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IGNITION OF HYDROGEN-OXYGEN ROCKET COMBUSTOR WITH CHLORINE TRIFLUORIDE AND TRIETHYLALUMINUM

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IGNITION OF HYDROGEN-OXYGEN ROCKET COMBUSTOR WITH CHLORINE TRIFLUORIDE AND TRIETHYLALUMINUM

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SUMMARY

Ignition of a nominal-125-pound-thrust cold (200° R) gaseous-hydrogen - liquid-oxygen rocket combustor with chlorine trifluoride (hypergolic with hydrogen) and triethylaluminum (hypergolic with oxygen) resulted in consistently smooth starting transients for a wide range of combustor operating conditions. The combustor exhaust nozzle discharged into air at ambient conditions.

Each starting transient consisted of the following sequence of events: injection of the lead main propellant, injection of the igniter chemical, ignition of these two chemicals, injection of the second main propellant, ignition of the two main propellants, increase in chamber pressure to its terminal value, and cutoff of igniter-chemical flow.

Smooth ignition was obtained with an ignition delay of less than 100 milliseconds for the reaction of the lead propellant with the igniter chemical using approximately 0.5 cubic inch (0.038 lb) of chlorine trifluoride or 1.0 cubic inch (0.031 lb) of triethylaluminum. These quantities of igniter chemical were sufficient to ignite a 20-percent-fuel hydrogen-oxygen mixture with a delay time of less than 15 milliseconds.

Test results indicated that a simple, lightweight chemical ignition system for hydrogen-oxygen rocket engines may be possible.

INTRODUCTION

Liquid-hydrogen - liquid-oxygen rocket engines are presently under development for several flight-vehicle stages and are being considered for various future space applications. This nonhypergolic propellant combination requires an ignition system, and the many applications contemplated for these propellants may result in a variety of environmental conditions under which the ignition system must function reliably.

The commonly used ignition methods for liquid-propellant engines are electric spark ignition and chemical ignition using solid, liquid, or gaseous igniter chemicals. Solid pyrotechnic igniters have the disadvantage of necessitating the safe ejection of mechanical parts from the engine after ignition. In the current state of development of hydrogen-oxygen engines, electric spark ignition systems have performed reliably using either flush-mounted plugs or augmentation chambers. The augmented spark ignition system provides a large amount of ignition energy by burning a small amount of propellants in a special augmentation chamber. However, this system introduces the added complications of sequencing and controlling these igniter propellant flows. Chemical ignition can provide many times as much ignition energy as the electric spark in these systems. Excellent starting charactersitics have been demonstrated with a chemical ignition system that required only 0.5 pound of gaseous fluorine to successfully ignite hydrogen-oxygen engines with thrusts up to 20,000 pounds (ref. 1).

Various liquid chemicals have advantages over gaseous chemicals in that they make possible a smaller, more compact system. In addition, a liquid chemical ignition system has the desirable attributes of simplicity, reliability, and restart capability, and it can supply a relatively large amount of ignition energy continuously during the starting transient. An investigation was made of the starting characteristics and flow requirements of a nominal-125-pound-thrust cold (200° R) gaseous-hydrogen - liquid-oxygen rocket combustor using two liquid igniter chemicals, one (chlorine trifluoride) hypergolic with hydrogen and the other (triethylaluminum) hypergolic with oxygen. The range of test conditions included chamber pressures from 140 to 550 pounds per square inch absolute and propellant mixtures from 9 to 70 percent fuel to cover the range of mixtures for both rocket engines and gas generators.

Typical starting transients for both chemicals are shown by time plots of flows and pressures. Starting-transient records were examined to determine: (1) the ignition delay time of the reaction between the igniter chemical and the lead propellant and (2) the delay time of the hydrogen-oxygen reaction following injection of the second propellant. These delay times are plotted as functions of propellant flow rates, propellant mixture, and igniter-chemical flow rate.

APPARATUS AND TEST PROCEDURE

Propellant Systems

A schematic diagram of the propellant systems is shown in figure 1. Gaseous hydrogen was supplied from high-pressure storage cylinders through a pressure regulator to a cooling coil consisting of 185 feet of 1-inch-diameter copper tubing. Gaseous-hydrogen flow was measured by two meters: (1) a critical-flow nozzle and (2) a sharp-edged, flat-plate orifice machined to ASME specifications. Liquid oxygen of 99.5-percent purity was transferred from a storage Dewar tank to the oxygen tank and was pressurized with helium. Liquid-oxygen flow was measured by a similar ASME orifice.

The hydrogen coil and flow line to the combustion chamber and the oxygen tank and flow line were immersed in liquid nitrogen. Cooling of the gaseous hydrogen to liquid-nitrogen temperature was done to simulate the hydrogen temperature at ignition of a regeneratively cooled liquid-hydrogen engine. Cooling of the liquid-oxygen system kept the oxygen in the liquid state and minimized boiloff.

Measurement of the very small igniter-chemical flows that were used required a special igniter-chemical system consisting of two tubing coils of known internal volume immersed in ice water and separated by a shutoff valve. Liquid chlorine trifluoride or triethylaluminum (purities given in table I) was transferred into one coil, and the other was pressurized with gaseous nitrogen. The nitrogen supply was then closed off and the valve between the coils opened to pressurize the chemical. The rate of pressure decrease of this known quantity of nitrogen gas was measured during each test to ascertain the flow rate of liquid igniter chemical.

The main-propellant and igniter-chemical flow lines each had a purge system that entered downstream of the fire valve. Gaseous nitrogen was used to purge the propellant and igniter-chemical flow lines and injector after each run. Propellant and igniter-chemical flow rates and flow buildup time depended on tank or coil pressure, since simple quick-opening fire valves were used.

Rocket Combustor and Injectors

The tests were conducted with a thrust chamber designed for a nominal thrust of 125 pounds at a chamber pressure of 300 pounds per square inch. The thrust-chamber configuration, consisting of an injector, combustion chamber, and exhaust nozzle which were separable units (fig. 2), was not changed throughout the program. The exhaust nozzle discharged directly into air at ambient conditions. Since the chamber and nozzle were uncooled, the duration of each test was limited to approximately 3 seconds.

The injector used was a simple showerhead similar to an element of one of the 20,000-pound-thrust injectors used in reference 1. One injector had a separate small-diameter tube extending through one oxidant tube for chlorine trifluoride injection (fig. 2). A second injector had a triethylaluminum injection tube passing through a special hole drilled in the injector face. The triethylaluminum impinged with the adjacent oxygen stream at an angle of 15°.

Instrumentation and Performance Measurements

Chamber pressure was measured by a strain-gage transducer and recorded on both a direct-reading oscillograph and a recording potentiometer. Propellant supply pressures, flowmeter inlet and differential pressures, and injector inlet pressures were measured and recorded by similar equipment. The probable maximum error of these steady-state pressure measurements was ±1 percent. Hydrogen orifice inlet temperature and hydrogen and oxygen injector inlet temperatures were measured by copper-constantan thermocouples and recorded on the direct-reading oscillograph. The maximum error in temperature measurements was ±3 percent.

Steady-state hydrogen flow rates computed from the critical-flow nozzle and the ASME orifice using standard flow equations agreed within ±2 percent. Values computed from the critical-flow nozzle had better precision and were therefore used for plotting the data. The critical-flow nozzle also prevented excessive hydrogen flow during the starting transient.

Liquid-oxygen flow rate was also computed using the standard orifice flow equation. Liquid-oxygen temperature at the orifice was assumed constant at 140° R. A cavitating Venturi meter was inserted in the oxygen flow line for the triethylaluminum tests to prevent excessive oxygen flow during the starting transient.

Hydrogen and oxygen flow measurements were all made at steady-state running conditions after the starting transient, since the instrumentation was not accurate for determining instantaneous flow rates during the transients.

Igniter-chemical flow rate was ascertained by two methods. One method was to measure the rate of pressure decrease of a known quantity of pressurizing gas, assuming ideal isothermal expansion, the rate of decrease being proportional to the rate at which the igniter chemical was displaced. The rate of pressure decrease was determined from the slope, at the time of ignition, of the igniter-chemical coil pressure trace on the direct-reading oscillograph record (figs. 3 and 4). The second method of igniter-chemical flow measurement was a water calibration of each capillary injection tube. From this calibration the friction factor of the tube was calculated using the pipe head loss equation, and a curve of friction factor as a function of Reynolds number was plotted for each tube. The pressure drop across the tube at ignition was then used to determine the flow rate of each igniter chemical.

Values of igniter-chemical flow rate obtained by the two methods differed by as much as ±0.005 pound per second (tables II and III). At the very small flow rates involved, difficulty was encountered in determining the slope of the pressure decay curve for the first method. The second method, based on flow calibration, was probably more accurate and was therefore used for the data presented herein.

Experimental Procedure

The range of test conditions investigated includes chamber pressures from 140 to 550 pounds per square inch absolute and hydrogen-oxygen mixtures from approximately 9 to 70 percent fuel by weight. This range of test conditions was chosen to include the range for both rocket engines and gas generators. Igniter-chemical flows were varied from approximately 0.006 to 0.021 pound per second to investigate a wide range of ignition characteristics.

A gaseous-hydrogen lead varying from 0.5 to 2.0 seconds was used for the chlorine trifluoride ignition tests. Chlorine trifluoride was then injected, ignition occurred, and liquid oxygen was introduced from 1.0 to 2.5 seconds later. Chlorine trifluoride flow was cut off approximately 1 second after the oxygen injection. No attempt was made to determine the minimum time required for injection of all three chemicals and buildup of full chamber pressure. The termination of the starting transient was taken as the time at which steady-state conditions had been established. Propellant flows were held constant for a series of runs, while igniter-chemical flow was continually reduced to determine the effect of this variable on ignition characteristics.

For the triethylaluminum tests an oxygen lead of approximately 0.5 second was used. Triethylaluminum was then injected, ignition occurred, and hydrogen flow was started approximately 1 second later.

Ignition delay times were read from the direct-reading oscillograph records as shown in figures 3 and 4. Ignition delay time for the reaction between the igniter chemical and the lead propellant τ_a was measured from the point on the igniter-chemical coil pressure trace where a steady slope was established after the fill time (e.g., at 0.72 sec in fig. 3) to the point where chamber pressure increased abruptly (at 0.86 sec in fig. 3) indicating that ignition had occurred. Because of the difficulty of determining, by this method, the exact time when igniter chemical entered the chamber, the maximum error in the values of τ_a was estimated as ±10 milliseconds. Delay time of the hydrogen-oxygen reaction τ_b following injection of the second propellant was measured from the point where injector inlet temperature of the second propellant decreased abruptly (1.86 sec in fig. 3) to the point where chamber pressure began to increase (1.94 sec in fig. 3). Usually, injector inlet pressure of the second propellant began to increase at approximately the same time that injector inlet temperature decreased. However, the temperature measurement was considered the better indication of the exact time when the second propellant entered the injector and was therefore used to measure the delay time. Thus, τ_b includes the injector cavity fill time of the second propellant and the ignition delay associated with the hydrogen-oxygen reaction. The maximum error in values of τ_b was estimated as ±5 milliseconds.

RESULTS AND DISCUSSION

Experimental data are presented for 114 starts with chlorine trifluoride ignition in table II and for 88 starts with triethylaluminum ignition in table III. Consistently smooth starting transients (see figs. 3 and 4) were obtained with both chlorine trifluoride and triethylaluminum ignition over the range of flow rates used. Starting transients are analyzed in terms of ignition delay time τ_a for the reaction between igniter chemical and lead propellant and delay time τ_b for the hydrogen-oxygen reaction. Values of τ_a and τ_b of 100 and 15 milliseconds, respectively, were considered reasonably allowable values for rocket-engine starts and were therefore arbitrarily chosen as a basis for comparison of the two igniter chemicals.

Ignition Performance Data

Igniter-chemical ignition delay time. - Figure 5 shows the effect of variations in chlorine trifluoride (ClF_3) flow rate on ignition delay time τ_a for the reaction of ClF_3 and cold (200° R) gaseous hydrogen. Ignition delay times of less than 100 milliseconds were obtained for all starts at a chlorine trifluoride flow rate of 0.0187 pound per second or higher. At progressively lower ClF_3 flows maximum τ_a values increased sharply, although low ignition delay times were still obtained for some runs. In the low chlorine trifluoride flow region, an effect of hydrogen flow rate on ignition delay time was observed. The higher values of τ_a were obtained at low hydrogen flows. This effect may perhaps be attributed to the influence of hydrogen injection velocity on the preparation of the reactants for ignition by atomization, vaporization, and mixing of the chlorine trifluoride.

As chlorine trifluoride flows were increased above 0.0187 pound per second, the maximum ignition delay time τ_a gradually decreased. At high chlorine trifluoride flows the effect of hydrogen flow rate was not discernible, because values of τ_a were small. Very small values of τ_a should result if ClF_3 flow is increased severalfold.

Ignition delay time τ_a for the reaction of triethylaluminum (TEA) and oxygen as a function of TEA flow rate is presented in figure 6. Ignition delay times of less than 100 milliseconds were obtained for all starts at a TEA flow of 0.0156 pound per second or higher. At lower TEA flows the maximum value of τ_a increased markedly, although small values of τ_a were obtained for many runs. As TEA flow rates were increased above 0.0156 pound per second, maximum values of τ_a gradually decreased. In some tests the oxygen temperature at the injector inlet indicated that gaseous oxygen was flowing into the chamber during the ignition delay time (fig. 4). In these cases oxygen flow rate was too low or lead time too short to allow full liquid-oxygen flow to develop before TEA was injected. The data obtained showed no apparent effect on τ_a of changes in oxygen flow rate or state.

Comparison of figures 5 and 6 reveals that maximum values of τ_a were less for TEA than for ClF_3 ignition at equal igniter-chemical weight flows over the entire range of flows covered. This fact is probably due to the greater energy release of the TEA-oxygen reaction than the ClF_3-hydrogen reaction (see table I) and the faster reaction rate of the liquid-liquid phase TEA-oxygen reaction than the liquid-gas phase ClF_3-hydrogen reaction.

Delay time of hydrogen-oxygen reaction. - The flame established by the reaction of igniter chemical and lead propellant provided the ignition source for the hydrogen-oxygen reaction following injection of the second of these propellants. The delay time τ_b associated with this reaction is plotted as a function of igniter-chemical flow rate and hydrogen-oxygen mixture in figures 7 and 8. Hydrogen-oxygen mixture is expressed as the percent fuel in the mixture at the termination of the starting transient and is calculated from steady-state hydrogen and oxygen weight flow rates. In addition to the variables shown in figures 7 and 8, measured values of τ_b may also have been influenced by injector cavity fill time, mixture ratio at ignition, and rate of flow buildup of the second propellant injected.

Delay time τ_b following liquid-oxygen injection is plotted as a function of chlorine trifluoride flow rate in figure 7. Maximum values of τ_b decreased steadily as ClF_3 flow rate was increased for a constant hydrogen-oxygen mixture. For a given ClF_3 flow rate higher values of τ_b were obtained at higher terminal percent fuel in the hydrogen-oxygen mixture.

Figure 8 shows the effect on τ_b of variations in triethylaluminum flow rate; delay time gradually decreased as TEA flow rate was increased. In this case the effect on τ_b of variations in hydrogen-oxygen mixture at a constant TEA flow rate appears small and opposite to the trend for ClF_3 ignition. This difference is probably due to the change in propellant scheduling from a hydrogen lead to an oxygen lead. Lower delay times were obtained for TEA ignition, probably because of the greater energy release provided by the TEA-oxygen reaction and the more rapid diffusion of gaseous hydrogen throughout the chamber as the second propellant was injected. For ClF_3 ignition, liquid oxygen was the second propellant injected, and it required more time to vaporize as well as to diffuse throughout the chamber.

Ignition energy release. - The ignition energies provided by the reaction of chlorine trifluoride with hydrogen and triethylaluminum with oxygen are given in table I. The energy released by either igniter chemical is much greater than that available from various spark ignition systems. The total quantity of chlorine trifluoride required to initiate a chlorine trifluoride - hydrogen reaction with a maximum ignition delay of 100 milliseconds was 0.5 cubic inch (0.038 lb). This amount released 140,000 joules of ignition energy in a 2-second interval. Similarly, ignition of the triethylaluminum - oxygen reactions that had a maximum value of τ_a of 100 milliseconds required a total quantity of 1.0 cubic inch (0.031 lb) of TEA, which released 600,000 joules of energy within 2 seconds. The energy release in each case was sufficient to ignite a terminal 20-percent-fuel hydrogen-oxygen mixture with a maximum delay time of 15 milliseconds after injection of the second propellant. These amounts of energy are greatly in excess of that obtainable from various spark ignition systems that furnish ignition energies from 10 to 50 joules per second.

The ignition delay times presented herein were obtained essentially at atmospheric chamber pressures. The chamber pressure during ignition delay time τ_b would be expected to be somewhat above atmospheric, because of the reaction between lead propellant and igniter chemical. Reduced chamber pressure, such as would occur during high-altitude or space starting of a rocket engine, would be expected to increase both ignition delay times τ_a and τ_b. The effects of chamber pressure at ignition on the delay times were not investigated.

Operating characteristics. - Generally smooth starting transients were obtained with both ClF_3 and TEA ignition, even when values of τ_a were greater than 100 milliseconds. Although it is usually considered desirable to minimize ignition delays, probably no engine-damaging effects would result from long ignition delays for the reaction of igniter chemical and lead propellant, provided that ignition occurred before injection of the second propellant. However, for ignition of the main propellants ignition delay should be held to a much lower figure, because a combustible mixture accumulates throughout the engine chamber during this interval and could produce hard starts.

After approximately 50 starts with triethylaluminum ignition, some aluminum oxide deposits were observed on the combustion-chamber walls, exhaust nozzle, and injector face near the TEA injection tube. However, no problem of deposit accumulation in lines or plugging of injection tubes was encountered. The TEA injection line was purged with gaseous nitrogen after each run to prevent this occurrence. After a few runs with ClF_3 ignition a light fluoride coating was observed on interior engine surfaces. No further accumulation occurred during the remainder of the ClF_3 runs.

No freezing of either chemical in the injection lines was encountered.

Chemical Ignition Systems for Flight Engines

The results of this investigation indicate that a small, compact chemical ignition system capable of being developed into a highly reliable component for hydrogen-oxygen engines or gas generators for flight vehicles may be possible. Such a system may be in the form of a capsule that could be preloaded with a suitable igniter chemical and inserted into the engine. The capsule could be a sealed flexible container such as a bellows with a pressure or mechanical means for pressurization. The capsule could be designed to combine all the necessary components into a self-contained unit needing only an initiating impulse or signal for completion of its functions.

The quantities of igniter chemical used in this investigation would probably be sufficient to ignite larger engines successfully, if local propellant flow conditions were similar. If local propellant flows were higher, special low-flow propellant scheduling during starting could be used. A severalfold increase in igniter-chemical flow rate would eliminate this complication.

As engine diameter increases, ignition at a single point becomes less suitable, because the time for flame propagation across the chamber becomes very long. If the propagation time were long enough to allow excess accumulation of combustible propellant mixture in the chamber, a detonation that could severely damage the engine might occur. Therefore, igniter-chemical injection at two or three points in a large-diameter engine might be necessary.

While only chlorine trifluoride and triethylaluminum were tested in this investigation, other chemicals, such as liquid fluorine or trimethylboron, may have equally satisfactory ignition characteristics and more desirable physical properties, such as lower freezing points.

SUMMARY OF RESULTS

Starting characteristics of a nominal-125-pound-thrust cold (200° R) gaseous-hydrogen - liquid-oxygen rocket combuster were determined using chlorine trifluoride and triethylaluminum for ignition. The following results were obtained:

1. Smooth ignition and chamber pressure buildup were attained for each igniter chemical over a wide range of operating conditions.

2. Maximum ignition delay time for the reaction of igniter chemical and lead propellant decreased as igniter-chemical flow rate was increased. At equal weight flow rates the maximum ignition delay times observed for triethylaluminum were less than those for chlorine trifluoride.

3. Approximately 0.5 cubic inch (0.038 lb) of chlorine trifluoride was needed per start to ignite with cold gaseous hydrogen with an ignition delay of less than 100 milliseconds. Approximately 1.0 cubic inch (0.031 lb) of triethylaluminum was required per start to ignite with liquid oxygen with an ignition delay of less than 100 milliseconds.

4. Maximum delay time for the hydrogen-oxygen reaction, measured from the time when the second propellant was introduced, decreased as igniter-chemical flow rate was increased. At equal igniter weight flows the maximum delay times for triethylaluminum ignition were less than those for chlorine trifluoride.

5. Approximately 0.5 cubic inch (0.038 lb) of chlorine trifluoride or 1.0 cubic inch (0.031 lb) of triethylaluminum provided sufficient energy to ignite a 20-percent-fuel hydrogen-oxygen mixture with a maximum delay time of 15 milliseconds.

Lewis Research Center
National Aeronautics and Space Administration
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REFERENCES

1. Straight, David M., and Rothenberg, Edward A.: Ignition of Hydrogen-Oxygen Rocket Engines with Fluorine. NASA TM X-101, 1959.

2. Anon.: Chlorine Trifluoride (CTF) and other Halogen Fluorides. Tech. Bull. TA-8532-2, Allied Chem. and Dye Corp.

3. Anon.: Technical Information on Aluminum Alkyls and Alkyl Aluminum Halides. Ethyl Crop., Feb. 1959.

TABLE I. - VARIOUS PHYSICAL AND CHEMICAL PROPERTIES OF CHLORINE TRIFLUORIDE AND TRIETHYLALUMINUM

Property	Chlorine trifluoride (a)	Triethylaluminum (b)
Formula	ClF_3	$(C_2H_5)_3Al$
Molecular weight	92.46	114.17
Freezing point, °F	-105	-52
Boiling point, °F	53	368
Liquid density (at 32° F), lb/cu ft	117.5	53.0
Liquid viscosity (at 32° F), (lb)(sec)/sq ft	1.11×10^{-5}	8.72×10^{-5}
Net heat of combustion (at 25° C), Btu/lb TEA	---------	18,352
Heat of reaction with hydrogen (at 25° C), Btu/lb ClF_3	3560	------
Composition of commercial material	99+ percent ClF_3	83 to 88 percent triethylaluminum 3 to 6 percent diethylaluminum hydride 3 to 6 percent tributylaluminum 0.2 to 1.0 percent diethylaluminum ethoxide

[a] Data from ref. 2.

[b] Data from ref. 3.

TABLE II. - ENGINE STARTING DATA WITH CHLORINE TRIFLUORIDE IGNITION

[Inside diam. of injection tube, 0.018 in.]

Injection-tube length, in.	Flow programming (a)			Hydrogen flow rate, lb/sec (b)	Oxygen flow rate, lb/sec	ClF_3 flow rate, lb/sec (c)	ClF_3 flow rate, lb/sec (d)	Chamber pressure after starting transient, lb/sq in. abs	Percent fuel after starting transient	Ignition delay time, τ_a, millisec (e)	Delay time, τ_b, millisec (e)
	Open ClF_3 valve, sec	Open oxygen valve, sec	Starting transient ends, sec								
36	2.00	4.00	4.50	0.0749	0.445	0.0182	0.0163	270	14.4	51	10
				.0749	.434	.0176	.0167	272	14.7	42	18
				.0749	.444	.0169	------	263	14.4	95	15
				.1001	.530	.0192	.0190	352	15.9	77	6
				.1002	.530	.0184	.0156	355	15.9	56	9
				.1005	.530	.0177	.0153	340	15.9	70	6
				.1015	.530	.0153	.0125	364	16.1	64	32
				.1017	.530	.0149	.0124	365	16.1	109	17
			4.60	0.1023	0.279	0.0145	0.0130	290	26.8	88	9
				.1017	.281	.0141	.0150	263	26.6	139	25
			4.65	0.0540	0.303	0.0149	0.0127	208	15.1	120	5
				.0536	.300	.0144	.0125	205	15.1	300	3
				.0531	.308	.0139	.0106	208	14.7	344	7
	1.50	4.00	4.65	0.0531	0.309	0.0135	0.00953	211	14.7	152	10
				.0535	.304	.0131	-------	209	15.0	301	9
				.0536	.303	.0127	.00880	211	15.0	267	5
			4.60	0.0518	0.515	0.0179	0.0139	268	9.1	22	6
				.0516	.515	.0171	.0154	252	9.1	25	0
				.0486	.500	.0164	.0130	252	8.9	20	3
				.0487	.500	.0158	.0112	250	8.9	28	5
				.0487	.500	.0151	.0135	247	8.9	55	7
18	1.50	4.00	4.50	0.1092	0.535	0.0102	0.0119	352	17.0	569	7
				.1090	.524	.0100	.0095	379	17.2	300	6
				.1073	.518	.00974	.0081	347	17.2	1470	5
				.0999	.529	.00950	.0042	352	15.9	746	0
			4.60	0.1050	0.288	0.0112	0.00633	279	26.4	625	10
				.1013	.291	.0107	.00869	279	25.5	565	8
				.1081	.393	.0101	.0149	267	21.0	1722	12
				.1077	.305	.00978	.00738	281	26.1	630	8
			4.70	0.0575	0.303	0.00963	0.00825	221	15.9	875	8
				.0570	.300	.00940	.00531	221	16.0	530	7
				.0571	.309	.00912	-------	217	15.6	1700	9
				.0571	.306	.00892	.00820	224	15.7	935	9
				.0574	.321	.00872	.00683	216	15.2	958	13
				.0573	.308	.00860	.00685	227	15.7	268	6
6	1.50	3.00	3.15	0.1370	-----	0.0188	0.0181	366	----	83	4
				.1370	-----	.0180	------	378	----	123	2
				.1374	0.562	.0203	------	452	19.7	14	7
				.1361	.569	.0197	.0183	435	19.3	24	0
				.1378	.565	.0190	.0166	450	19.6	59	0
				.1502	.624	.0188	.0177	450	19.4	47	0
				.1502	.656	.0183	.0150	450	18.6	82	0
				.1573	-----	.0161	.0200	452	----	58	3
				.1518	.779	.0158	.0181	450	18.3	35	0
			3.25	0.1460	0.612	0.0190	0.0257	537	15.2	16	0
				.1475	-----	.0202	------	544	----	47	0
			3.40	0.1396	-----	0.0207	0.0182	240	----	76	9
	0.60	2.00	2.30	0.1274	0.810	0.0211	0.0185	544	13.6	13	--
			2.25	0.1269	0.765	0.0204	0.0173	525	14.2	55	0
				.1284	.768	.0199	.0215	522	14.3	48	0
				.1266	.741	.0192	.0160	514	14.6	76	4
				.1268	.721	.0188	.0169	514	15.0	81	4
				.1279	.741	.0181	.0194	512	14.7	90	5
			2.40	0.1335	0.362	0.0200	0.0218	359	27.0	22	69
				.1334	.420	.0195	.0221	382	24.1	40	75
				.1339	.420	.0196	.0192	385	24.2	38	18
				.1338	.420	.0162	.0200	388	24.2	24	37
				.1338	.425	.0179	.0181	382	24.0	59	0
				.1338	.264	.0200	.0249	307	33.6	14	92
				.1304	.286	.0196	.0253	316	31.3	27	0
				.1339	.307	.0189	.0146	316	30.4	33	90
				.1387	.325	.0185	.0187	315	29.9	27	76
				.1385	.348	.0178	.0122	288	28.5	29	0
				.1378	.325	.0174	.0126	304	30.0	20	0
				.1311	.330	.0170	-----	315	28.4	59	5
				.1365	.339	.0164	.0112	312	28.7	100	0
				.1310	.325	.0161	.0157	321	25.7	51	4

[a] Based on hydrogen valve opening at zero time.

[b] Data computed from critical-flow-nozzle measurements.

[c] Data computed from water calibration of injection tube.

[d] Data computed from slope of pressurizing gas record.

[e] See figs. 3 and 4.

TABLE II. - Concluded. ENGINE STARTING DATA WITH CHLORINE TRIFLUORIDE IGNITION

[Inside diam. of injection tube, 0.018 in.]

Injection-tube length, in.	Flow programming (a)			Hydrogen flow rate, lb/sec (b)	Oxygen flow rate, lb/sec	ClF_3 flow rate, lb/sec (c)	ClF_3 flow rate, lb/sec (d)	Chamber pressure after starting transient, lb/sq in. abs	Percent fuel after starting transient	Ignition delay time, τ_a, millisec (e)	Delay time, τ_b, millisec (e)
	Open ClF_3 valve, sec	Open oxygen valve, sec	Starting transient ends, sec								
6	0.60	2.00	2.50	0.1397	0.202	0.0176	0.0199	218	40.8	34	7
				.1338	.203	.0171	.0218	220	39.7	42	0
				.1387	.231	.0166	.0118	224	37.5	30	32
				.1385	.203	.0162	.0128	230	40.5	21	0
	0.80	2.00	2.60	0.1338	0.128	0.0178	0.0144	143	51.1	41	140
				.1334	.0949	.0174	------	145	58.4	35	7
				.1363	.172	.0170	.0210	145	44.2	15	5
				.1382	.128	.0164	------	151	51.9	75	12
				.1360	.128	.0160	.0143	138	51.5	20	0
18	0.70	1.90	2.30	0.1390	0.568	0.0125	0.0116	452	19.7	11	0
				.1351	.560	.0122	.00997	461	19.4	257	52
				.1315	.560	.0108	.00890	470	19.0	36	0
				.1290	.560	.0106	.0131	470	18.7	20	0
				.1314	.564	.0104	.00989	470	18.9	234	0
				.1314	.568	.0101	.0112	465	18.8	151	0
		1.80	2.20	0.1313	0.423	0.00996	------	408	23.7	257	60
				.1323	.413	.00983	0.0119	401	24.3	105	0
	0.65	1.85	2.15	0.1309	0.750	0.0107	0.0111	553	14.9	16	56
				.1346	.748	.0105	.0114	542	15.3	36	62
				.1327	.739	.0103	.00749	552	15.2	129	60
				.1310	.726	.0101	.00519	543	15.3	183	4
				.1284	.743	.00996	.00927	543	14.7	214	4
			2.20	0.1363	0.413	0.00948	0.00944	408	24.8	127	73
				.1344	.418	.00926	.00411	397	24.3	242	59
				.1344	.395	.00913	.0144	411	25.4	19	41
				.1369	.417	.00898	-----	395	24.7	27	48
				r.1368	.311	.00888	.00708	336	30.6	143	72
	0.55	1.80	2.20	0.1314	0.304	0.0103	0.0108	341	30.2	24	130
				.1151	.304	.0101	.00899	338	27.4	22	63
				.1191	.311	.00987	.00664	338	27.7	17	0
		1.70	2.15	0.1115	0.198	0.00963	0.00436	247	36.0	181	158
				.1361	.167	.00952	.00795	252	44.9	136	10
		1.80	2.30	0.1127	0.0992	0.00933	-------	182	53.2	25	20
				.1305	.0573	.00917	0.00632	182	69.5	202	308
				.1353	.118	.00905	-------	190	53.4	254	320
				.1299	.118	.00887	-------	190	52.4	310	268
				.1203	.140	.00880	-------	183	46.2	175	272
6	2.00	4.00	4.50	0.1007	----	0.0172	0.0192	350	----	122	6
				.1001	----	.0159	.0111	357	----	37	0
18	1.50	4.00	4.60	0.1090	0.293	0.00946	-------	287	27.1	--	128
				.0521	.489	.00740	0.00796	240	9.6	--	22
				.0523	.503	.00713	-------	250	9.4	--	3
				.0517	.504	.00702	-------	253	9.3	--	86
				.0517	.498	.00682	-------	256	9.4	--	27
				.0517	.504	.00663	-------	255	9.3	--	92
	0.60	1.80	2.30	0.1418	0.410	0.0115	-----	395	25.7	121	110
			2.10	0.1381	0.560	------	-----	458	19.8	254	0

[a] Based on hydrogen valve opening at zero time.

[b] Data computed from critical-flow-nozzle measurements.

[c] Data computed from water calibration of injection tube.

[d] Data computed from slope of pressurizing gas record.

[e] See figs. 3 and 4.

TABLE III. - ENGINE STARTING DATA WITH TRIETHYLALUMINUM IGNITION

TEA injection tube		Flow programming (a)			Hydrogen flow rate, lb/sec	Oxygen flow rate, lb/sec	TEA flow rate, lb/sec	TEA flow rate, lb/sec	Chamber pressure after starting transient, lb/sq in. abs	Percent fuel after starting transient	Ignition delay time, τ_a, millisec	Delay time, τ_b, millisec	Oxygen-injector temperature at ignition, °F
Inside diam., in.	Length, in.	Open TEA valve, sec	Open hydrogen valve, sec	Starting transient ends, sec	(b)		(c)	(d)			(e)	(e)	
0.018	3	0.40	1.45	1.75	0.0747	0.407	0.0152	0.0156	275	[illegible]	10	27	-221
					.0760	.413	.0142	.0164	282	[illegible]	0	0	-233
					.0747	.360	.0131	.0122	---	17.2	--	--	----
		0.35	1.45	1.65	0.0785	0.401	0.0155	0.0154	295	16.0	0	[illegible]	-241
					.0756	.410	.0145	.0157	265	15.6	0	0	-244
				1.55	0.0760	0.415	0.0136	0.0157	303	16.8	0	0	-241
					.0757	.412	.0129	.0143	279	15.5	0	14	-237
					.0774	.408	.0124	.0128	303	16.0	0	0	-259
					.0769	.408	.0119	.0131	278	16.9	0	19	-250
					.0768	.390	.0105	.00985	291	16.5	57	41	-237
					.0772	.401	.0104	.0112	307	16.1	0	26	-236
					.0733	-----	.0102	.0113	---	----	0	17	-235
		0.40	1.40	2.00	0.0769	0.414	0.0131	0.00938	267	15.7	27	[illegible]	-252
					.0752	.411	.0128	.0109	259	15.5	0	[illegible]	[illegible]
					.0742	.411	.0120	.0103	292	15.3	0	[illegible]	[illegible]
					.0747	.408	.0115	.00885	292	15.5	[illegible]	[illegible]	-260
					.0750	.403	.0112	.00963	289	15.7	0	0	-260
					.0749	.411	.0103	.00717	291	15.4	0	[illegible]	-260
		0.35	1.50	2.10	0.0592	0.268	0.0151	-------	217	15.1	---	[illegible]	-217
					[illegible]	.277	.0142	-------	215	17.2	126	0	-205
					.0575	.278	.0131	-------	215	17.2	0	0	-250
					.0569	.275	.0120	-------	217	17.2	0	[illegible]	-227
					.0572	.271	.0110	-------	217	17.4	0	0	-259
					.0580	.275	.0103	-------	213	17.4	0	5	-272
					.0517	.276	.0133	0.00967	222	16.3	---	5	-231
					.0511	.273	.0127	.0096	222	16.2	[illegible]	0	-237
			1.40	2.00	.0509	.270	.0119	.00889	218	15.5	162	0	-243
		0.50	1.50	2.10	0.0511	0.273	0.0115	0.00994	224	15.8	22	0	-257
		0.60	1.50	2.20	0.0509	0.279	0.0104	0.00555	221	15.3	138	0	-245
		0.30	1.40	1.80	0.1053	0.232	0.0132	0.00899	252	30.3	---	0	-245
		0.35	1.40	1.90	0.1022	0.226	0.0126	0.0114	250	30.8	9	[illegible]	-243
					.1024	.241	.0121	.00973	272	[illegible]	0	[illegible]	-244
					.1021	.234	.0116	.00966	265	30.1	37	[illegible]	-182
					.1030	.243	.0113	.00812	268	29.2	0	[illegible]	-142
					.1027	.245	.0110	.0127	272	29.1	21	21	-96
					.1027	.242	.0106	.0107	272	29.4	40	[illegible]	-96
				2.00	0.0535	0.410	0.0137	0.0111	279	11.5	36	39	-96
					.0531	.407	.0130	.0131	268	11.5	0	27	-245
					.0525	.407	.0124	.0119	268	11.4	0	20	-219
					.0528	.410	.0117	.00989	266	11.4	0	[illegible]	-201
				1.80	0.0529	0.411	0.0113	0.00911	266	11.4	27	11	[illegible]
					.0522	.410	.0110	.00901	266	11.3	0	0	[illegible]
					.0526	.410	.0107	.00967	266	11.4	42	0	-231
			1.35	1.85	0.0997	0.412	0.0139	0.0155	352	19.6	0	0	-249
					.1008	.416	.0131	.0127	330	19.5	0	0	-169
					.0983	.410	.0124	.00785	312	19.7	23	18	-199
					.0988	.413	.0120	.00997	282	19.6	0	0	-169
					.0993	.412	.0115	.00968	256	19.6	31	0	-186
					.0990	.408	.0112	.0108	244	19.8	0	[illegible]	-118

[a] Based on oxygen valve opening at zero time.

[b] Data computed from critical-flow-nozzle measurements.

[c] Data computed from water calibration of injection tube.

[d] Data computed from slope of pressurizing gas record.

[e] See figs. 3 and 4.

TEA injection tube		Flow programming (a)			Hydrogen flow rate, lb/sec (b)	Oxygen flow rate, lb/sec	TEA flow rate, lb/sec (c)	TEA flow rate, lb/sec (d)	Chamber pressure after starting transient, lb/sq in. abs	Percent fuel after starting transient	Ignition delay time, τ_a, millisec (e)	Delay time, τ_b, millisec (e)	Oxygen-injector temperature at ignition, $^{\circ}F$
Inside diam., in.	Length, in.	Open TEA valve, sec	Open hydrogen valve, sec	Starting transient ends, sec									
0.018	3	0.45	1.40	----	0.0560	-----	0.0102	0.0131	---	----	---	12	11
		0.50	1.40	2.20	0.0559	0.122	0.00979	------	148	31.5	145	10	-193
					.0537	.122	.00943	0.0101	153	30.6	15	13	-154
				2.30	.0535	.122	.00912	.0107	152	30.6	6	10	-199
					.0539	.127	.00886	.00999	160	29.7	0	0	-134
					.0556	.131	.00861	.00851	157	29.8	282	9	-19
					.0540	.133	.00850	.00501	161	28.9	34	24	-119
					[f].0552	.131	.00831	.00562	160	29.6	236	20	-67
					.0540	.127	.00819	.00628	153	29.8	340	18	-83
					.0891	.144	.00938	.0120	164	36.3	247	17	-45
					.1017	.154	.00909	.0119	178	39.8	204	18	-60
					------	.160	.00884	.0127	195	----	72	14	-190
		0.45	1.40	----	0.0576	0.197	0.0102	0.0131	---	22.6	124	--	-84
		0.50	1.40	2.10	0.0570	0.222	0.00986	0.00966	219	20.5	24	0	-66
				2.00	0.0570	0.224	0.00950	0.0106	223	20.3	0	0	-268
					.0570	.222	.00893	.0110	221	20.5	0	0	-245
					.0583	.225	.00838	------	221	20.6	0	0	-213
		0.70	1.40	2.00	0.0580	0.224	0.00822	------	226	20.6	0	9	-274
		0.50	1.40	1.85	0.1106	0.185	0.00945	0.0113	261	37.4	36	0	-116
				1.90	0.1083	0.191	0.00887	0.00985	259	36.2	23	16	-218
					.1066	.191	.00828	.00825	256	35.9	85	0	-260
					.1066	.194	.00804	.0136	256	35.5	123	0	-276
					.1097	.194	.00793	.0123	259	36.1	60	13	-275
					.1066	.191	.00745	.0119	256	35.8	125	0	-263
					.0591	.337	.00749	------	273	14.9	166	18	-271
				2.00	0.0572	0.338	0.00769	0.0107	263	14.5	142	24	-271
					.0566	.333	.00732	------	263	14.5	133	18	-266
					.0555	.336	.00715	------	261	14.2	174	20	-268
					.1094	.345	.00745	------	361	24.1	260	0	-271
0.018	6	0.50	1.45	2.10	0.1053	0.342	0.00745	------	371	23.6	278	17	-270
					.1056	.344	.00742	------	370	23.5	263	14	-270
					.1073	.346	.00735	------	360	23.7	314	17	-266
0.026	6	0.35	1.45	1.90	0.0497	0.247	0.0190	-----	176	16.8	---	0	-40
		0.45	1.45	1.90	0.0640	0.254	0.0193	0.0119	207	20.1	67	0	-23
					.0634	.252	.0182	.0175	206	20.1	0	0	-71
					.0623	.251	.0172	.0130	207	19.9	0	0	-63
					.0603	.254	.0164	-----	206	19.2	0	0	-97
		0.55	1.50	2.00	0.0609	0.252	0.0159	0.0129	202	19.5	0	0	-270
					.0602	.255	.0154	.0118	195	19.1	83	0	-260

[a] Based on oxygen valve opening at zero time.

[b] Data computed from critical-flow-nozzle measurements.

[c] Data computed from water calibration of injection tube.

[d] Data computed from slope of pressurizing gas record.

[e] See figs. 3 and 4.

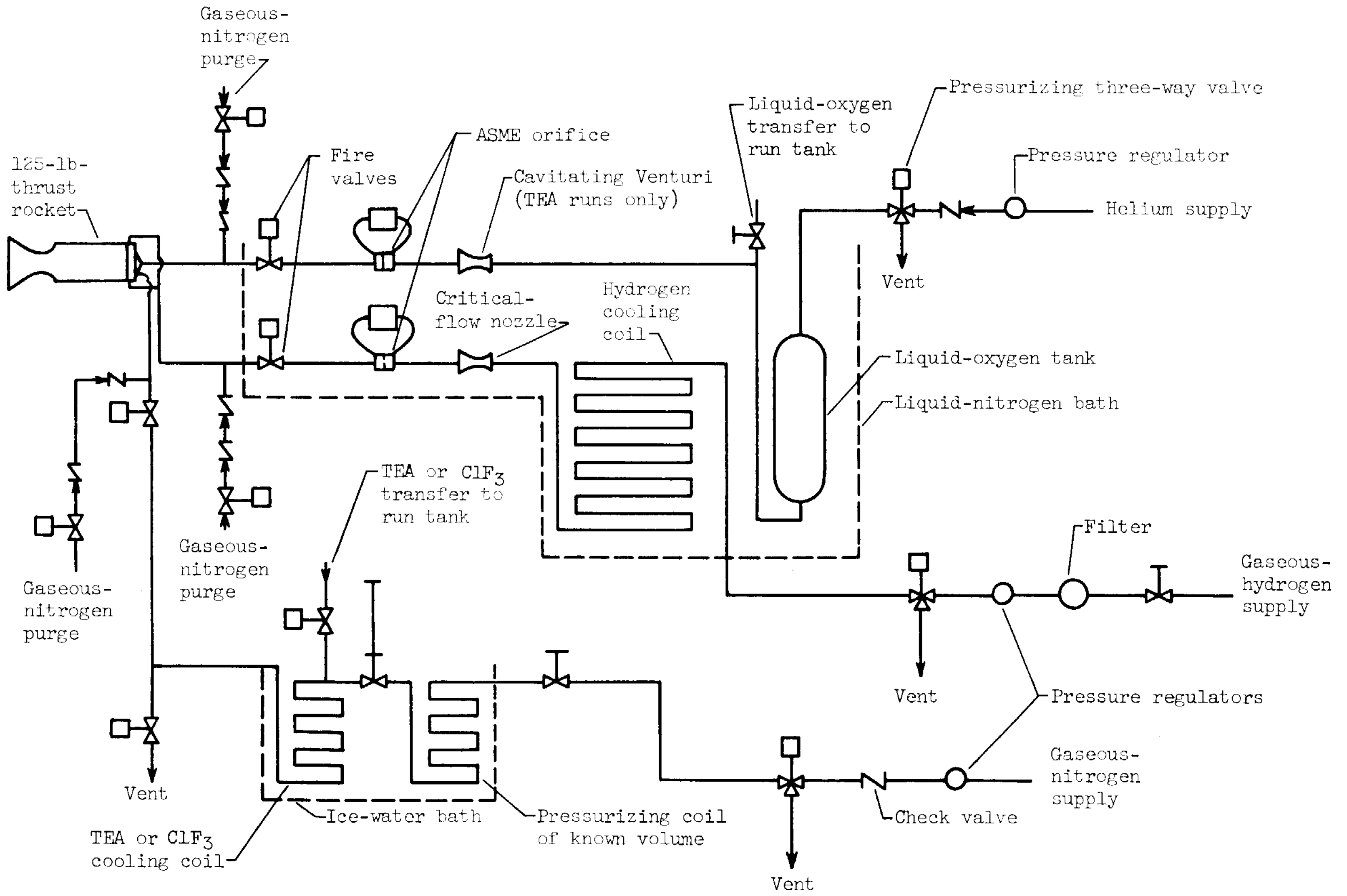

Figure 1. - Schematic diagram of gaseous-hydrogen, liquid-oxygen, and chlorine trifluoride or triethylaluminum propellant systems.

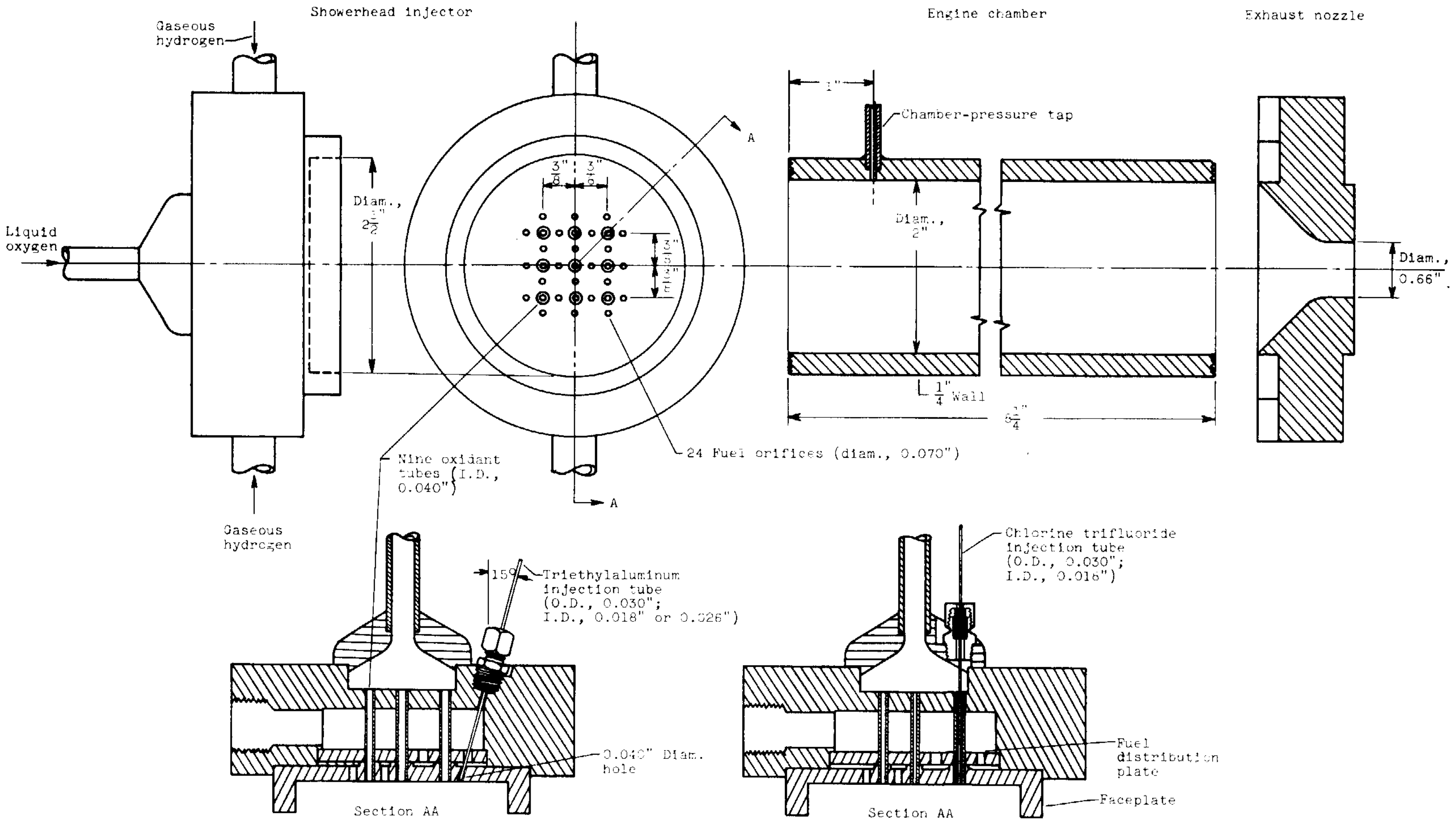

Figure 2. - Nominal-125-pound-thrust hydrogen-oxygen engine assembly showing chlorine trifluoride and triethylaluminum injection method.

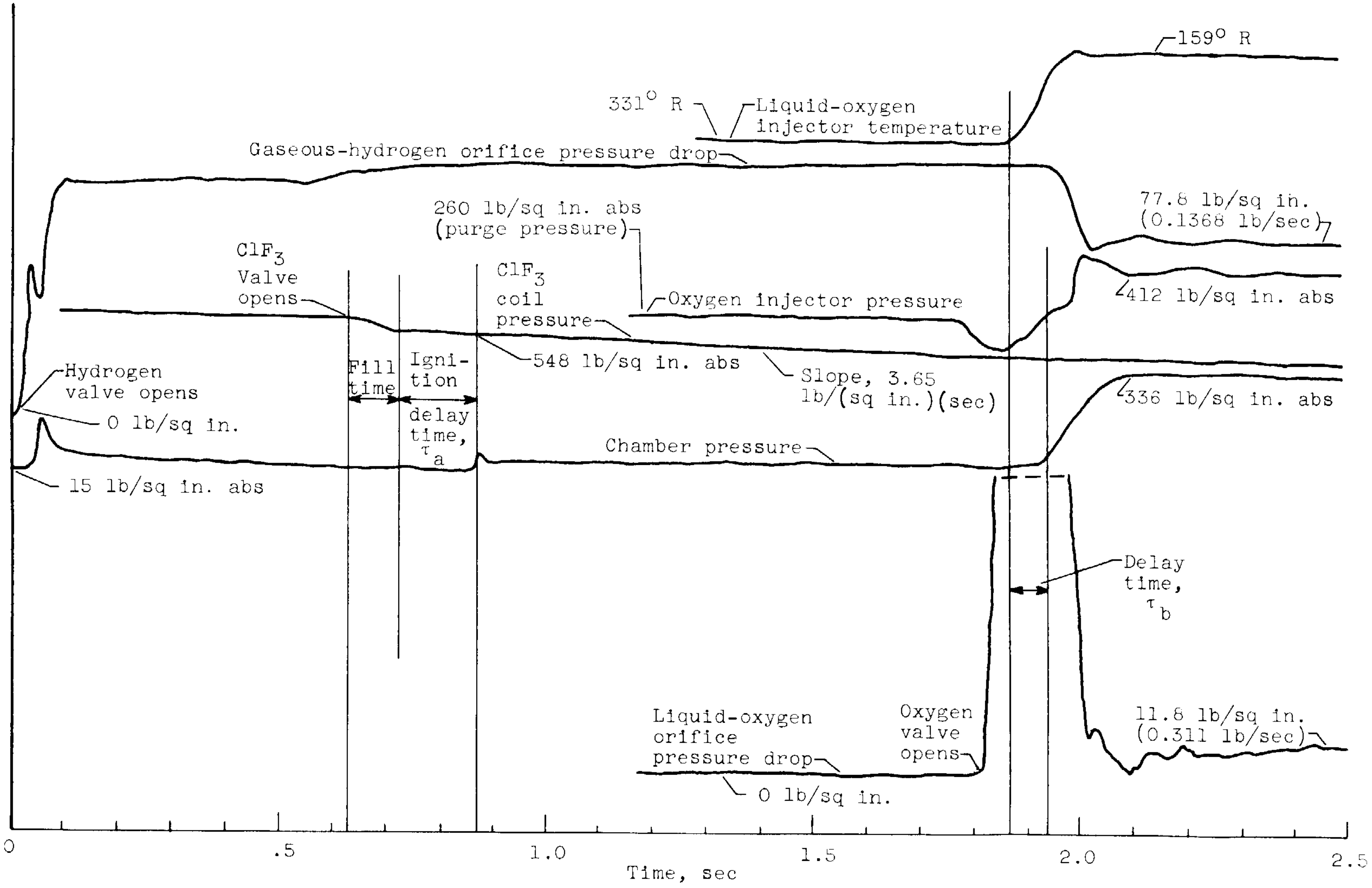

Figure 3. - Typical starting transient with chlorine trifluoride ignition.

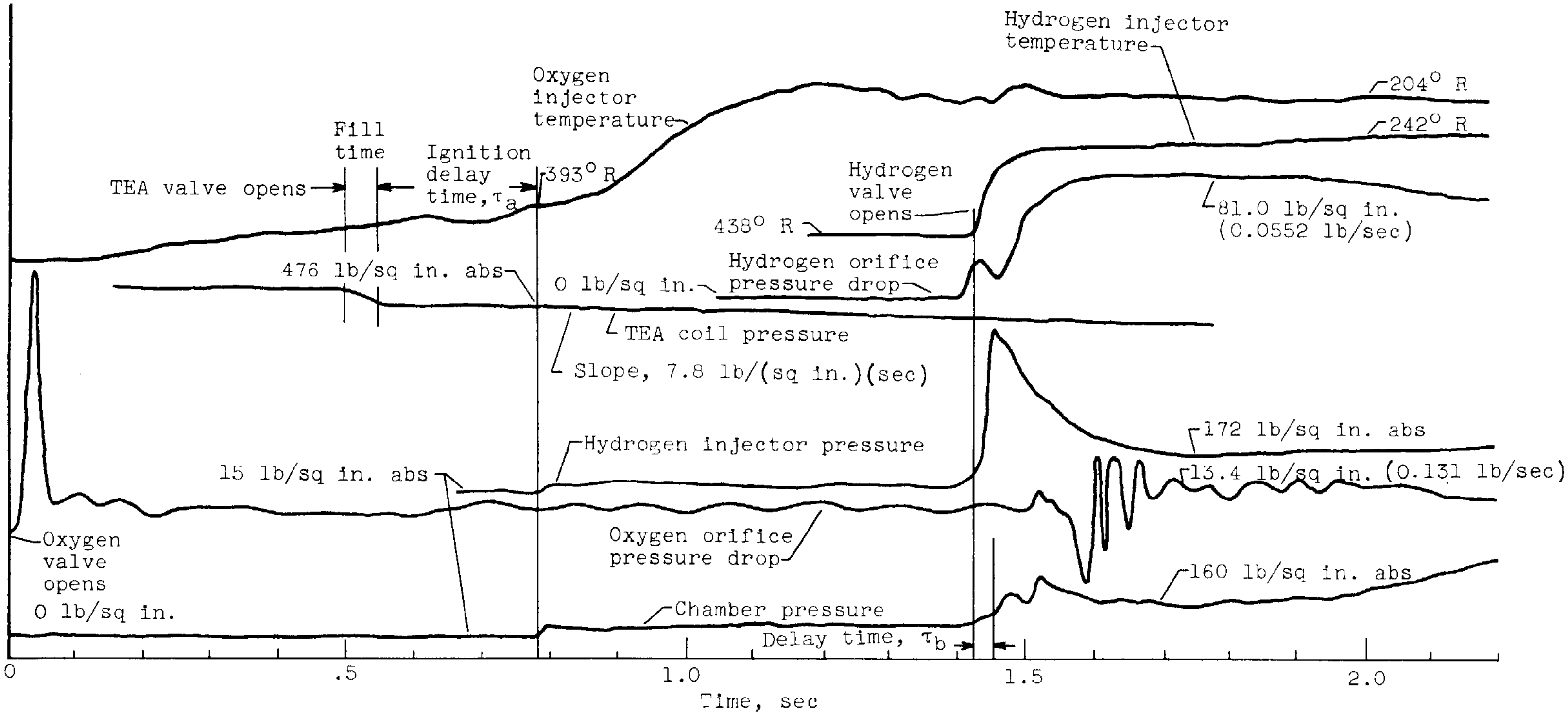

Figure 4. - Typical starting transient with triethylaluminum ignition.

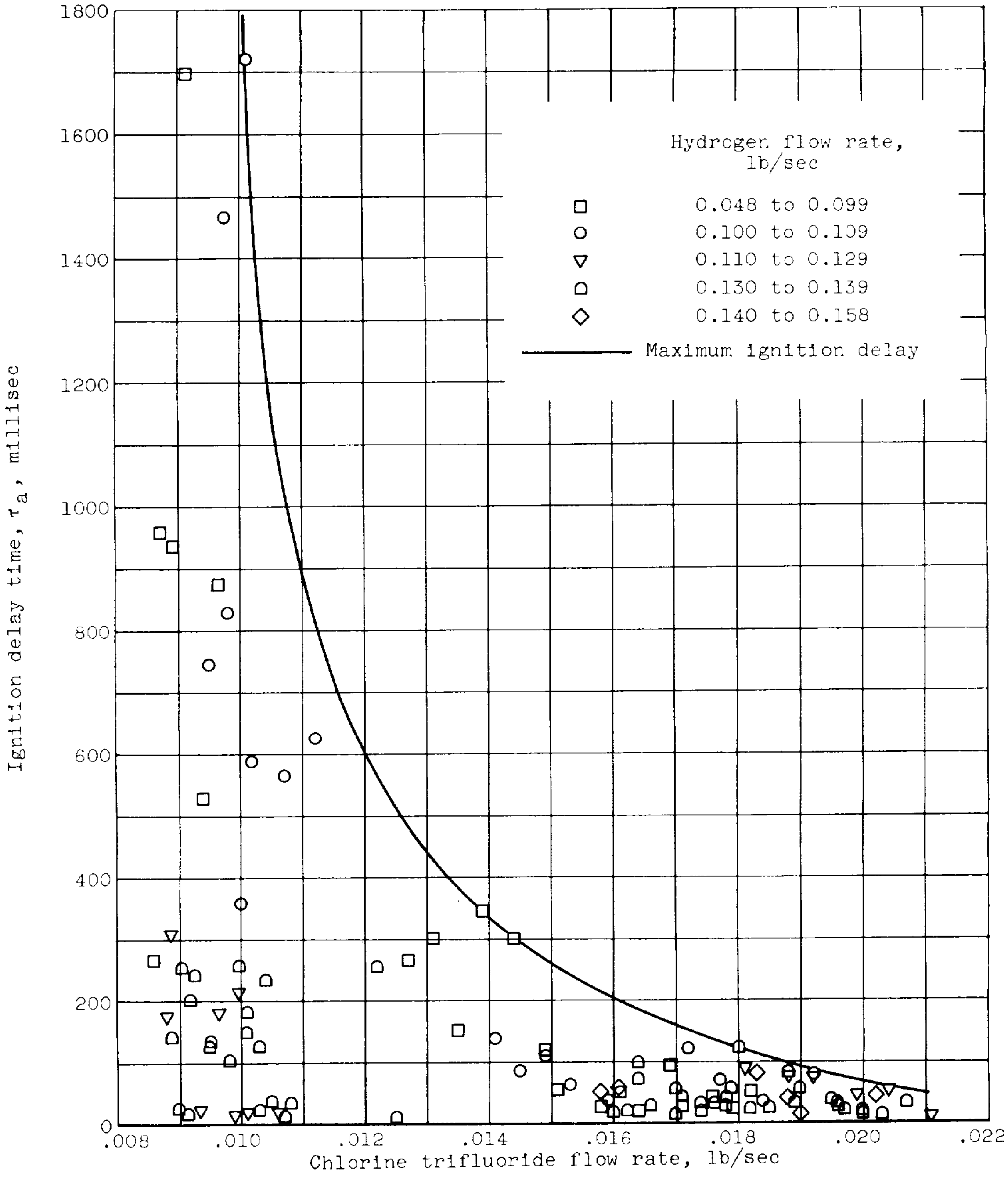

Figure 5. - Ignition delay time of reaction of chlorine trifluoride and hydrogen as function of chlorine trifluoride flow rate.

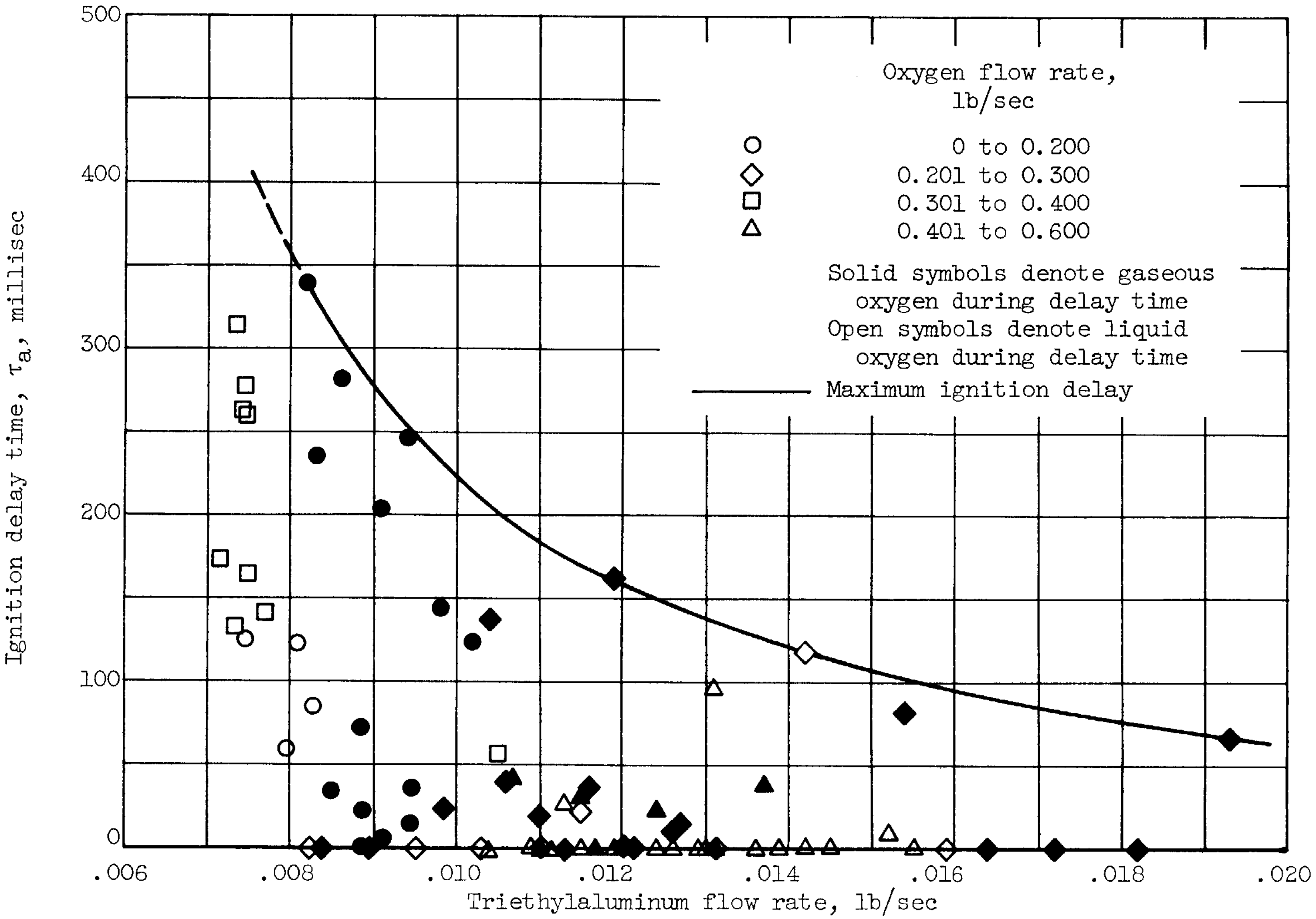

Figure 6. - Ignition delay time of reaction of oxygen and triethylaluminum as function of triethylaluminum flow rate.

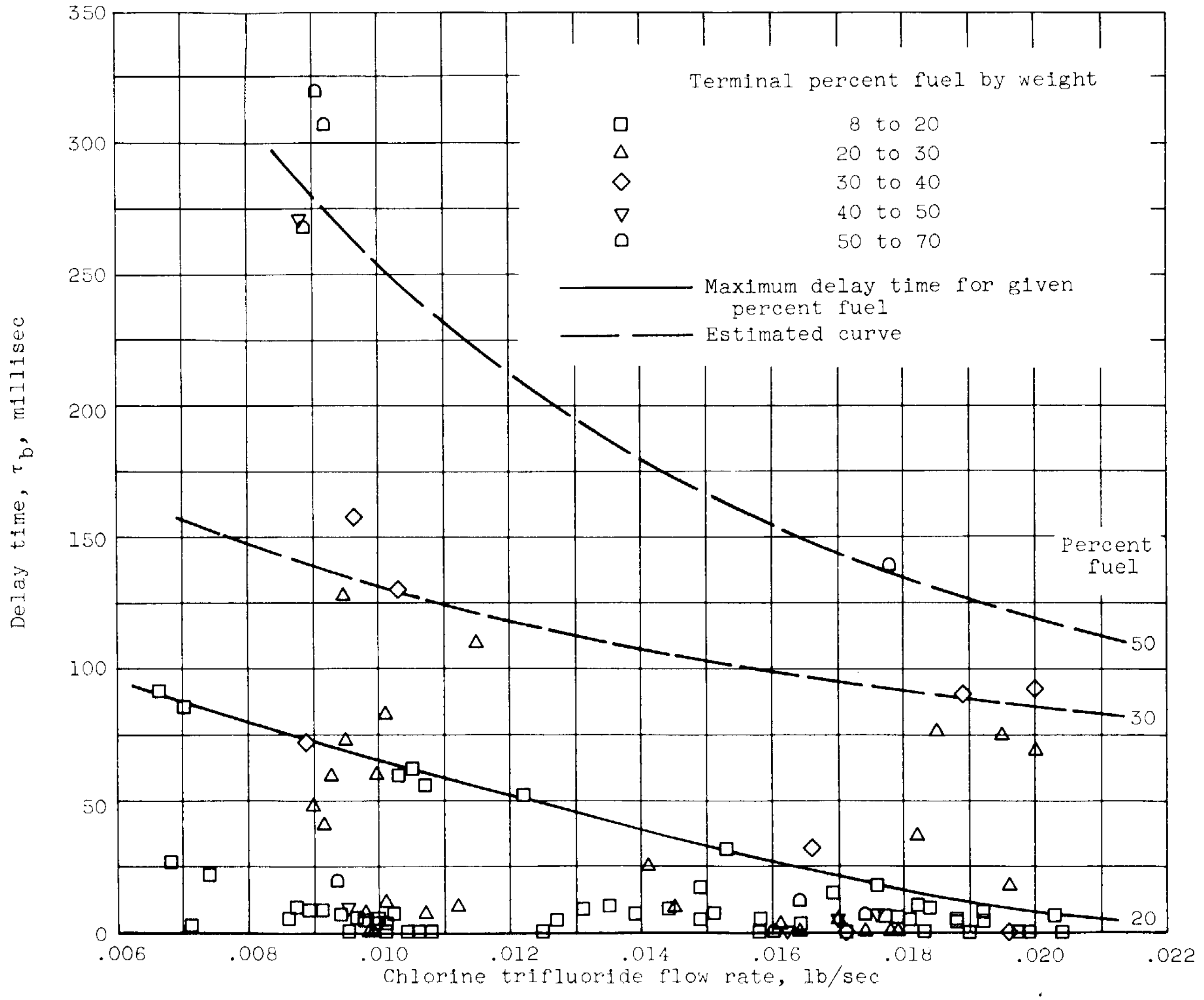

Figure 7. - Delay time of hydrogen-oxygen reaction as function of chlorine trifluoride flow rate and percent fuel in hydrogen-oxygen mixture.

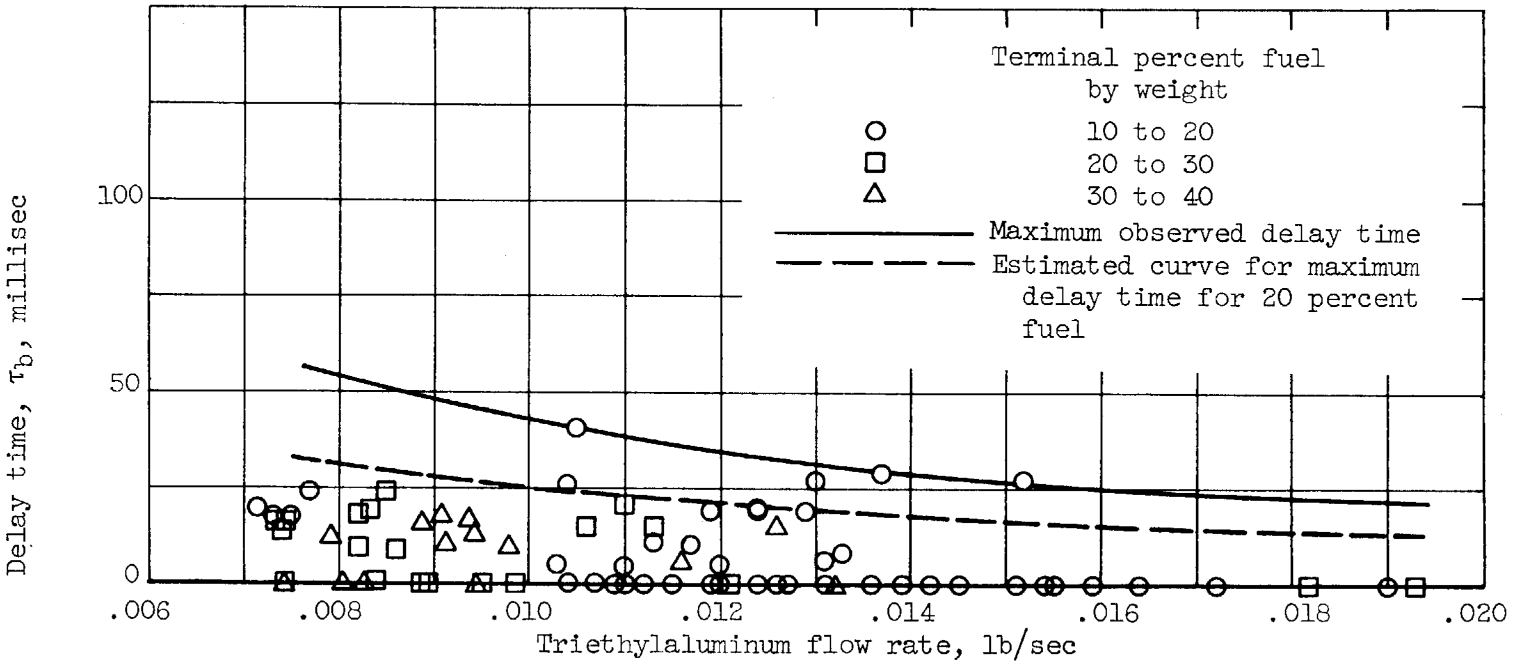

Figure 8. - Delay time of hydrogen-oxygen reaction as function of triethylaluminum flow rate and percent fuel in hydrogen-oxygen mixture.

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