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EFFECT OF PROPELLANT AND CATALYST BED TEMPERATURES ON THRUST BUILDUP IN SEVERAL HYDROGEN PEROXIDE REACTION CONTROL ROCKETS

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EFFECT OF PROPELLANT AND CATALYST BED TEMPERATURES ON THRUST BUILDUP IN SEVERAL HYDROGEN PEROXIDE REACTION CONTROL ROCKETS

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SUMMARY

An investigation was undertaken to determine the effect of chamber and propellant feed temperatures on the starting characteristics of hydrogen peroxide thrust chambers. Start delay times for two types of thrust chamber designs in the 1- to 24-pound-thrust range were obtained over a range of chamber and propellant feed temperatures from 30° to 100° F. Start delay times obtained during the first minute of catalyst bed life and again after 6 minutes of total accumulated running time are presented as a function of chamber and propellant feed temperatures.

The initial cold-start delay time of the hydrogen peroxide thrust chambers investigated was approximately 0.150 second to attain 90 percent of steady-state chamber pressure at chamber and propellant feed temperatures of 70° F and above. Both thrust chamber designs could be started at chamber and propellant feed temperatures as low as 30° F; start delay times did, however, generally increase at low temperatures. When the chamber was at an elevated temperature from a preceding firing, the start delay time was reduced to approximately 0.050 second, indicating a marked effect of chamber temperature at constant propellant feed temperatures. Accumulated run time affected the starting characteristics only when both the chamber and propellant feed temperatures were at reduced levels.

INTRODUCTION

Since 1953, when the X-1 series experimental aircraft reached altitudes where conventional aerodynamic surfaces were inadequate for control purposes, forces developed by catalytic decomposition of 90 percent hydrogen peroxide in small rocket thrust chambers have been used extensively to provide attitude control at high altitudes. The X-1B used 75-pound-thrust hydrogen peroxide rockets mounted on the wing tips to provide control forces. The reaction control system for the X-15 research airplane also incorporates hydrogen peroxide rockets. Presently, hydrogen peroxide reaction control systems have been incorporated for the space vehicles of Projects Mercury, Scout, and Centaur. These vehicles will use hydrogen peroxide rockets with thrust ranging from 1 to 100 pounds to produce functions of (1) vehicle alinement prior to firing final stages, (2) pitch over and initial stabilization in orbit, (3) orbit attitude control, (4) vehicle alinement prior to retrorocket firing, and (5) attitude control during reentry.

The starting delay, or response time, of hydrogen peroxide control rockets becomes an important consideration in the design of a reaction control system to perform these functions. Excessive start delay times would impair the automatic reaction control system performance and result in trajectory errors, destabilization during orbital and reentry modes, and touchdown errors. Also, long start delay times result in an increase in propellant consumption.

The investigation described herein was undertaken to determine the starting characteristics of representative commercial production samples of the reaction control thrust chambers of Project Mercury. Three different size thrust chambers for each of two different catalyst bed designs were evaluated on the basis of starting characteristics and catalyst bed endurance. The catalyst bed configurations investigated were (1) a straight through-flow catalyst bed consisting of nickel screen coated with a silver-gold alloy, and (2) a catalyst bed consisting of silver screen activated with samarium nitrate and incorporating a preheater. The thrust sizes of the motors investigated were 1, 6, and 24 pounds. The investigation was conducted over a range of thrust chamber and propellant feed temperatures from 30° to 100° F.

APPARATUS

Thrust Chambers

Schematic drawings of the hydrogen peroxide thrust chamber configurations investigated are shown in figures 1 and 2. The basic components are a propellant distribution plate; a decomposition chamber, which contains the catalyst; and a nozzle. The hydrogen peroxide is decomposed in passing through the catalyst, forming superheated steam and gaseous oxygen. The gases are discharged through the nozzle, converting the thermal energy of the decomposition products into the useful kinetic energy of an exhaust jet.

The three configuration A thrust chambers, shown in figure 1, had straight through-flow catalyst beds designed for a bed loading of approximately 20 (ratio of the pounds of propellant flow per minute to the cross-sectional area of the catalyst bed in square inches). The catalyst bed consisted of disks of nickel screen electroplated with an alloy of 99 percent silver and 1 percent gold. The disks were packed into cups or cartridges and installed in the decomposition chamber. The number of cartridges and the mesh description of the disks employed for each size chamber are indicated on figure 1. To prevent channeling of the propellant flow, the cartridges were so designed that the flow from one cartridge to another would be directed toward the center of the catalyst bed. Also, the design was such that, when the bed was assembled, pressure from one cartridge to another caused the upstream end of the cartridge to flare and form a seal with the thrust chamber wall.

The configuration B thrust chambers, shown in figure 2, were designed for a bed loading of approximately 10. The catalyst material was silver screen activated with a treatment of samarium nitrate. The catalyst bed details are indicated on the figure. In this design, the propellant was injected radially into a silver screen scroll preheater and then was directed axially through the main catalyst bed. The catalyst bed was designed for an interference fit with the chamber wall to prevent channeling of the propellant flow along the edges of the bed.

Environmental Compartment

A photograph of the test installation is presented in figure 3. The test installation consisted of an insulated compartment enclosing the propellant tank, instrumentation, associated valves and piping, and the hydrogen peroxide thrust chamber. The various environmental temperature levels were obtained by either admitting carbon dioxide into the compartment or by circulating the ambient air through an electric heater with a blower. Adjustable temperature sensors, which operated the electric heater and the valves that admitted carbon dioxide into the compartment, automatically controlled the compartment ambient temperature to within a degree of the desired value. The decomposition products of the thrust chamber were ducted from the nozzle and discharged into the atmosphere.

Instrumentation

A diagrammatic sketch of the hydrogen peroxide flow system and the location of the instrumentation is shown in figure 4. Measurements of pressure and temperature were made with high-response instrumentation. Chamber, propellant feed, and propellant tank pressures were measured by strain-gage transducers and recorded on a direct-reading oscillograph. Temperatures were measured using iron-constantan thermocouples and recorded on self-balancing potentiometers and a direct-reading oscillograph. Electric energy to the fire valve was also recorded on the oscillograph to indicate the position of the fire valve.

Propellant and Propellant System

The propellant system (fig. 4) consisted of a $1\frac{1}{2}$-gallon propellant tank, shutoff valve, propellant temperature conditioning coil, and a fire valve. Associated equipment included pressurizing and venting system, overboard dump system, propellant fill system, nitrogen purge system, and a propellant bleed system. Components of the propellant system were fabricated of 300 series stainless steel (ref. 1). The procedures used for material passivation and cleaning are described in references 2 and 3.

The 90 percent hydrogen peroxide used in this investigation conformed to military specification MIL-H-16005

PROCEDURE

Start delay time of the hydrogen peroxide rocket motors is defined as the time from application of electrical energy to open the fire valve to the development of 90 percent of steady-state chamber pressure. Start delay time is then dependent upon several factors: namely, the fire valve opening time, the time required to fill the volume of the flow line between the fire valve and the catalyst bed with propellant, and the time required for decomposition of the hydrogen peroxide in the catalyst bed. Fast response valves closely coupled to the motor were used to minimize the time lag due to flow system hardware. Examination of instrumentation traces shows that system time lag did not exceed 0.030 second.

Each thrust chamber was subjected to a series of tests consisting of (1) initial cold-start tests; (2) cycling, or endurance tests; and (3) cold-start tests after endurance tests. The initial cold-start tests consisted of determining starting characteristics for each thrust chamber over a range of chamber and propellant feed temperatures from 30° to 100° F. At each temperature level investigated, five or more runs were made in order to account for experimental inaccuracies. After completion of the initial start tests, the thrust chamber was then subjected to cycling tests simulating operation of a "bang-bang" reaction control system. The cycling tests for the 24- and 6-pound-thrust chambers consisted of 50 cycles of operation at each of three propellant feed temperatures (40°, 70°, and 100° F). A cycle consisted of 1 second "on" and 20 seconds "off." Also, the thrust chambers were subjected to two periods of continuous operation for 30 seconds at rated chamber pressure. The configuration A 1-pound-thrust chamber was subjected to 2000 consecutive cycles of operation. Each cycle consisted of 0.2 second "on" and 40 seconds "off." A third of the test was run at each of three propellant feed temperatures (40°, 70°, and 100° F). Cold-start delays were then again obtained after completion of the endurance tests to determine the effect of accumulated run time on starting characteristics. The endurance tests and the cold-start tests after endurance were not completed for the configuration B 1-pound-thrust chamber. Additional samples of configuration A thrust chambers of each thrust size were subjected to the cold-start tests to determine the degree of reproducibility of the start delays from one sample catalyst bed to another.

The tests were initiated by establishing a temperature level in the environmental test chamber and allowing the propellant and hardware to condition to the desired temperature. For the cold-start tests, the catalyst bed was purged with nitrogen to remove any products of decomposition from the previous firing. After the catalyst bed was purged, the propellant system was filled to the fire valve by allowing the trapped nitrogen to escape through the propellant bleed system. The thrust chamber was fired manually by applying electric energy to the fire valve; the duration of the firing was controlled by a timer. Cycling of the fire valve for the endurance tests was accomplished by means of automatic sequencing timers.

RESULTS AND DISCUSSION

Start-Delay Characteristics

Typical oscillograph records of cold-start tests of a hydrogen peroxide 24-pound-thrust chamber (configuration A) at two environmental temperature conditions are presented in figure 5. Electric energy to open the fire valve is indicated by the step in the fire valve voltage trace. Timing lines of 0.100-second interval are included on the figure. The dip in the feed pressure trace indicates that the fire valve had opened and propellant flow (considered herein as being indicated by the feed pressure) had been established approximately 0.015 second after the voltage was applied to open the fire valve. Examination of the feed pressure trace during the end of the initial pulse in figure 5(a) shows that the propellant flow was terminated approximately 0.025 second after the electric energy to the fire valve was interrupted. The pressure oscillations observed at the termination of each pulse can be attributed to the entrapped gases in the feed pressure measuring transducer.

Figure 5(a) shows an oscillograph record of 1-second duration pulse tests with the thrust chamber and propellant feed at 40° F. The thrust chamber required about 0.700 second to attain 90 percent of steady-state chamber pressure as shown by the first pulse of the test record. Thus, although the thrust chamber was sequenced for 1-second operation, the start delay time resulted in a thrust chamber operating time of only 0.300 second. After 20 seconds had elapsed, a second pulse of 1-second duration was made with the thrust chamber at an elevated temperature, which resulted from the preceding pulse; propellant feed temperature was maintained at 40° F. The start delay time of the second pulse was reduced to 0.075 second. The start delay times of succeeding pulses were further reduced to an average value between 0.040 to 0.050 second. Thus, at a constant propellant feed temperature, the starting characteristics of the hydrogen peroxide thrust chambers were greatly affected by thrust chamber temperature. The effect of both thrust chamber and propellant feed temperature on cold-start delay times of hydrogen peroxide thrust chambers can be observed by comparing the first pulse of the oscillograph records presented in figures 5(a) and (b). Start delay times decreased from 0.700 second at an environmental temperature condition of 40° to 0.325 second at an environmental temperature of 60° F.

Records of pulse tests of 0.2-second duration of a configuration A 1-pound-thrust chamber are presented in figure 6. These data were obtained at an environmental condition of 40° F and a firing frequency of 3 pulses per minute. Negligible chamber pressure was produced by the initial pulse of 0.2-second duration; however, the thrust chamber skin temperature had increased to approximately 130° F prior to the second pulse. After 20 seconds, a second pulse of 0.2-second duration was made, which resulted in a buildup to 90 percent of steady-state chamber pressure in 0.160 second and increased the thrust chamber temperature to approximately 230° F. The third pulse attained 90 percent of steady-state chamber pressure in 0.100 second. The start delay time of succeeding pulses was reduced to approximately 0.050 second.

Effect of Temperature on Start Delay Time

Cold-start delay times measured with the three different size configuration A and B chambers are presented in figures 7 to 12 as a function of chamber and propellant feed temperature. The results of endurance tests to determine the effect of accumulated run time on the catalyst bed are presented in an abbreviated form in tables I and II. Chamber pressure, feed pressure, pressure drop across the bed, and start delay time are tabulated at various values of total accumulated run time for three different size thrust chambers of both designs, with the exception of the configuration B 1-pound-thrust chamber.

Figures 7(a), 8(a), and 9(a) present start delay times of configuration A thrust chambers in 24-, 6-, and 1-pound-thrust sizes, respectively. The curves represent the upper limit of cold-start delay times measured with several catalyst beds of each thrust size. The solid curves represent the upper limits of cold-start delay times for the first sample bed; the dashed curves with no data point represent the limits with the second and third sample beds. These data were obtained during the first minute of accumulated run time. Examination of the curves with data points shows that considerable scatter in start delay times occurred at all three thrust levels. Although only limited data were obtained with the additional sample beds, a similar scatter would be expected. An even greater variation in starting characteristics was experienced with different samples of the same catalyst bed. For example, variations in start delays of 0.200 to 1.200 second were obtained with two sample 24-pound-thrust chambers at the same environmental condition of 40° F (fig. 7(a)). For all three sizes of configuration A thrust chamber, the spread in the start delay time data was reduced as the chamber and propellant feed temperatures were increased. At chamber and propellant feed temperatures of 70° F and above, the start delays of the hydrogen peroxide thrust chambers were reproducible within 0.050 second. At these higher temperatures, approximately 0.150 second was required to attain 90 percent of steady-state chamber pressure.

Figures 7(b), 8(b), and 9(b) present start delay times of the thrust chambers after approximately 6 minutes of accumulated run time. In most cases, accumulated run time adversely affected the starting characteristics of the thrust chambers when both the chamber and propellant feed temperatures were at reduced levels. The start delay times of the 6- and 1-pound thrust chambers increased considerably at chamber and propellant feed temperatures of 70° F and below, while no significant change in start delay time was obtained for the 24-pound thrust chamber until the environmental temperature was reduced to 40° F. Occasional "flood-outs", with no chamber pressure buildup in 2 seconds, were experienced with each thrust chamber when the chamber and propellant feed temperatures were reduced to approximately 40° F. Accumulated run time appeared to have no effect on starting characteristics at elevated environmental temperature conditions. The pressure drop across the catalyst bed increased slightly with accumulated run time (table I).

Figures 10(a), 11(a), and 12 present similar data obtained during the first minute of operation with the three configuration B thrust chambers for a range of chamber and propellant feed temperature. Only one sample of each size thrust chamber was investigated. Starting delays of the thrust chambers were short, reproducible, and relatively insensitive to environmental temperature condition. Approximately 0.150 second was required to attain 90 percent of steady-state chamber pressure with the 24- and 6-pound thrust chambers at environmental conditions of 60° F and above (fig. 10(a) and 11(a)). The start delay time of the 1-pound-thrust chamber at the same environmental condition was 0.350 second. All three configuration B thrust chambers exhibited a slight increase in start delay time as the environmental temperature was decreased below 60° F. The increased start delay times obtained with the 1-pound-thrust chamber (0.300 to 0.400 sec) may be attributed to the fact that the system fill time was increased as a result of an orifice incorporated by the manufacture at the motor inlet (fig. 2(a)), thereby reducing the effective injection pressure.

Figures 10(b) and 11(b) present the start delay times for the 24- and 6-pound configuration B thrust chambers, respectively, after approximately 6 minutes of accumulated run time. The accumulated run time adversely affected the starting characteristics of the 24-pound chamber; start delay times (fig. 10(b)) increased rapidly with decreased environmental temperature, and "flood-outs" occurred at chamber and propellant feed temperatures of 40° F. Accumulated run time had very little effect on the starting characteristics of the 6-pound-thrust chamber (fig. 11(b)). The pressure drop across the catalyst bed increased slightly for only the 6 pound thrust chamber with accumulated run time (table II). No corresponding data were obtained for the 1-pound-thrust chamber.

CONCLUDING REMARKS

The thrust chambers of both configuration A and B designs demonstrated the capability of starting at reduced chamber- and propellant-feed-temperature conditions during the first minute of bed life. The start delay times of configuration B thrust chambers obtained during the first minute of operation were short, reproducible, and relatively insensitive to environmental condition. However, only one sample of each size thrust chamber was investigated. The initial start delay times of configuration A thrust chambers varied greatly from one sample catalyst bed to another particularly at reduced environmental conditions. Certain catalyst beds had short and reproducible start delay times over the entire range of environmental conditions; other beds had start delays that were adversely affected when both the chamber and propellant feed temperatures were at reduced levels.

The starting characteristics of the configuration A 6- and 1-pound-thrust chambers were adversely affected by accumulated run time at reduced chamber and propellant feed temperatures; no significant change was observed for the 24-pound thrust chamber until the environmental condition was reduced to 40° F. The configuration B 24-pound-thrust chamber was also adversely affected by accumulated run time at environmental temperature conditions of 60° F and below. No appreciable change was observed for the configuration B 6-pound-thrust chamber with accumulated run time. "Flood-out" occurred at environmental temperature conditions of approximately 40° F for both thrust chamber designs after 6 minutes of prior accumulated run time. Catalyst bed pressure drop increased with run time for most of the thrust chambers investigated.

It is believed that the combination of the catalyst bed treatment with samarium nitrate, the low bed loading employed, and the preheat design concept of configuration B thrust chambers contributed to the shorter and more reproducible start delays observed with these chambers.

The start delay tests were conducted with the thrust chambers exposed to normal atmospheric conditions between runs. It is not known to what extent moisture and contaminants introduced in this way influence the starting characteristics and the bed life of the thrust chambers. Application of such thrust chambers to a space vehicle control system would not entail similar exposure.

SUMMARY OF RESULTS

The starting characteristics of 90 percent hydrogen peroxide reaction control thrust chambers of two different catalyst bed designs, herein referred to as configurations A and B, were studied experimentally over a range of environmental temperatures conditions from 30° to 100° F. The following results were obtained:

1. In general, the initial cold-start delay times of thrust chambers of both catalyst bed designs investigated was approximately 0.150 second at environmental temperatures of 70° F and above. These thrust chambers were capable of starting at chamber and propellant feed temperatures as low as 30° F; however, in some cases start delay times were adversely affected by reduced temperatures.

2. The initial cold-start delay times of configuration A thrust chambers varied greatly from one sample catalyst bed to another at reduced environmental temperature conditions. Certain sample beds produced short and reproducible start delays over the range of environmental temperatures investigated; other sample beds had start delay times that increased rapidly when the chamber and propellant feed temperatures were reduced.

3. The initial cold-start delay times of configuration B thrust chambers were short, reproducible, and relatively insensitive to environmental temperature; however, only one sample of each size thrust chamber was investigated.

4. Start delay times of the hydrogen peroxide thrust chambers were significantly affected by thrust chamber temperature at a given propellant feed temperature. At conditions where the chamber was at an elevated temperature resulting from a preceding firing, the start delay time decreased to a value of about 0.050 second.

5. Accumulated run time (6 min) significantly affected starting characteristics of some of the chambers at reduced chamber and propellant feed temperatures; no effects were observed at elevated temperatures.

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National Aeronautics and Space Administration
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TABLE I. - ENDURANCE TEST OF 90 PERCENT HYDROGEN PEROXIDE THRUST CHAMBERS; CONFIGURATION A

Run	Chamber pressure, lb/sq in.	Propellant feed pressure, lb/sq in.	Pressure drop across bed, lb/sq in.	Propellant feed temp., $^{\circ}F$	Start delay, sec	Accumulated run time, sec
24 lb thrust chamber						
1	248	425	177	48	0.511	103
2	232	429	197	48	.070	104
3	256	452	196	50	.062	105
4	254	452	198	50	.059	106
5	254	450	196	50	.059	107
20	266	463	197	47	.054	122
21	264	463	199	47	.055	123
22	265	464	199	47	.057	124
23	264	463	199	47	.052	125
24	264	460	196	47	.054	126
25	262	457	195	47	.053	127
40	263	463	200	47	.052	142
41	262	463	201	47	.058	143
42	264	464	200	47	.054	144
43	264	460	196	48	.052	145
44	261	458	197	48	.054	146
45	259	460	201	48	.053	147
60	264	471	207	69	.051	192
61	264	468	204	68	.051	193
62	265	468	203	69	.053	194
63	264	466	202	69	.051	195
64	266	468	202	69	.050	196
65	264	463	199	70	.051	197
80	260	463	203	67	.052	212
81	260	463	203	67	.053	213
82	260	461	201	67	.053	214
83	258	463	205	67	.052	215
84	260	463	203	68	.049	216
85	257	458	201	68	.053	217
100	258	466	208	69	.055	232
101	258	462	204	69	.054	233
102	260	458	198	69	.052	234
103	257	461	204	69	.053	235
104	257	458	201	69	.053	236
105	261	468	207	69	.053	237
120	258	464	206	99	.058	282
121	259	464	205	99	.060	283
122	262	466	204	99	.059	284
123	259	462	203	99	.059	285
124	259	462	203	99	.058	286
125	259	458	199	99	.059	287
140	260	464	204	100	.060	302
141	261	464	203	100	.060	303
142	258	461	203	100	.059	304
143	258	458	200	100	.060	305
144	257	461	204	100	.061	306
145	262	467	205	100	.060	307
156	261	467	206	100	.056	318
157	259	467	208	100	.056	319
158	259	464	205	100	.055	320
159	260	464	204	99	.054	321
160	258	466	208	99	.054	322
161	258	467	209	100	.058	323

TABLE I. - Continued. ENDURANCE TEST OF 90 PERCENT HYDROGEN

PEROXIDE THRUST CHAMBERS; CONFIGURATION A

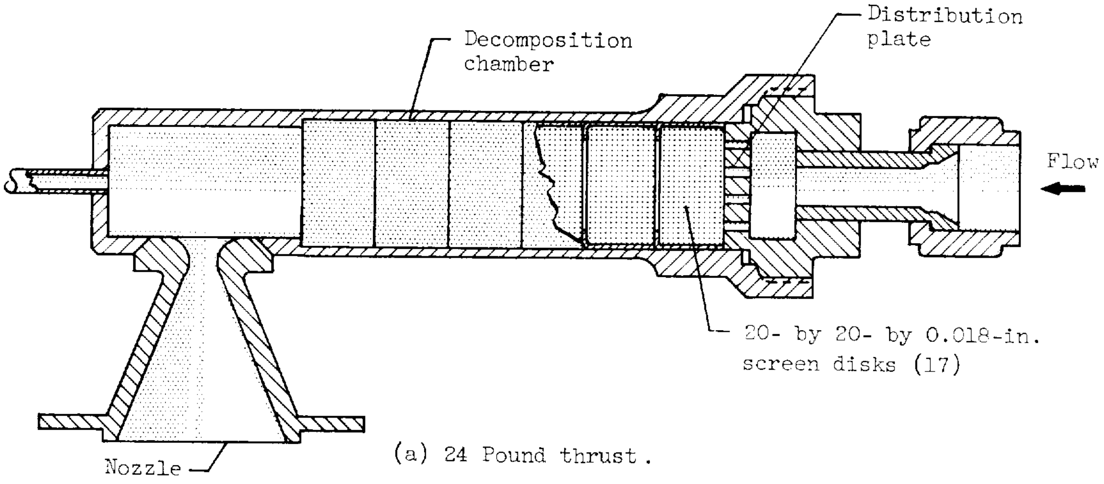
Run	Chamber pressure, lb/sq in.	Propellant feed pressure, lb/sq in.	Pressure drop across bed, lb/sq in.	Propellant feed temp., °F	Start delay, sec	Accumulated run time, sec
6 lb thrust chamber						
1	217	453	236	52	0.490	133
2	217	453	236	52	.065	134
3	217	453	236	52	.061	135
4	218	454	236	52	.037	136
5	218	451	233	53	.035	137
20	210	450	240	53	.032	152
21	208	451	243	53	.035	153
22	210	451	241	53	.034	154
23	211	450	239	53	.036	155
24	211	451	241	53	.035	156
25	209	451	242	53	.034	157
40	208	457	249	53	.034	172
41	208	459	251	53	.035	173
42	210	453	243	53	.033	174
43	208	459	251	53	.034	175
44	209	460	251	53	.032	176
45	210	454	244	53	.033	177
60	208	459	251	80	.037	222
61	211	459	248	80	.035	223
62	218	456	238	80	.040	224
63	218	456	238	80	.038	225
64	219	456	237	80	.039	226
65	221	457	236	80	.040	227
80	223	459	236	79	.041	242
81	223	459	236	79	.042	243
82	223	459	236	79	.043	244
83	223	456	233	79	.041	245
84	224	460	236	79	.043	246
85	223	459	236	79	.042	247
100	223	459	236	79	.043	262
101	223	459	236	79	.046	263
102	222	459	237	79	.045	264
103	223	459	236	79	.045	265
104	221	456	235	79	.044	266
105	221	457	236	79	.042	267
120	218	457	239	100	.049	312
121	216	459	243	100	.047	313
122	217	459	242	100	.051	314
123	217	456	239	100	.044	315
124	217	459	242	100	.048	316
125	216	456	240	100	.047	317
154	219	460	241	100	.053	346
155	218	460	242	100	.048	347
156	218	459	241	100	.049	348
157	219	460	241	100	.044	349
158	219	459	240	100	.049	350
159	219	459	240	100	.044	351

TABLE I. - Concluded. ENDURANCE TEST OF 90 PERCENT HYDROGEN PEROXIDE THRUST CHAMBERS; CONFIGURATION A

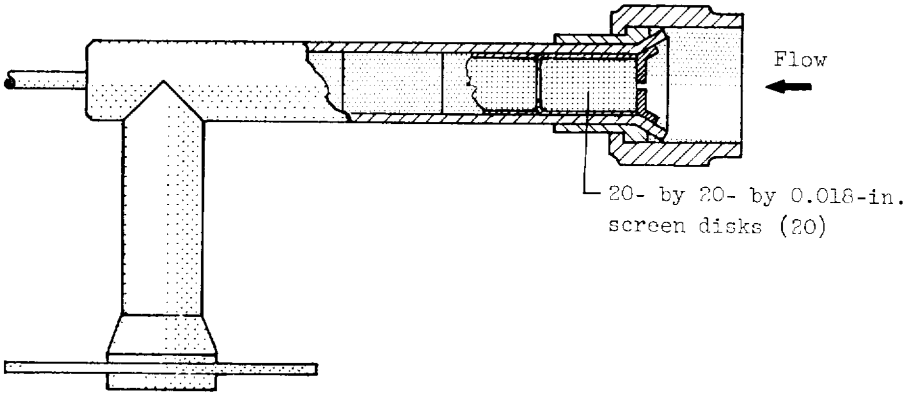
Run	Chamber pressure, lb/sq in.	Propellant feed pressure, lb/sq in.	Pressure drop across bed, lb/sq in.	Propellant feed temp., °F	Start delay, sec	Accumulated run time, sec
1 lb thrust chamber						
1	---	455	---	48	----	82.2
2	148	457	309	48	0.092	82.4
3	151	455	304	48	.068	82.6
101	167	458	291	49	.050	102.2
102	166	458	292	49	.046	102.4
201	151	448	297	47	.039	122.2
202	149	448	299	47	.037	122.4
301	151	452	301	47	.041	142.2
302	148	452	304	47	.045	142.4
401	144	455	306	49	.040	162.2
402	149	455	306	49	.039	162.4
501	146	457	311	47	.040	182.2
502	146	457	311	47	.036	182.4
601	142	454	312	48	.038	202.2
602	143	454	311	48	.040	202.4
701	147	457	310	81	.047	222.2
702	145	457	312	81	.047	222.4
801	149	458	309	80	.047	242.2
802	149	458	309	80	.045	242.4
901	151	459	308	80	.050	262.2
902	151	459	308	80	.050	262.4
1001	153	459	306	80	.050	282.2
1002	153	459	306	80	.046	282.4
1101	150	460	310	80	.049	302.2
1102	151	460	309	80	.046	302.4
1201	149	457	308	80	.050	322.2
1202	149	457	308	80	.048	322.4
1301	150	458	308	79	.050	342.2
1302	151	458	307	79	.054	342.4
1401	145	462	317	99	.048	362.2
1402	147	464	317	99	.049	362.4
1501	142	464	322	100	.047	382.2
1502	142	464	322	99	.046	382.4
1601	138	464	326	99	.049	402.2
1602	139	464	325	99	.051	402.4
1701	139	465	326	99	.051	422.2
1702	138	465	327	99	.048	422.4
1801	134	465	331	98	.048	442.2
1802	137	465	328	98	.050	442.4
1901	136	462	326	98	.050	462.2
1902	131	462	331	98	.049	462.4
2006	135	465	330	98	.050	482.2
2007	131	465	334	98	.048	482.4

TABLE II. - ENDURANCE TEST OF 90 PERCENT HYDROGEN PEROXIDE THRUST CHAMBERS; CONFIGURATION B

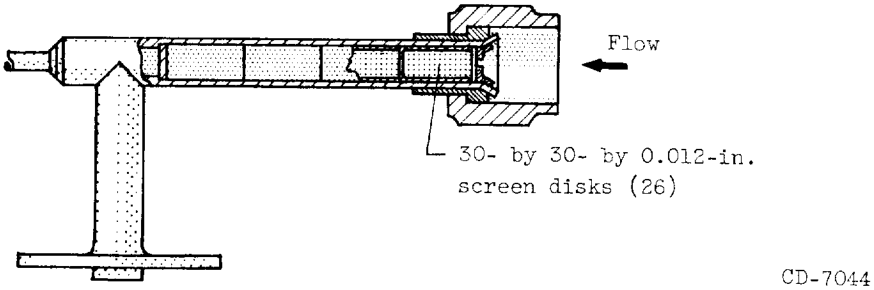
Run	Chamber pressure, lb/sq in.	Propellant feed pressure, lb/sq in.	Pressure drop across bed, lb/sq in.	Propellant feed temp., °F	Start delay, sec	Accumulated run time, sec	Run	Chamber pressure, lb/sq in.	Propellant feed pressure, lb/sq in.	Pressure drop across bed, lb/sq in.	Propellant feed temp., °F	Start delay, sec	Accumulated run time, sec
24 lb thrust chamber							6 lb thrust chamber						
1	287	428	141	40	0.240	51	1	296	449	153	72	0.200	95
2	288	431	143	40	.057	52	2	315	449	134	72	.060	96
3	298	431	133	40	.057	53	3	323	449	126	72	.055	97
4	299	429	130	40	.058	54	4	326	447	121	72	.043	98
5	301	429	128	40	.060	55	5	329	447	115	72	.046	99
21	302	429	127	41	.052	71	21	331	445	117	72	.042	115
22	302	429	127	41	.049	72	22	331	447	116	72	.045	116
23	301	431	130	41	.050	73	23	331	452	121	72	.043	117
24	301	431	130	41	.052	74	24	331	452	121	72	.041	118
25	300	431	131	41	.052	75	25	329	451	122	72	.043	119
41	298	429	131	42	.052	91	41	325	455	127	72	.043	135
42	298	429	131	42	.050	92	42	329	455	126	72	.045	136
43	297	431	134	42	.050	93	43	327	455	128	72	.043	137
44	297	429	132	42	.050	94	44	327	454	127	72	.042	138
45	298	431	133	42	.049	95	45	327	454	127	72	.041	139
61	296	426	130	77	.068	141	61	321	451	130	73	.037	185
62	297	425	128	77	.066	142	62	321	451	130	73	.040	186
63	296	425	129	77	.062	143	63	321	451	130	73	.043	187
64	297	426	129	77	.058	144	64	321	452	131	73	.034	188
65	297	426	129	77	.056	145	65	321	451	130	73	.038	189
81	297	425	128	77	.050	161	81	323	458	135	73	.040	205
82	297	425	[illegible]	77	.057	162	82	[illegible]	[illegible]	[illegible]	73	.040	[illegible]
83	297	426	129	77	.053	163	83	324	458	134	73	.038	207
84	297	425	128	77	.054	164	84	322	458	136	73	.040	208
85	296	425	129	77	.054	165	85	322	456	134	73	.039	209
101	296	426	130	78	.057	181	101	319	455	136	73	.042	225
102	296	428	132	78	.057	182	102	321	455	134	73	.040	226
103	295	426	131	78	.058	183	103	324	454	130	73	.039	227
104	295	428	133	78	.058	184	104	321	454	133	73	.040	228
105	295	428	133	78	.056	185	105	319	454	135	73	.037	229
121	313	434	121	101	.059	231	121	314	454	140	73	.040	275
122	313	433	120	101	.056	232	122	314	452	138	73	.038	276
123	313	434	121	100	.055	233	123	314	452	138	73	.040	277
124	313	435	122	100	.052	234	124	314	452	138	73	.039	278
125	313	433	120	100	.058	235	125	314	452	138	73	.041	279
152	312	433	121	100	.049	262	145	311	451	140	73	.039	302
153	313	433	120	100	.049	263	149	312	451	139	73	.041	303
154	313	438	125	100	.050	264	150	311	451	140	73	.041	304
156	313	438	125	100	.049	265	151	311	451	140	73	.042	305
156	317	443	126	100	.043	266	152	310	451	141	73	.040	306



(a) 24 Pound thrust.

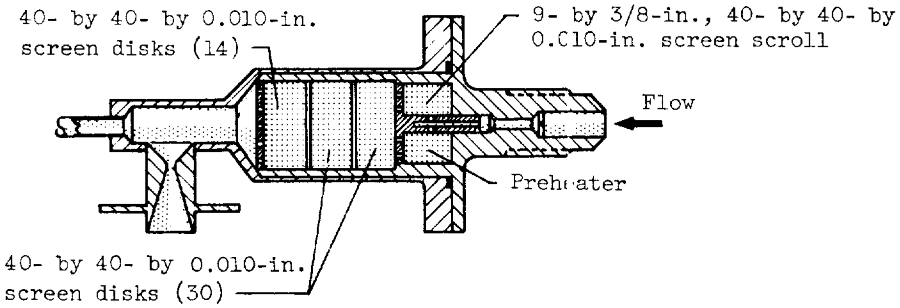


(b) 6 Pound thrust.

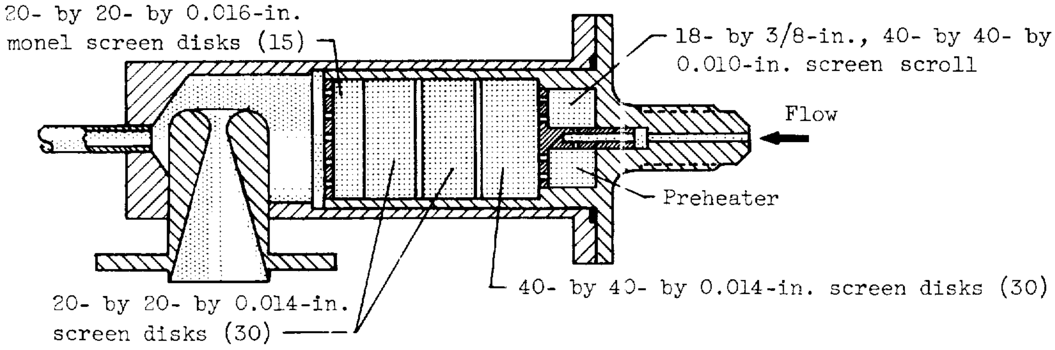


(c) 1 Pound thrust.

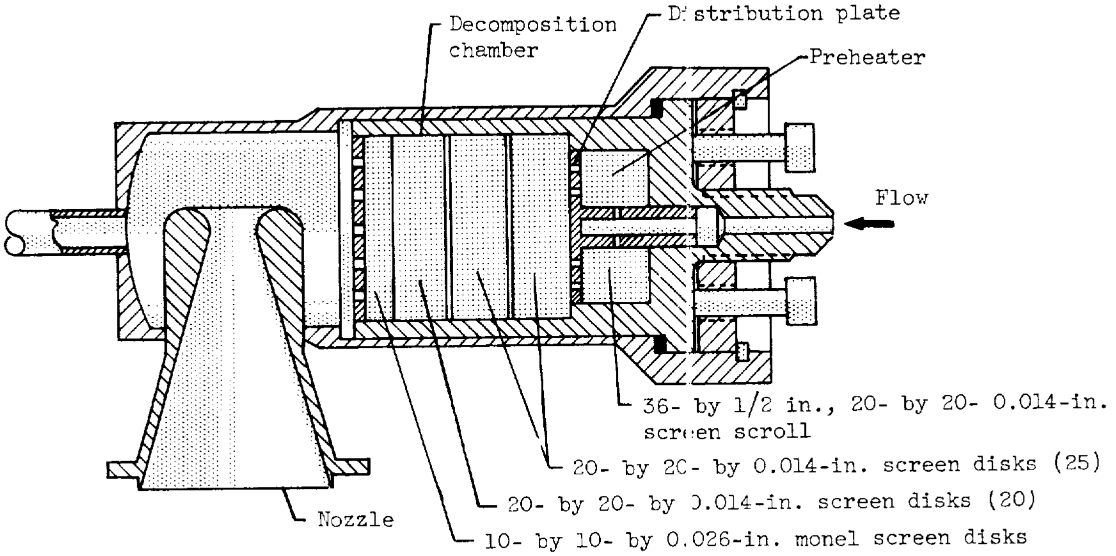
Figure 1. - Schematic of configuration A hydrogen peroxide thrust chambers.



(a) 1 Pound thrust.



(b) 6 Pound thrust.



(c) 24 Pound thrust.

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Figure 2. - Schematic of configuration B hydrogen peroxide thrust chambers.

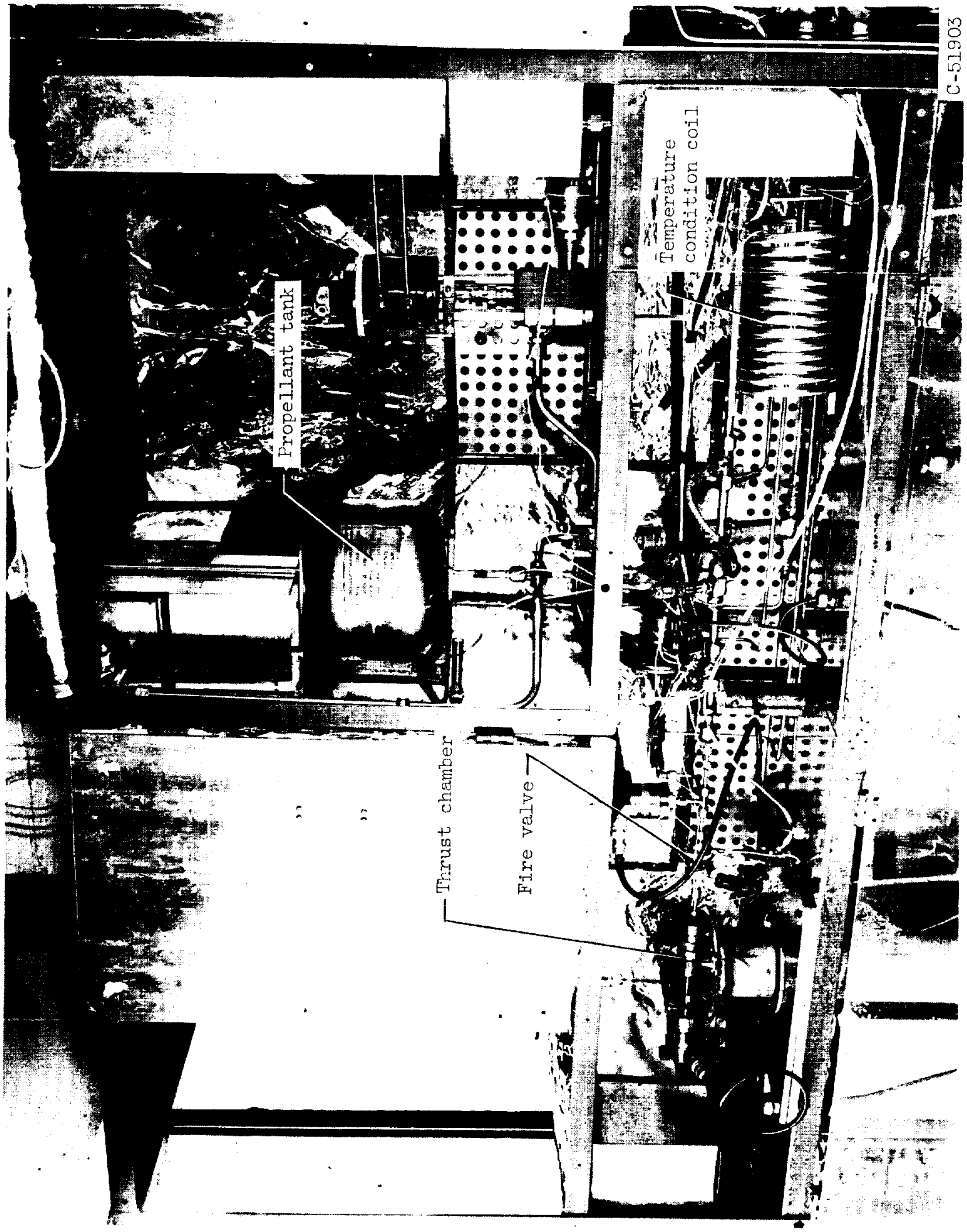


Figure 3. - Environmental test chamber with doors open.

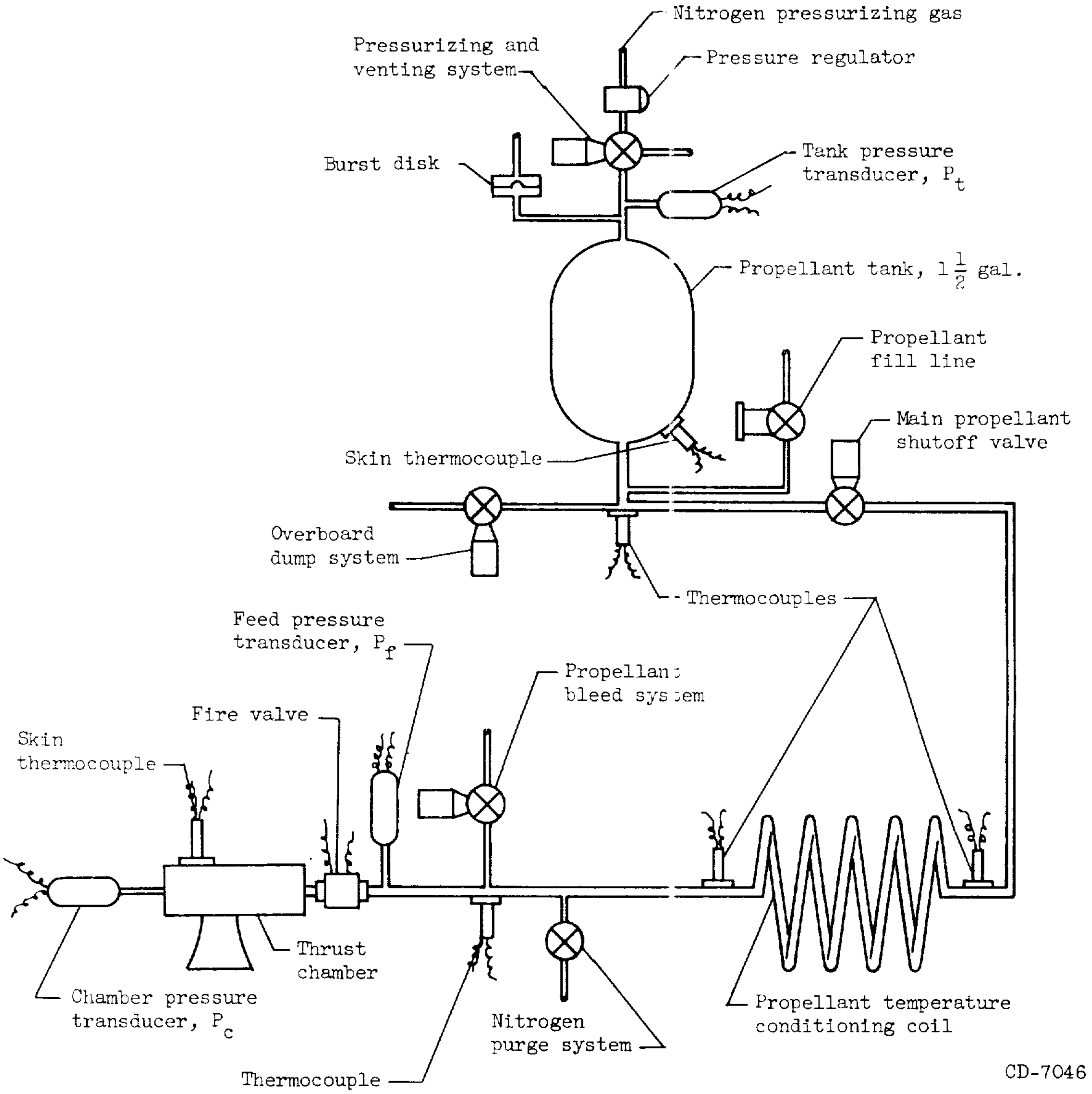
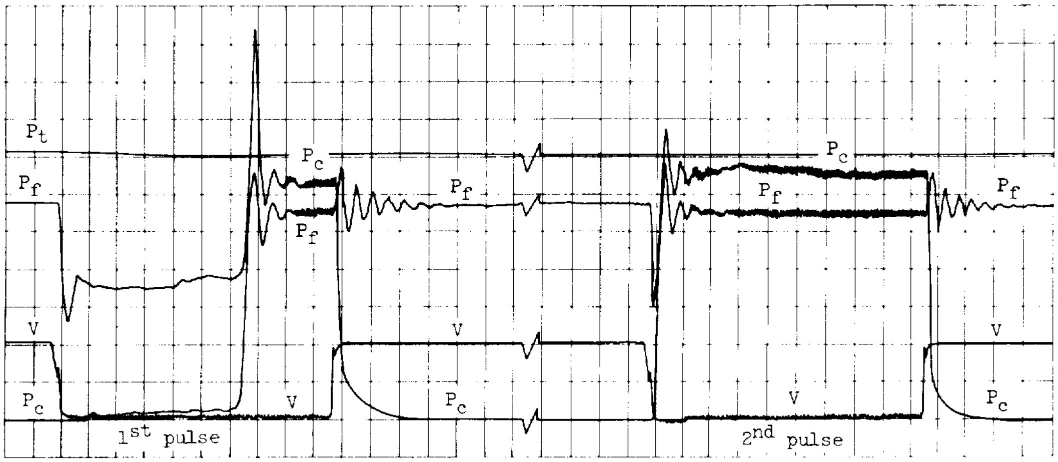
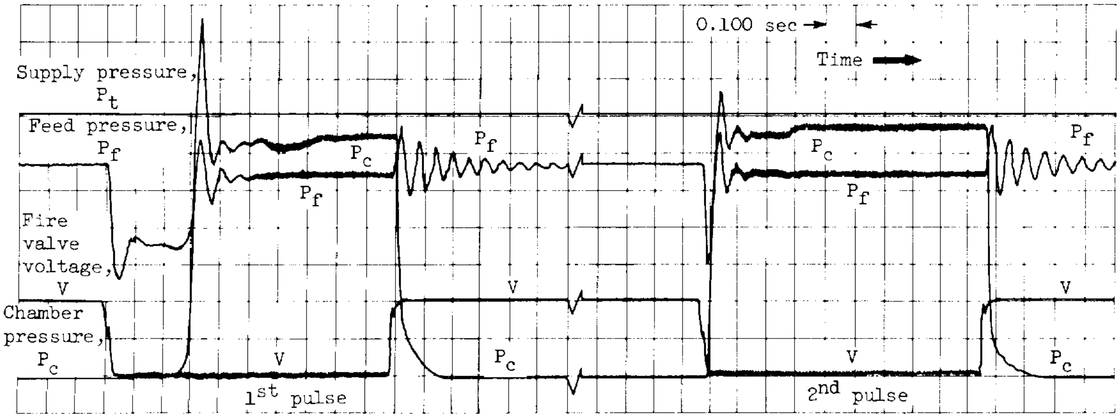


Figure 4. - Flow diagram and instrumentation layout of propellant system.



(a) Environmental temperature, 40° F.



(b) Environmental temperature, 60° F.

Figure 5. - Oscillograph records illustrating start delay times at two environmental temperature conditions for the 24-pound configuration A thrust chamber.

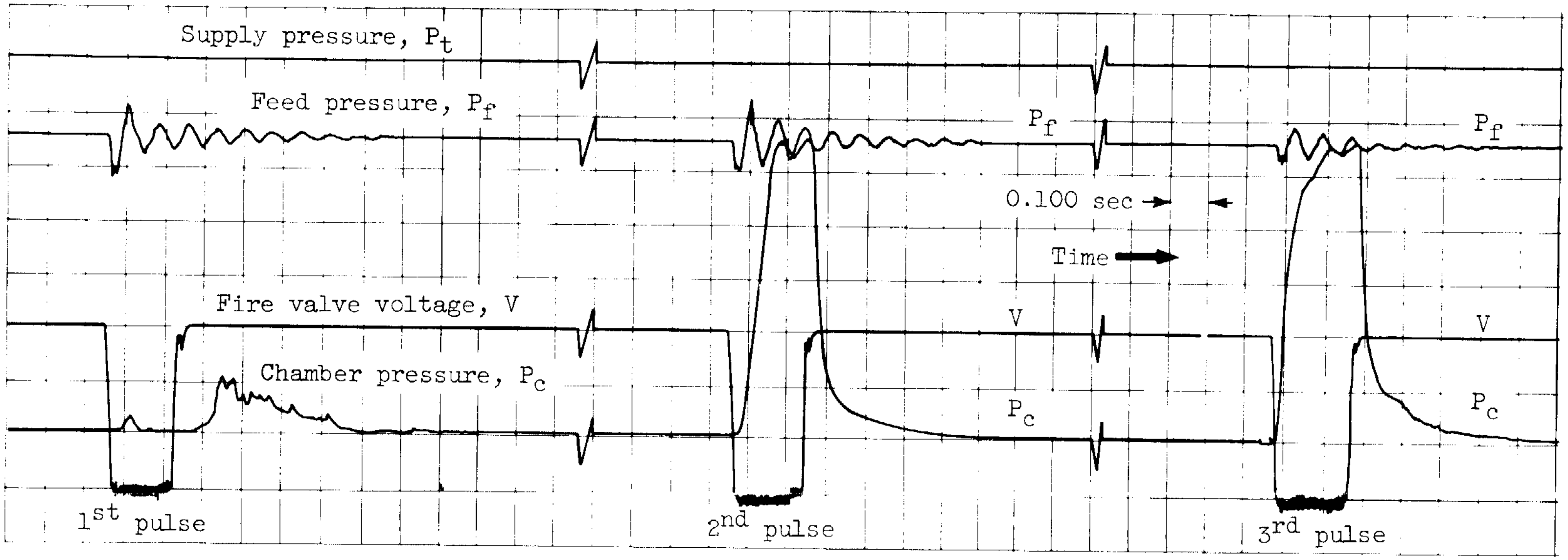
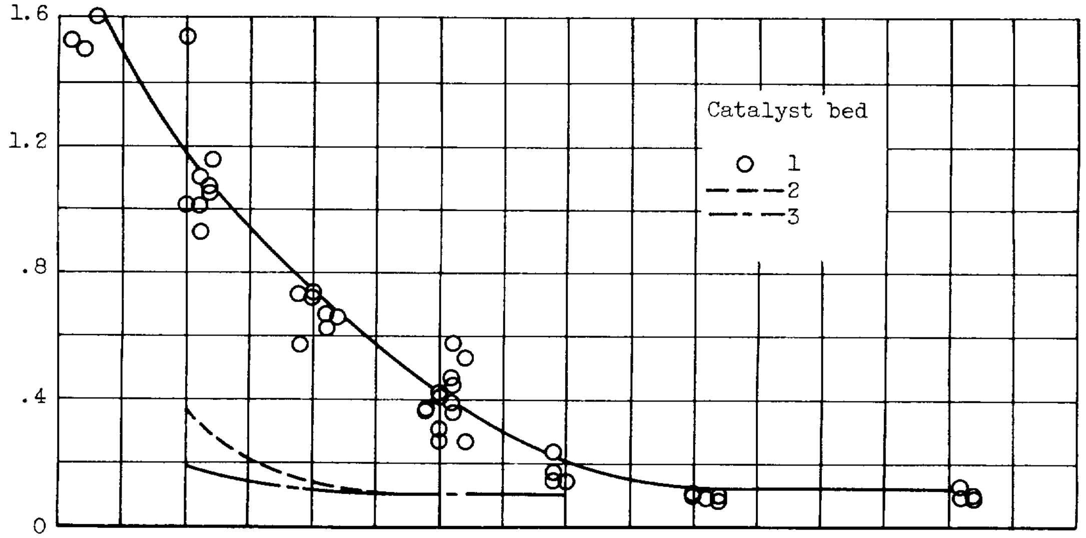
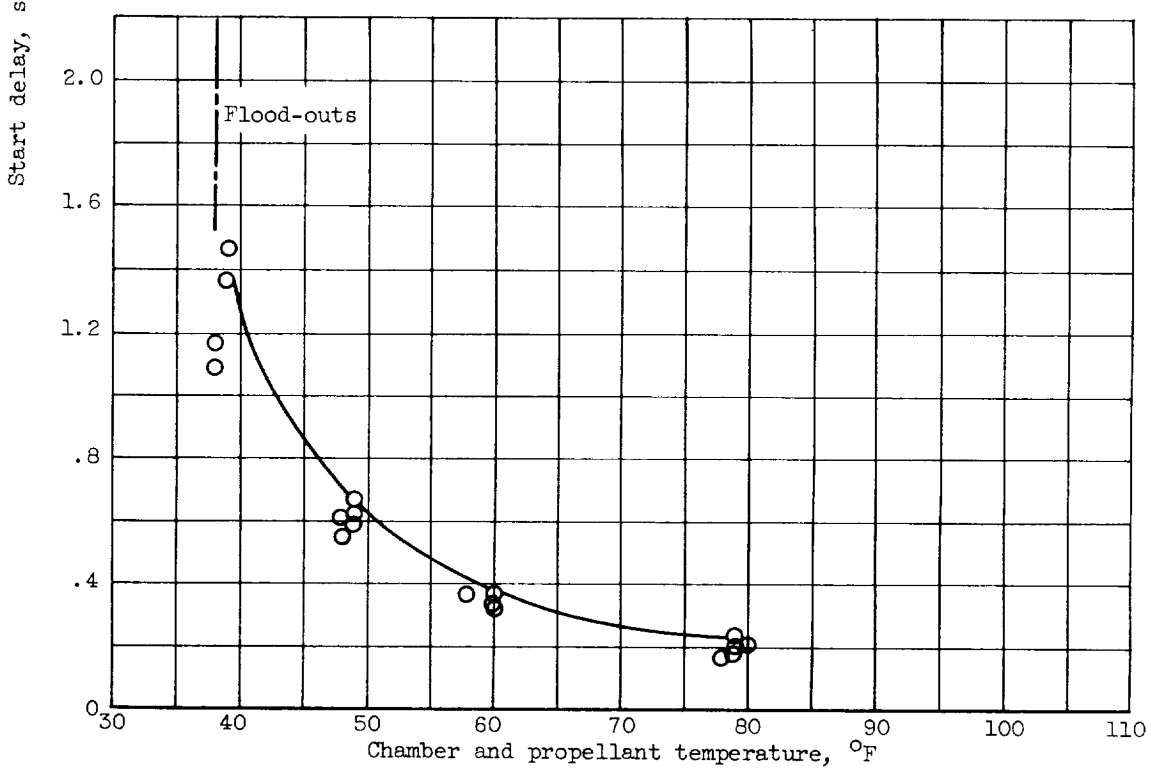


Figure 6. - Oscillograph record illustrating start delay time at environmental temperature condition of 40° F for the 1-pound configuration A thrust chamber.

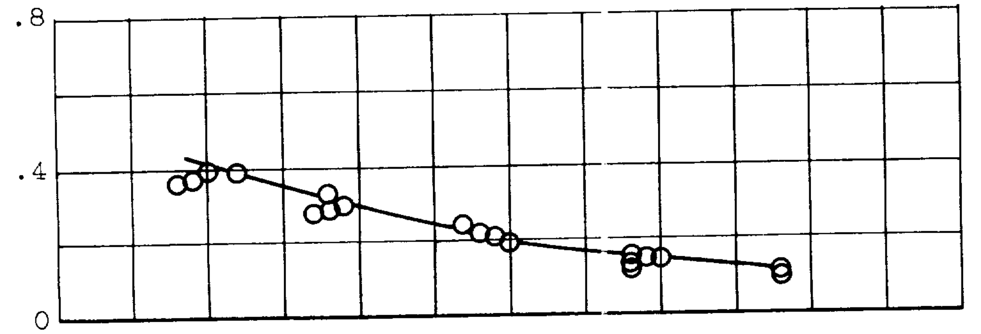


(a) Initial cold-start delays.

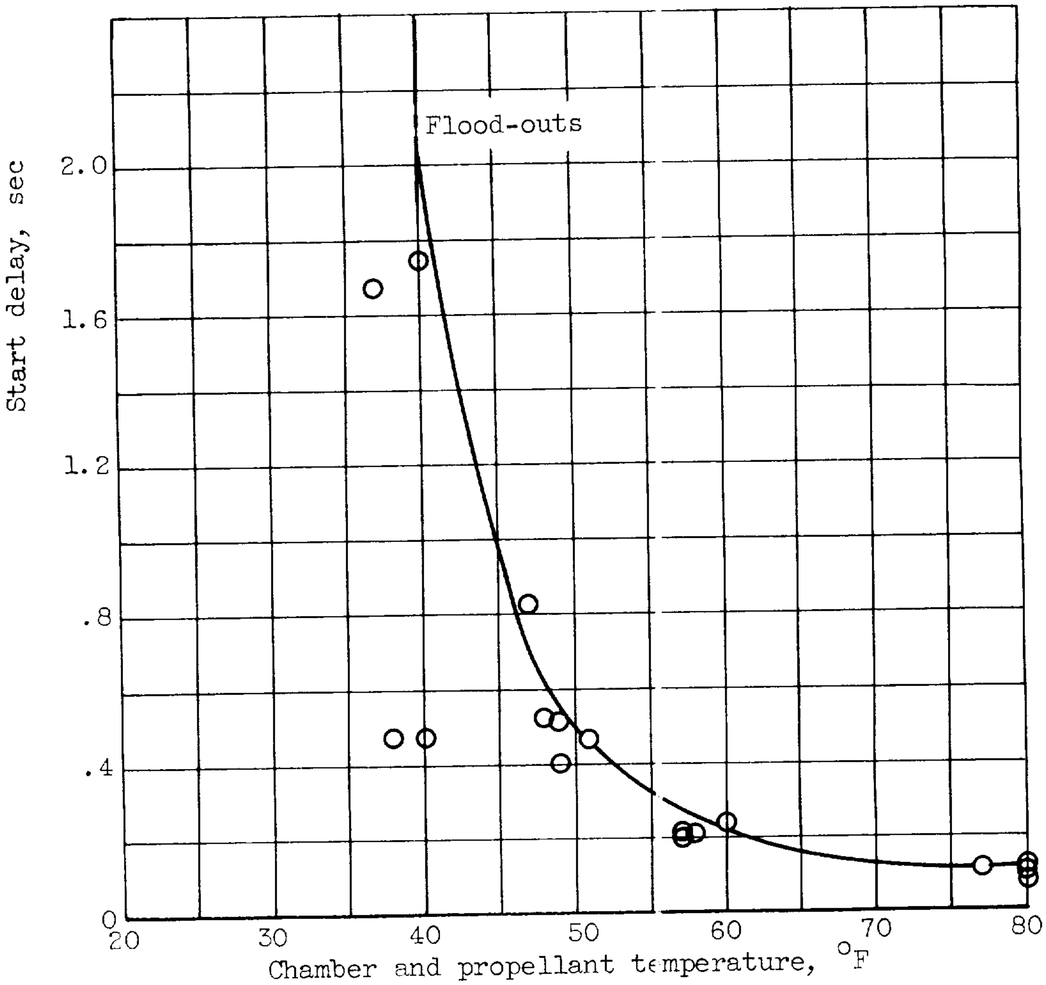


(b) Cold-start delays after 6 minutes of accumulated run time.

Figure 7. - Starting characteristics for hydrogen peroxide 24-pound-thrust chamber. Configuration A.

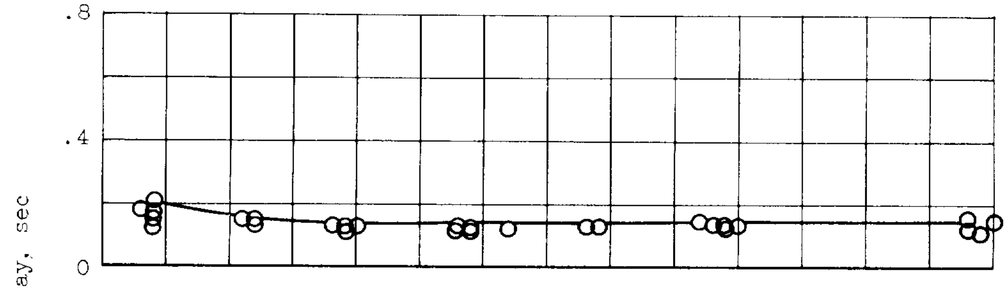


(a) Initial cold-start delays.

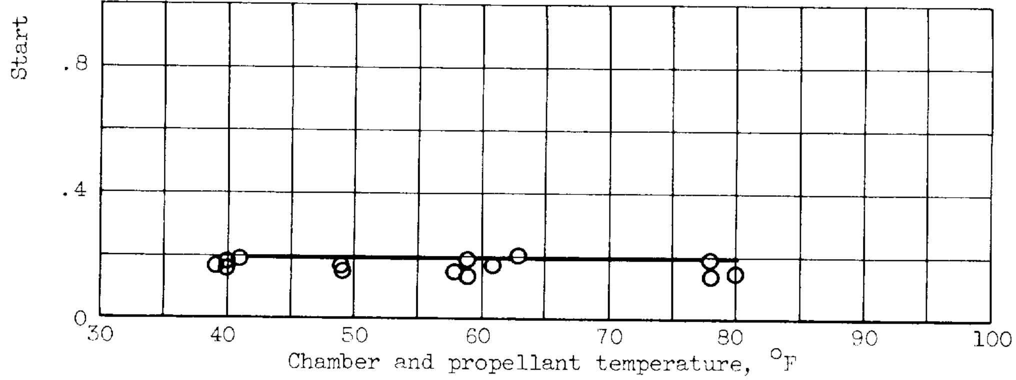


(b) Cold-start delays after 6 minutes of accumulated run time.

Figure 10. - Starting characteristics for hydrogen peroxide 24-pound-thrust chamber. Configuration B.



(a) Initial cold-start delays.



(b) Cold-start delays after 6 minutes of accumulated run time.

Figure 11. - Starting characteristics for hydrogen peroxide 6-pound-thrust chamber. Configuration B.

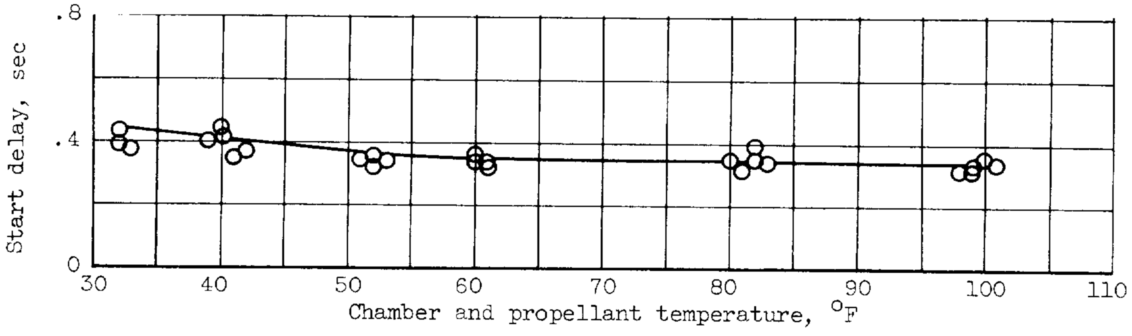


Figure 12. - Starting characteristics for hydrogen peroxide 1-pound-thrust chamber. Configuration B.