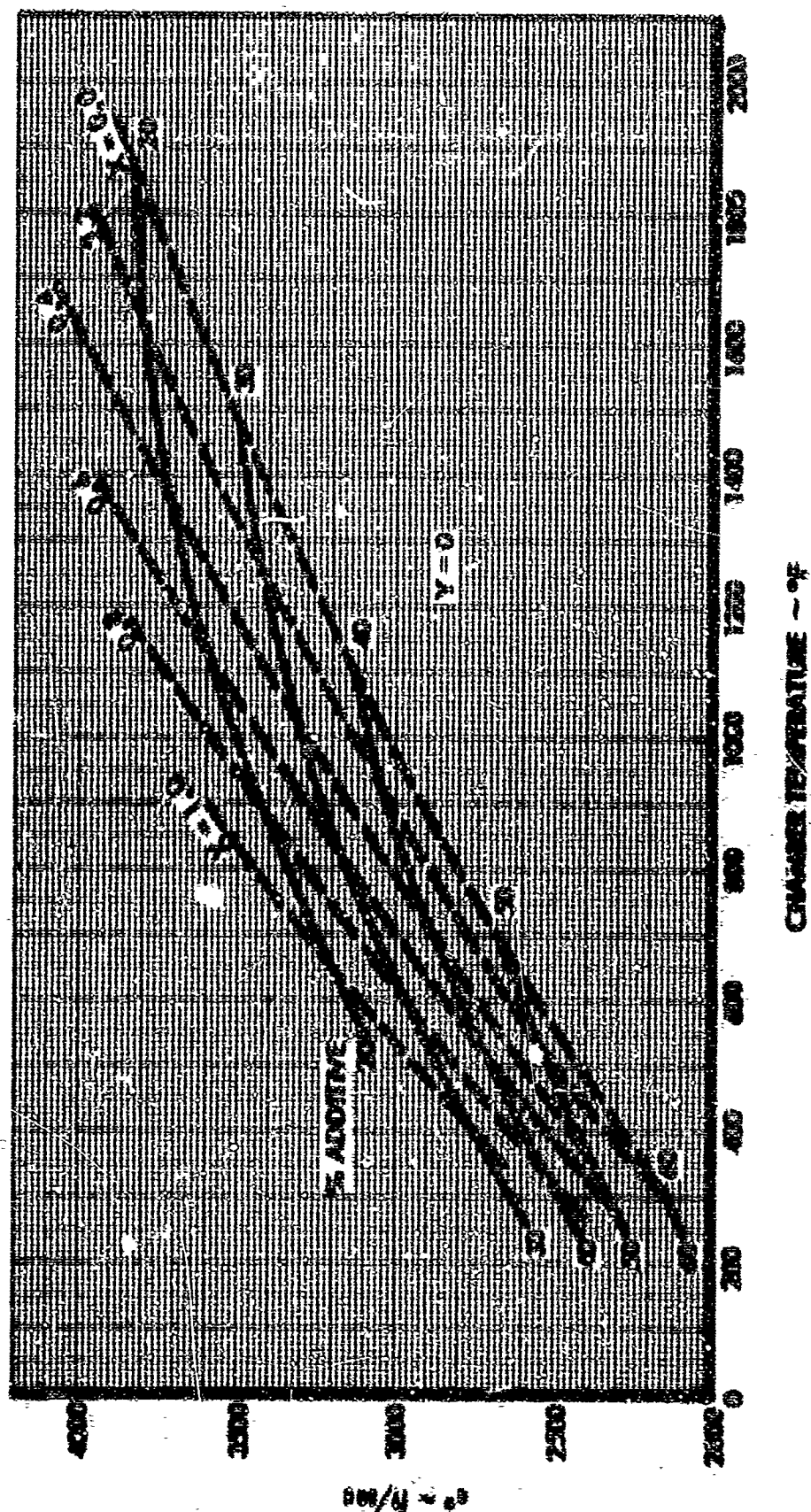


FIGURE 9

PERFORMANCE OF THE HYDRAZINE - EQUAL WT % H_2O AND NH_3 SYSTEM
AS A FUNCTION OF TEMPERATURE AND NH_3 DISSOCIATION



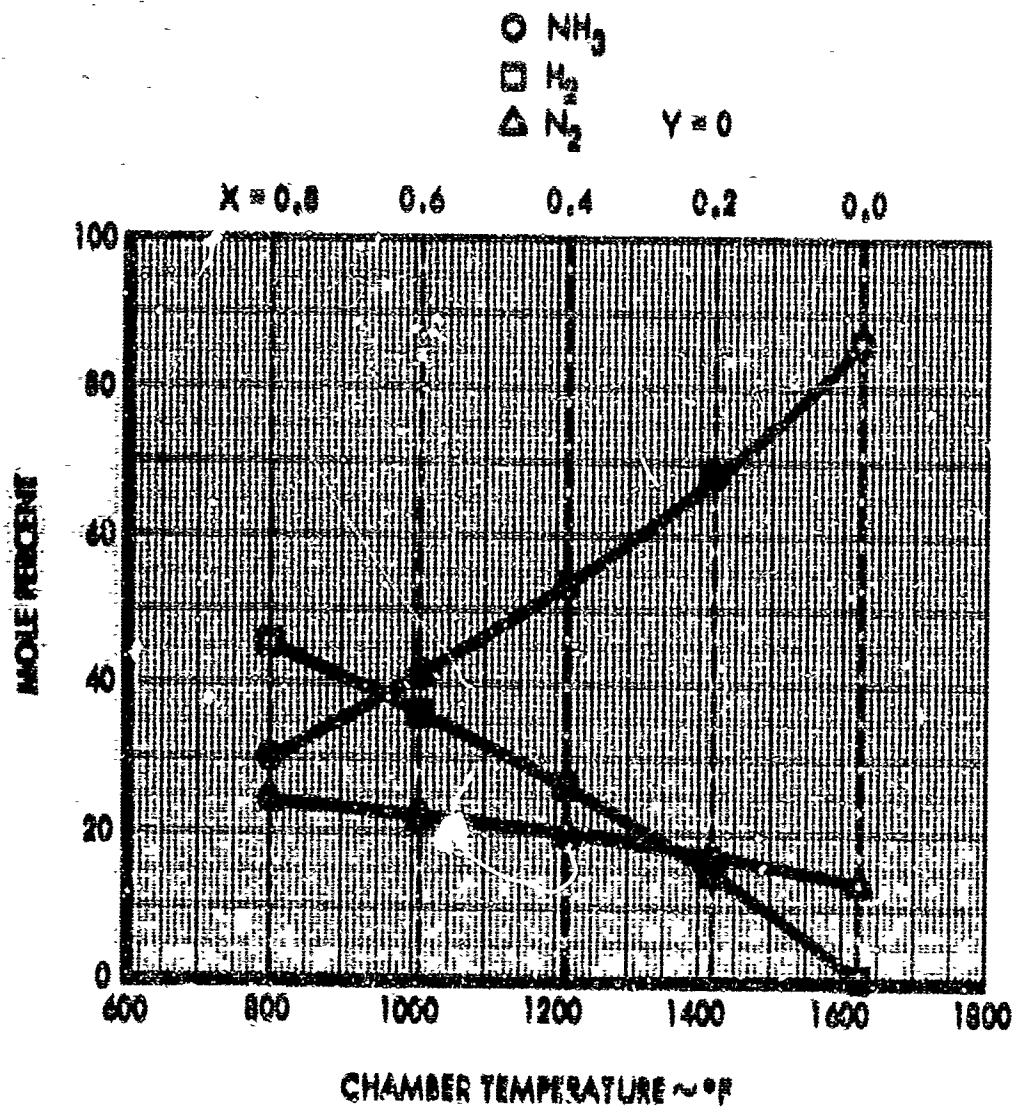
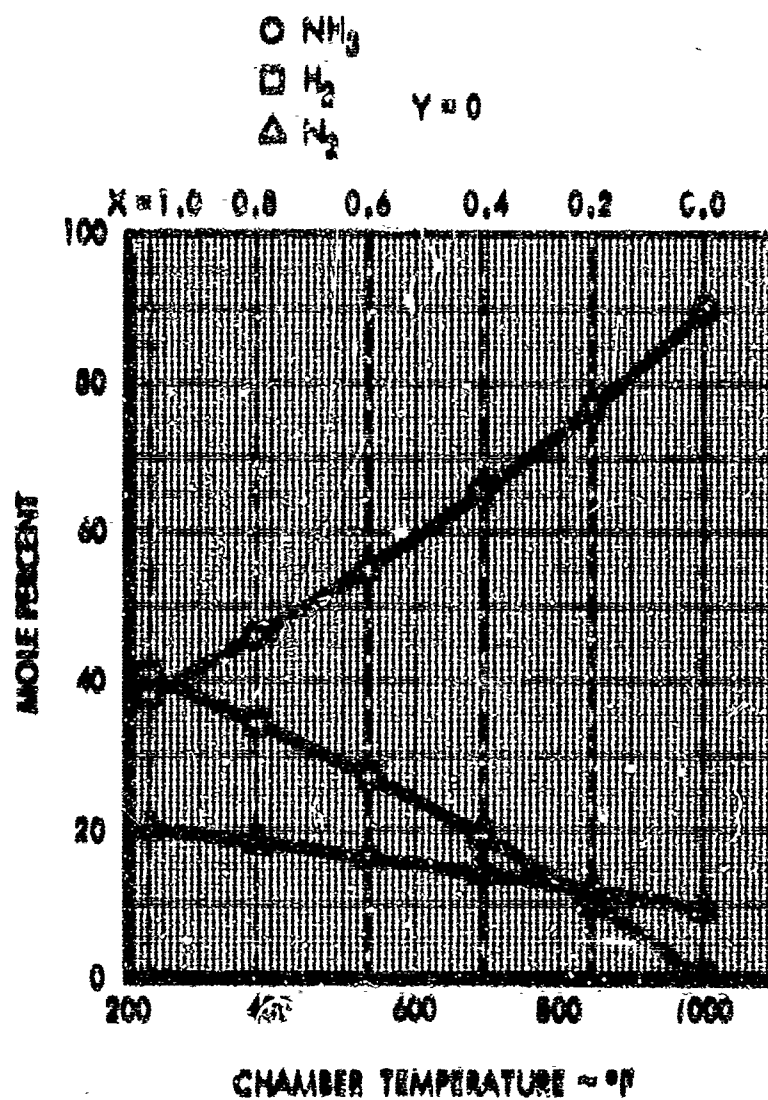
70% HYDRAZINE - 30% NH_3 SYSTEM
REACTION PRODUCT COMPOSITION

FIGURE 11

50% HYDRAZINE - 50% NH_3 SYSTEM REACTION PRODUCT COMPOSITION



60% HYDRAZINE - 40% NH_3 SYSTEM

REACTION PRODUCT COMPOSITION

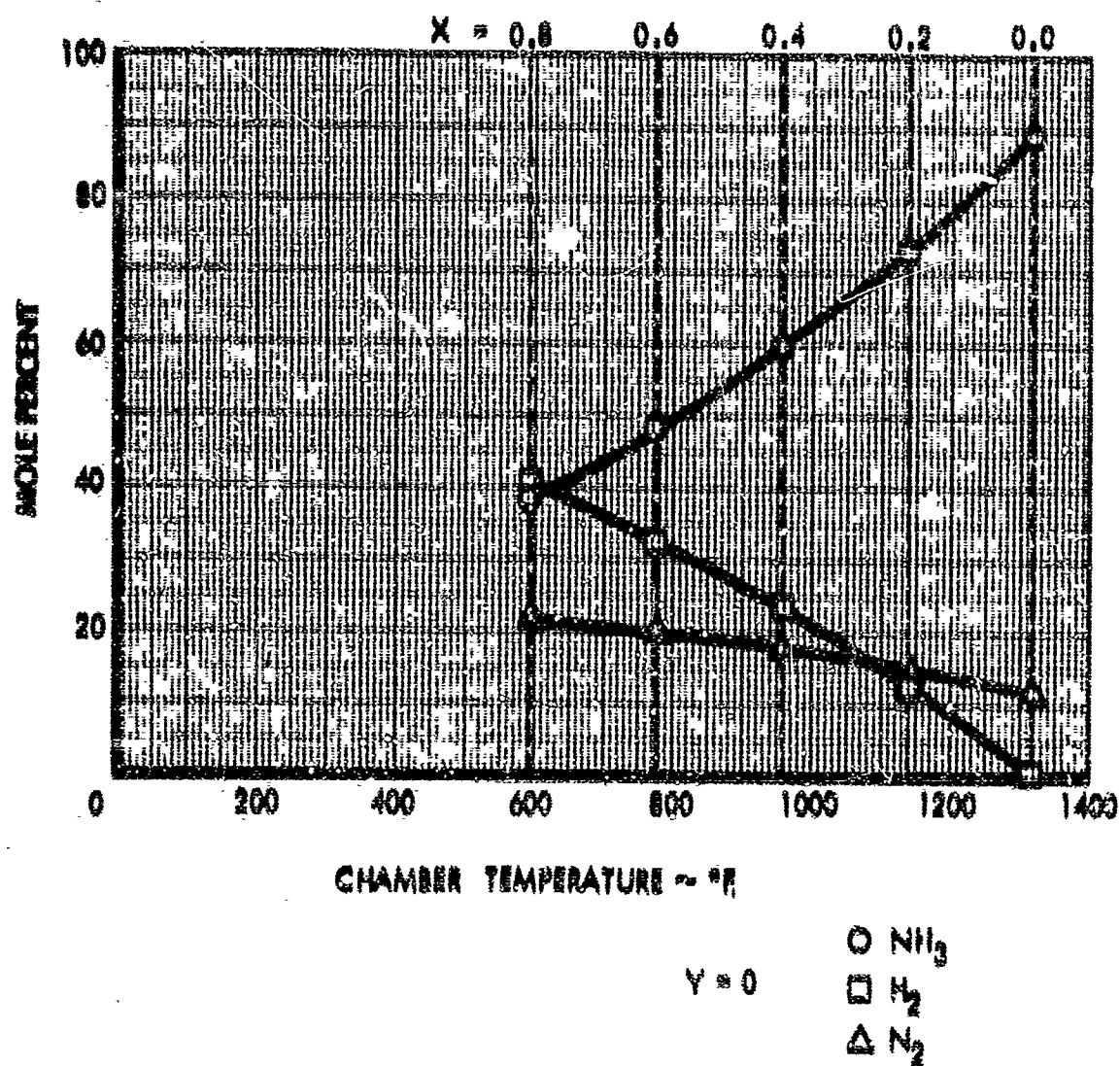
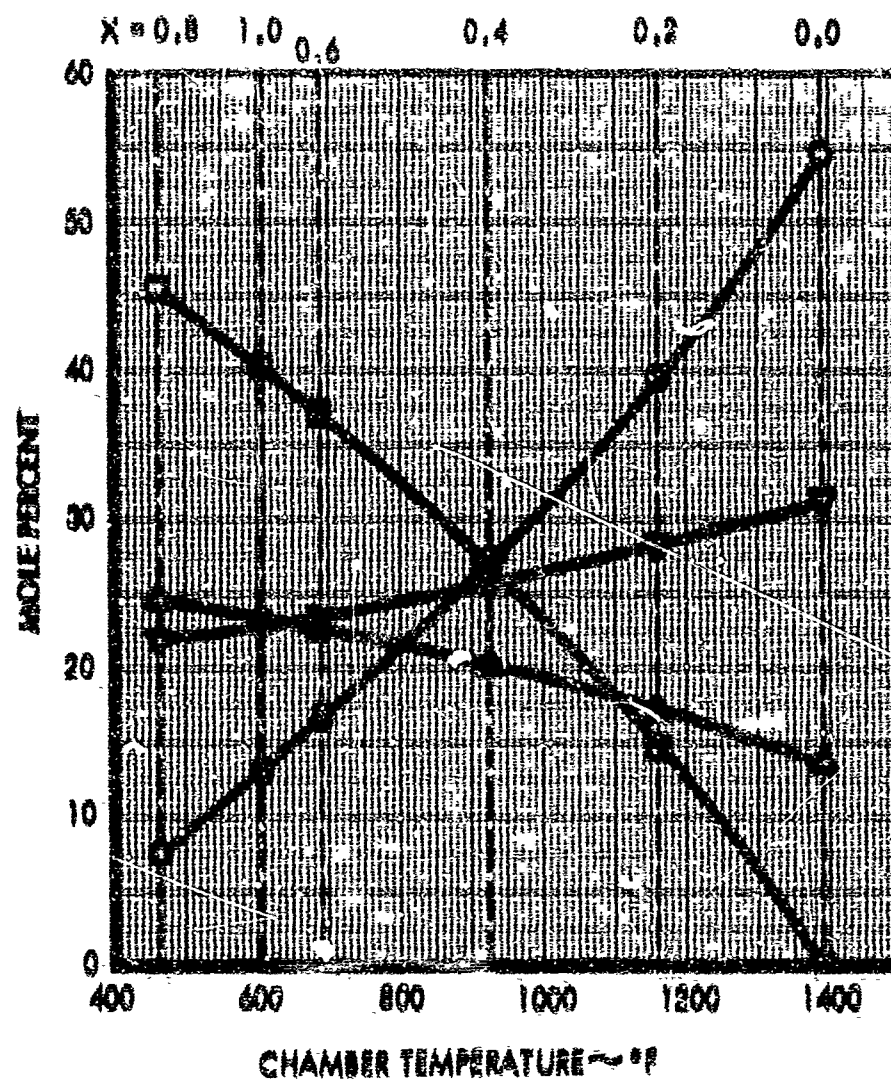


FIGURE 13

70% HYDRAZINE - 30% H_2O SYSTEM
REACTION PRODUCT COMPOSITION

$\square$ NH_3 $\triangle$ N_2
 $\square$ H_2 ∇ H_2O



85% HYDRAZINE - 45% H₂O SYSTEM
REACTION PRODUCT COMPOSITION

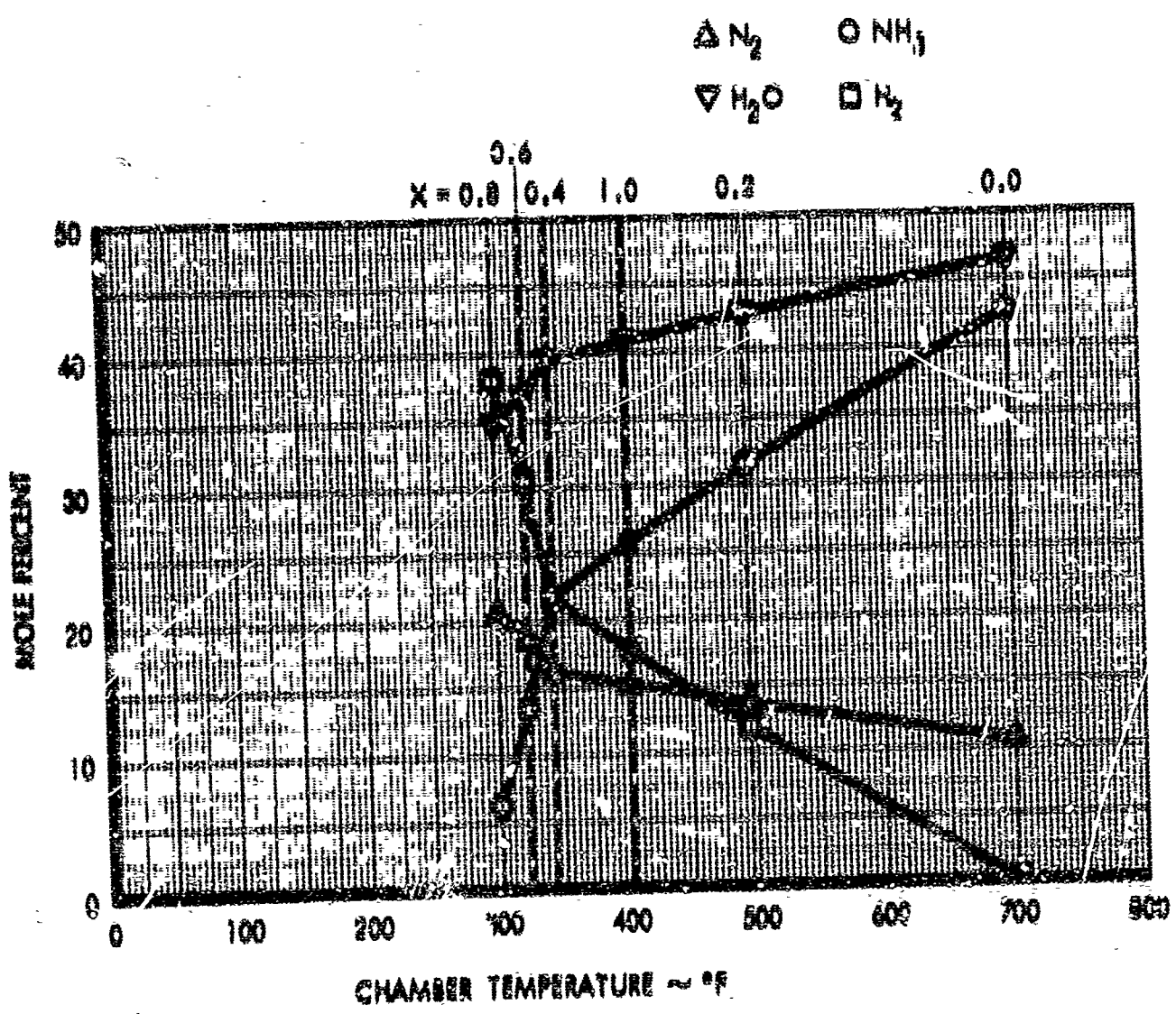


FIGURE 15

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3. REPORT TITLE Development of Low Temperature Gas Generator Technology		
4. DESCRIPTIVE NOTES (Type of report and dates (if dates)) Final Report January 3, through November 14, 1966		
5. AUTHOR (Last name, first name, initial) Poole, Donald R.		
6. REPORT DATE December 1966	7. TOTAL NO. OF PAGES 65	7A. NO. OF PAGES 4
8. CONTRACT OR GRANT NO. AF 04(611)-11576	9. ORIGINATOR'S REPORT NUMBER(S) RRC-66-R-74	
10. SUBJECT NO.	11. AIR FORCE REPORT NO. (Any other numbers that may be assigned) AFRPL-TR-66-226	
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The objective of this program was to characterize monopropellant hydrazine-based monopropellants which, by the use of ammonia and ammonia-water diluents, are capable of producing clean, low temperature gases when passed through a catalytic decomposition chamber. During the course of the 12-month program, thermoechemical calculations were performed on a large number of cases involving various compositions of hydrazine, ammonia, and water. The effect of varying the amount of ammonia dissociation was investigated in the above calculations. Based upon the results of the thermoechemical calculations and preliminary physical property testing, seven different solutions composed of various concentrations of hydrazine, water and/or ammonia were selected for further evaluation. The freezing points of the solutions were determined; and the vapor pressures, densities, and viscosities were measured over a wide temperature range. A low temperature gas generator was designed to produce approximately 60 standard cubic feet of gas per minute and to operate at a nominal chamber pressure of 300 psi. This gas generator was fired with each of the seven monopropellants in order to determine their steady state performance characteristics. In addition, a 1 lbf gas generator thruster was fired in pulse mode operation at various pulse widths and duty cycles with each of the seven monopropellants. The complete test results are presented in tabular form.		

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12. KEY WORDS	LINK A		LINK B		LINK C	
	RULE	BY	RULE	BY	RULE	BY
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Gas Generator						
Propellants						
Monopropellant						
Hydrazine						

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