View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by NASA Technical Reports Server

[redacted]

Copy
NASA MEMO 1-23-59E

C. 290

LOAN COPY: RETURN TO
AFWL (WLL—)
AFB, N MEX

TECH LIBRARY KAFB, NM
0062897

NASA MEMO 1-23-59E

NASA

MEMORANDUM

INVESTIGATION OF SMALL-SCALE HYDRAZINE-FLUORINE INJECTORS

By R. James Rollbuhler and William A. Tomazic

Lewis Research Center
Cleveland, Ohio

Classification cancelled ~~(or changed to ________________)~~
by authority of NASA CCN No. 67 6/29/66
Helen Medwick GS-3 26 Oct 66
Name & Grade of Officer making change — Date

[redacted]

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON
January 1959

[redacted]

2 cpls removed
1/64 rc

[redacted]

TECH LIBRARY KAFB, NM
0062897

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MEMORANDUM 1-23-59E

INVESTIGATION OF SMALL-SCALE HYDRAZINE-FLUORINE INJECTORS*

By R. James Rollbuhler and William A. Tomazic

E-216

SUMMARY

The performance of the liquid-hydrazine - liquid-fluorine propellant combination was investigated in nominal-300-pound-thrust uncooled rocket engines with different injectors. Data are presented for characteristic velocity as a function of weight percent fuel flow. All tests were made at a chamber pressure of 300 pounds per square inch absolute.

The injectors, showerhead, like-on-like, and triplet types, were made of individual elements which could be used as "building blocks" in fabricating larger thrust injectors.

CS-1

The highest performance was obtained with triplet injectors. A maximum characteristic velocity of 6690 feet per second (94 percent of theoretical equilibrium) was reached at 36 weight percent fuel flow. The like-on-like and one showerhead injector gave performance which was about 82 percent of equilibrium theoretical, and another showerhead injector gave performance of 81 percent of theoretical equilibrium.

In none of the runs was there any corrosion or erosion of the injectors, either from the propellants or combustion heat flux. There was no problem from hydrazine decomposition, propellant ignition, or combustion oscillation.

INTRODUCTION

The hydrazine-fluorine combination offers high specific impulse coupled with high bulk density. It offers 20 percent higher specific impulse and 29 percent greater bulk density than today's "work horse" combination for large engines, liquid oxygen and kerosene. It holds a 1.3-percent advantage in specific impulse and a 12.2-percent advantage in bulk density over a competitor in its own class, ammonia and fluorine. Coupled with this increased performance is a corresponding increase in combustion temperature and heat flux. Fortunately, hydrazine is an excellent coolant, although not without problems. Almost three times the ultimate heat flux is possible with hydrazine as with ammonia (refs. 1

*Title, [redacted].

[redacted]

SWC 9C2036 /290

and 2). The over-all heat capacity of hydrazine for cooling a 300-pound-per-square-inch absolute engine is twice that of ammonia. However, hydrazine has a tendency to decompose rapidly at elevated temperatures. Therefore, care must be taken to avoid stagnant regions in cooling passages and to avoid contact with substances which may catalyze decomposition (refs. 3 and 4).

Relatively little experimental work with the hydrazine-fluorine combination has been reported. Some small-scale experiments are reported in reference 5, and work with fluorine and a hydrazine-ammonia mixture is reported in reference 6. E-216

This report covers experiments with small-scale (300-lb nominal thrust) injectors of the triplet, showerhead, and like-on-like types. The performance and regenerative cooling ability of these injectors were studied. Operational characteristics including combustion stability and starting were also studied. The injectors were designed so as to allow scaling up in thrust by increasing the number of individual independent elements without changing the size or spacing of injector holes or cooling passages. Nine elements were used in this case to give a nominal 300-pound thrust. Uncooled copper thrust chambers with convergent nozzles were used. Runs were at a chamber pressure of 300 pounds per square inch absolute with from 28 to 45 percent fuel. The hydrazine was heated to approximately 200° F to simulate more closely the output from a regeneratively cooled engine. Although 200° F is a low temperature for fuel coming out of a regeneratively cooled engine (theoretical calculations indicate the temperature would be 360° F for a 20,000-lb-thrust engine), it was used because it was the easiest temperature to maintain (hot water bath) without causing thermal decomposition of the hydrazine. Experimental characteristic velocity is shown as a function of percent fuel concentration and compared with the theoretical characteristic velocity.

APPARATUS

Propellants

Gaseous fluorine was obtained in gas cylinders from a commercial supplier. Each cylinder contained approximately 6 pounds of 98 percent pure fluorine under a pressure of about 380 pounds per square inch absolute. Liquid hydrazine was obtained from an industrial supplier in glass, aluminum, and stainless steel containers. NASA laboratory analysis showed that the hydrazine was 97.6 percent pure, the remainder being water and a trace of ammonia.

Propellant System

A flow diagram of the system used in making this investigation is shown in figure 1. The oxidant flow system consisted of a 1/3-cubic-foot

E-216

CS-1 back

monel tank from which the fluorine flowed to the injector through a stainless steel line, a flowmeter, and a fire valve. The entire system was submerged in a liquid nitrogen bath up to the engine. A stainless steel line, a flowmeter, and a fire valve were between the 1/4-cubic-foot stainless steel fuel tank and the injector. The hydrazine tank was in a heated water bath.

Instrumentation

The oxidant and fuel flowmeters were turbine type meters, and the signal from each was recorded on a totalizer, a recording self-balancing-potentiometer strip chart, and an oscillograph. Because the oxidant tank and flowmeter were immersed in liquid nitrogen, the fluorine temperature was constant at -320° F. The temperature of the hydrazine was measured with thermocouples and recorded on self-balancing-potentiometer strip charts. The engine chamber pressure was measured by a strain-gage pressure transducer and by a Bourdon-tube strip chart recorder. Accuracy of the calculated data, based on reading errors and instrument and indicator inaccuracy, was about $\pm 2\frac{1}{2}$ percent.

Injectors

The injectors used in this program are shown in figure 2. Each of these injectors consisted of nine independent elements. Each element consisted of an axial oxidant jet of 0.043-inch diameter together with two fuel jets, either axial or impinging, depending on the injector type. The diameter of the fuel jets was 0.025 inch for the triplets and like-on-likes and 0.021 inch for the showerheads. A distribution plate directly beneath the faceplate channeled the fuel flow so that the face was kept cooled. Two types of distribution plates were used; all the injectors used plates with 0.08- by 0.02-inch fuel channels except showerhead A, which had a distribution plate with 0.16- by 0.01-inch channels. The latter channels increased the face area cooled by hydrazine. Showerhead A also had smaller diameter oxidant rods (less end area), because less face cooling capability was required of the oxidant.

The oxidant jet rods, distribution plates, and faceplates were made of copper for heat transfer. All copper surfaces which would be exposed to hydrazine were gold plated to avoid possible catalysis of hydrazine decomposition by copper oxide.

Six configurations embracing three basic types were used. They are identified as:

(1) Thirty-degree-impingement-angle triplet - an injector in which two fuel jets impinged on each oxidant jet at an included angle of 30° (fig. 2(a))

(2) Sixty-degree-impingement-angle triplet - an injector identical to the 30° triplet except that the fuel jets formed 60° included angles (fig. 2(b))

(3) Fuel like-on-like - an injector in which the oxidant jets were axial in flow and the fuel jets paired into like-on-like impingement sets (fig. 2(c))

(4) Showerhead A - a configuration in which both fuel and oxidant jets were axial and the internal design was different from the other injectors (fig. 2(d))

(5) Showerhead B - a configuration with face identical to showerhead A but internal design the same as the triplets and like-on-like

(6) Showerhead BL - the same injector as showerhead B but with considerable fuel leakage around each oxidant rod

Thrust Chambers

The thrust chambers were made of $2\frac{1}{2}$-inch-diameter copper pipe with 1/4-inch-thick walls. They were all 8 inches long and had a characteristic length of 32. The nozzles were solid uncooled copper with no divergent section. One engine was ceramic lined to allow runs of approximately 8-second duration.

PROCEDURE

The oxidant line trough and tank bath were filled with liquid nitrogen after calibration and pressure checking. Gaseous fluorine was then condensed in the oxidant tank, and the hydrazine in the fuel tank was warmed to about 200° F. Both propellant tanks were pressurized with helium gas and flow was varied by changes in tank pressure. Fuel and oxidant were introduced into the rocket simultaneously. Ignition was spontaneous, and stable combustion conditions were achieved within 1 second. The runs lasted 3 or 4 seconds, except for some of 6- and 8-second duration made in order to better test the injector face cooling capabilities. After each run the engine and flow lines were purged with helium. After a series of runs with any one injector it was disassembled and visually inspected for metal burning, erosion, or corrosion.

Characteristic velocity was calculated from the experimentally determined values of chamber pressure and total propellant flow during stable portions of each run.

RESULTS

Experimental results are presented in table I and figures 3 and 4. Figure 3 shows characteristic velocity as a function of percent fuel concentration for all the injectors. Performance efficiency (percent of theoretical characteristic velocity) is given in figure 4.

Triplet injectors. - The 30° triplet gave characteristic velocities ranging from 6160 to the peak value of 6690 feet per second obtained at approximately 36 percent fuel. This is 94 percent of the theoretical maximum. The 60° triplet had slightly lower performance; maximum characteristic velocity was about 6590 feet per second, or 93 percent of the theoretical at 37 percent fuel.

Like-on-like injector. - This injector gave a maximum characteristic velocity of 5770 feet per second, or 82 percent of the theoretical at 39 percent fuel.

Showerhead injectors. - In the mixture range studied, showerhead A gave a maximum characteristic velocity of 5890 feet per second (84 percent of theoretical) at 41 percent fuel. The highest characteristic velocity with showerhead B was 5720 feet per second at 41 percent fuel. This was 81 percent of theoretical. Showerhead BL gave a maximum characteristic velocity of 6600 feet per second or 95 percent of theoretical at 45 percent fuel.

Operations. - In none of these runs were hard starts or combustion oscillations noted. Checking of each injector after running showed no erosion or corrosion.

DISCUSSION

The injectors used in this investigation were chosen to provide a relatively broad picture of the problems involved with hydrazine-fluorine injection. It was felt that the triplets would give good performance but might be handicapped by excessive heat transfer or combustion oscillations. In contrast, the showerhead injector offered less potential performance, but heat transfer and stability were expected to be more favorable. The like-on-like injector was considered a compromise between these two extremes.

Each injector was composed of nine independent injection elements. These elements were considered as individual basic units which could be combined in any number to build any size injector desired. This could be done without changing their size or spacing. Both the face pattern and the underface cooling design would remain the same regardless of thrust size.

[redacted]

As shown in the section RESULTS, the triplet injectors gave the highest consistent performance for the fuel-oxidant range tested. It would appear that an oxidant jet hitting the impingement point of two fuel jets adds to atomization and vaporization of the fuel. Also, the oxidant was well mixed and vaporized by such an injector.

The fuel like-on-like injector gave performance which was between that of the triplet and the showerhead injectors. The lower performance (from that of the triplets) was due to lack of atomization of the oxidant. Without the oxidant jet hitting the impingement point of the fuel jets there was not enough kinetic energy to do as adequate a job. As a result, mixing and distribution of the propellants suffered also.

E-216

The results from the showerhead injector A were similar to those of the fuel like-on-like injector except that the fuel-rich runs gave slightly greater performance. This injector gave performance about 5 percent greater than showerhead B, and the only difference between them was the size of the hydrazine underface passages and the outside diameter of the oxidant tubes.

Showerhead injector B gave the lowest performance of any of the injectors tested. The data also are more scattered than for the other injectors. Because the propellant flow was axial and there was no impingement, less mixing and atomization resulted and performance was poor.

Performance of the showerhead injector BL was good, particularly with fuel-rich runs, evidently because of the greater fuel flow from the thin slit around each oxidant jet, which gave improved atomization and distribution.

The injector faces were designed to be primarily cooled by the fuel. But in regeneratively cooled engines the hydrazine entering the injector would be so hot that its cooling potential would be greatly reduced. Consequently, two backface cooling designs were tested. For one design some of the injector face cooling load was shifted from the fuel to the oxidant. This was done by increasing the oxidant rod face ~~and~~ area and decreasing the hydrazine channel width. This design theoretically offered the best method of keeping the injector face cool; therefore, all the injectors used in these tests were built this way except showerhead A. Showerhead A used the other cooling design, in which virtually all the face cooling depended on the fuel (wider channels). When the injectors were run, both designs resulted in adequately cooled faces, and there was no difficulty from the additional heat load put on the oxidant. However, if the temperature of the hydrazine entering the injector were increased, more of the injector face cooling load would have to be shifted to the oxidant, the proportioning of the load depending on the temperature of the entering hydrazine.

Several runs approximately 8 seconds in duration were made to better test the cooling capacity of these injectors. Tests were held to

[redacted]

8 seconds because the temperature of the uncooled chamber outer wall went over 1100° F, in spite of a ceramic inner wall liner. No signs of metal burning, erosion, or corrosion were apparent in these or any of the shorter tests with any of the injectors

SUMMARY OF RESULTS

The performance of a hydrazine-fluorine 300-pound-thrust uncooled rocket engine was studied experimentally. The propellant mixture range was 28 to 45 weight percent fuel, and the combustion chamber pressure approximately 300 pounds per square inch absolute. The following results were obtained:

E-216

1. The highest characteristic velocities (6160 to 6690 ft/sec) over a varied propellant mixture range were obtained with the 30° and 60° impingement triplet injectors. Peak performance was 94 percent of equilibrium theoretical at 36 weight percent fuel flow with the 30° impingement triplet.

2. Maximum performance values obtained for the fuel like-on-like, the showerhead A, and the showerhead B injectors were 82, 84, and 81 percent of theoretical equilibrium, respectively.

3. Cooling of the injector faces during the tests was no problem.

4. No decomposition of the heated hydrazine was apparent. No corrosion or erosion of any surface in contact with either propellant was noticeable. There were no starting or oscillation difficulties, and no deposits were built up in the chamber or pressure tap during any of the runs.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, October 27, 1958

REFERENCES

1. Bartz, D. R.: Factors which Influence the Suitability of Liquid Propellants as Rocket Motor Regenerative Coolants. Jet Prop., vol. 28, no. 1, Jan. 1958, pp. 46-53.

2. Anon.: Combined Bimonthly Summary No. 58, Feb. 1 to Apr. 1, 1950. Jet Prop. Lab., C.I.T., Apr. 15, 1957, p. 25.

3. Anon.: Liquid Propellant Handbook. Vol. I. Hydrazine and Fluorine Sections. Battelle Memorial Inst., 1955.

4. Anon.: Symposium on Hydrazine and Its Applications. FRO 205/3. Res. and Dev. Board, Comm. on Fuels and Lubricants, Sept. 1953.

5. Doyle, W. L.: Experimental Evaluation of Liquid-Fluorine and Hydrazine Propellant System. Rep. AL-830, North Am. Aviation, Inc., Oct. 28, 1949.

6. Ordin, Paul M., Rothenberg, Edward A., and Rowe, William H.: Investigation of Liquid Fluorine and Hydrazine-Ammonia Mixture in 100-Pound-Thrust Rocket Engine. NACA RM E52H22, 1952.

7. Gordon, Sanford, and Huff, Vearl N.: Theoretical Performance of Liquid Hydrazine and Liquid Fluorine as a Rocket Propellant. NACA RM E53E12, 1953.

E-216

[redacted]

TABLE I. - SUMMARY OF PERFORMANCE OF LIQUID HYDRAZINE AND LIQUID FLUORINE

Fuel flow, percent	Total propellant flow, lb/sec	Fuel temperature, °F	Chamber pressure, lb/sq in. abs	Characteristic velocity, ft/sec	Percent of theoretical characteristic velocity
30° Impingement-angle triplet injector					
29.0	0.944	200	265	6160	87.1
30.2	1.034	190	294	6240	87.9
32.2	.940	190	277	6470	90.8
34.4	.996	180	303	6680	93.7
34.7	.999	160	304	6680	93.7
35.5	.935	190	284	6670	93.7
37.9	1.011	172	308	6690	94.3
42.0	.931	180	272	6410	91.4
60° Impingement-angle triplet injector					
31.0	1.068	193	305	6270	88.2
33.3	1.055	191	302	6280	88.2
36.8	1.006	185	302	6590	92.8
Like-on-like fuel and showerhead oxidant injector					
33.7	0.985	190	253	5640	79.1
33.8	1.047	182	272	5730	80.0
34.1	1.047	172	277	5690	79.9
35.2	1.073	168	280	5730	80.4
38.8	1.066	156	280	5770	81.5
43.7	.846	192	214	5550	79.5
Showerhead injector A					
32.2	1.025	200	257	5500	77.2
35.8	1.016	200	262	5660	79.5
36.8	1.074	200	277	5660	79.6
40.6	1.044	200	280	5890	83.6
Showerhead injector B					
28.6	1.033	195	257	5460	77.4
29.8	1.051	180	260	5430	76.6
33.0	0.954	210	236	5400	75.7
35.6	1.014	200	260	5630	79.0
37.5	.938	195	233	5450	76.8
38.9	1.018	205	237	5080	71.9
40.8	1.048	195	273	5720	81.2
41.5	1.031	200	260	5540	78.8
Showerhead injector BL					
34.8	1.078	204	293	5970	83.7
38.1	1.092	200	298	5990	84.5
40.0	1.034	196	300	6370	90.3
41.1	.953	180	281	6470	91.9
44.8	.988	180	297	6600	94.8
45.5	1.047	180	313	6560	94.4

[redacted]

[redacted]

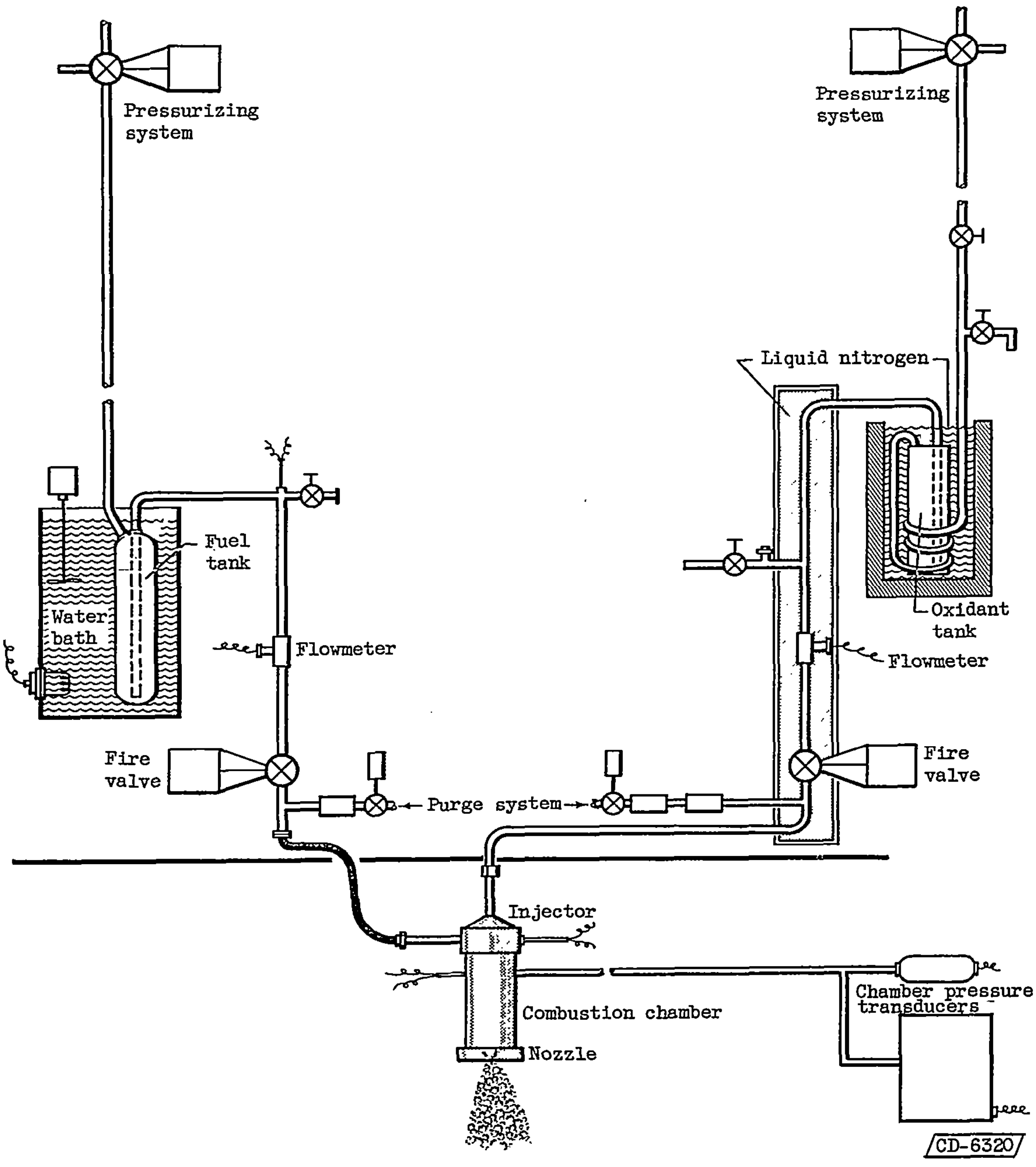
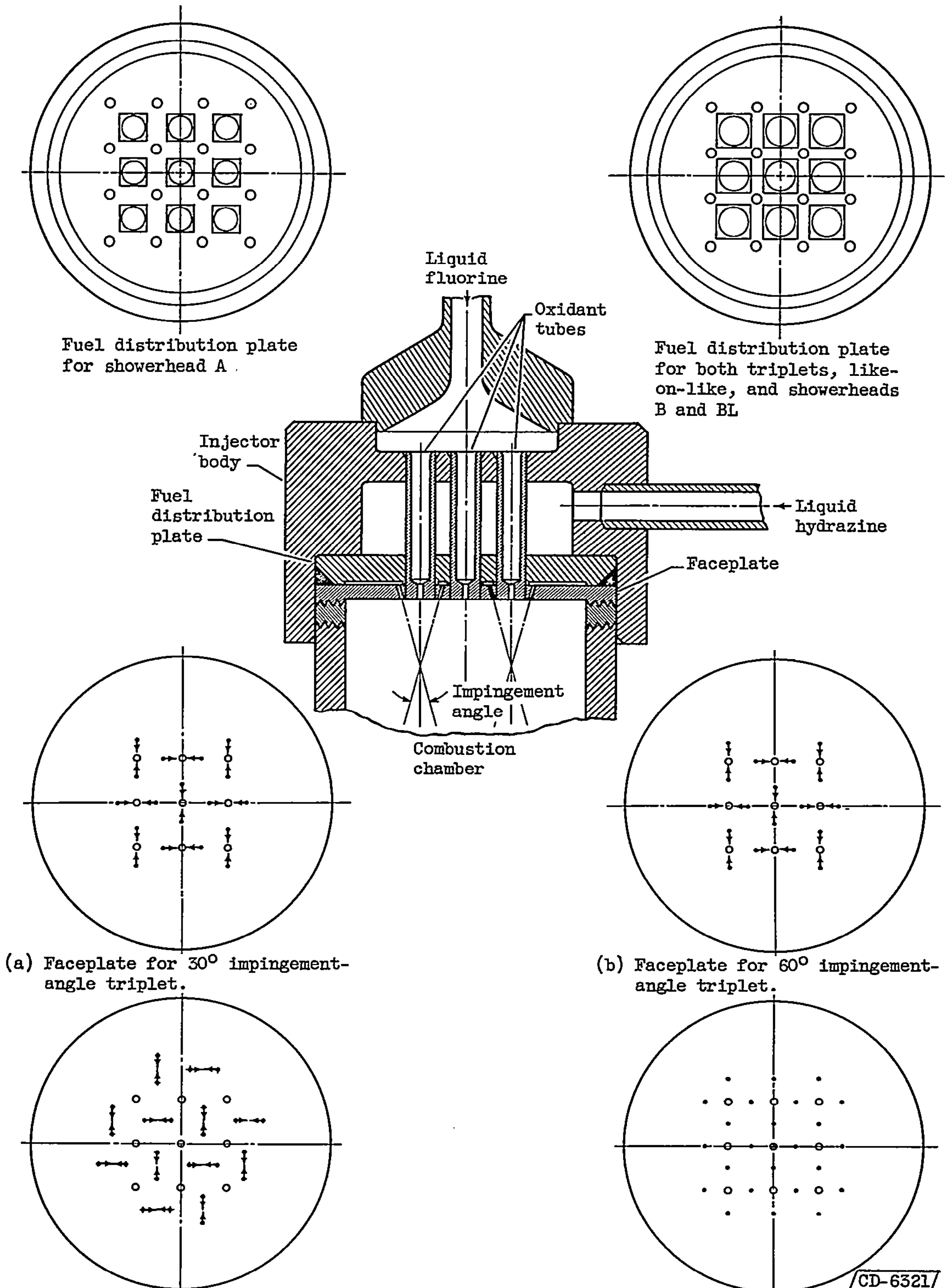


Figure 1. - Rocket engine test system (not drawn to scale).

[redacted]

[redacted]



(a) Faceplate for 30° impingement-angle triplet.

(b) Faceplate for 60° impingement-angle triplet.

(c) Faceplate for like-on-like injector.

(d) Faceplate for showerheads A, B, and BL.

Figure 2. - Hydrazine-fluorine injector designs.

[redacted]

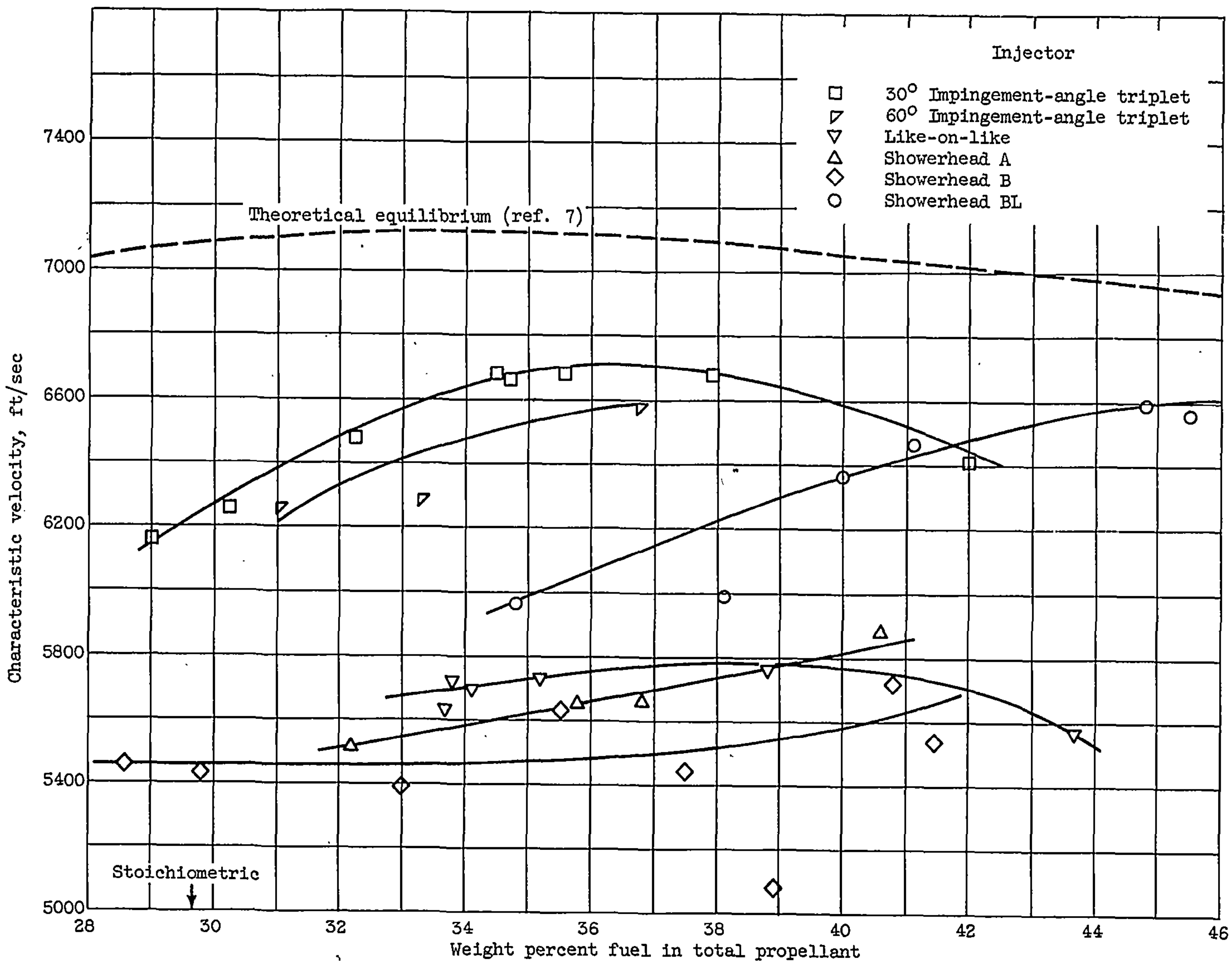


Figure 3. - Theoretical and experimental characteristic velocity of liquid hydrazine and liquid fluorine in 300-pound-thrust engine. Chamber pressure, 300 pounds per square inch absolute.

[redacted]

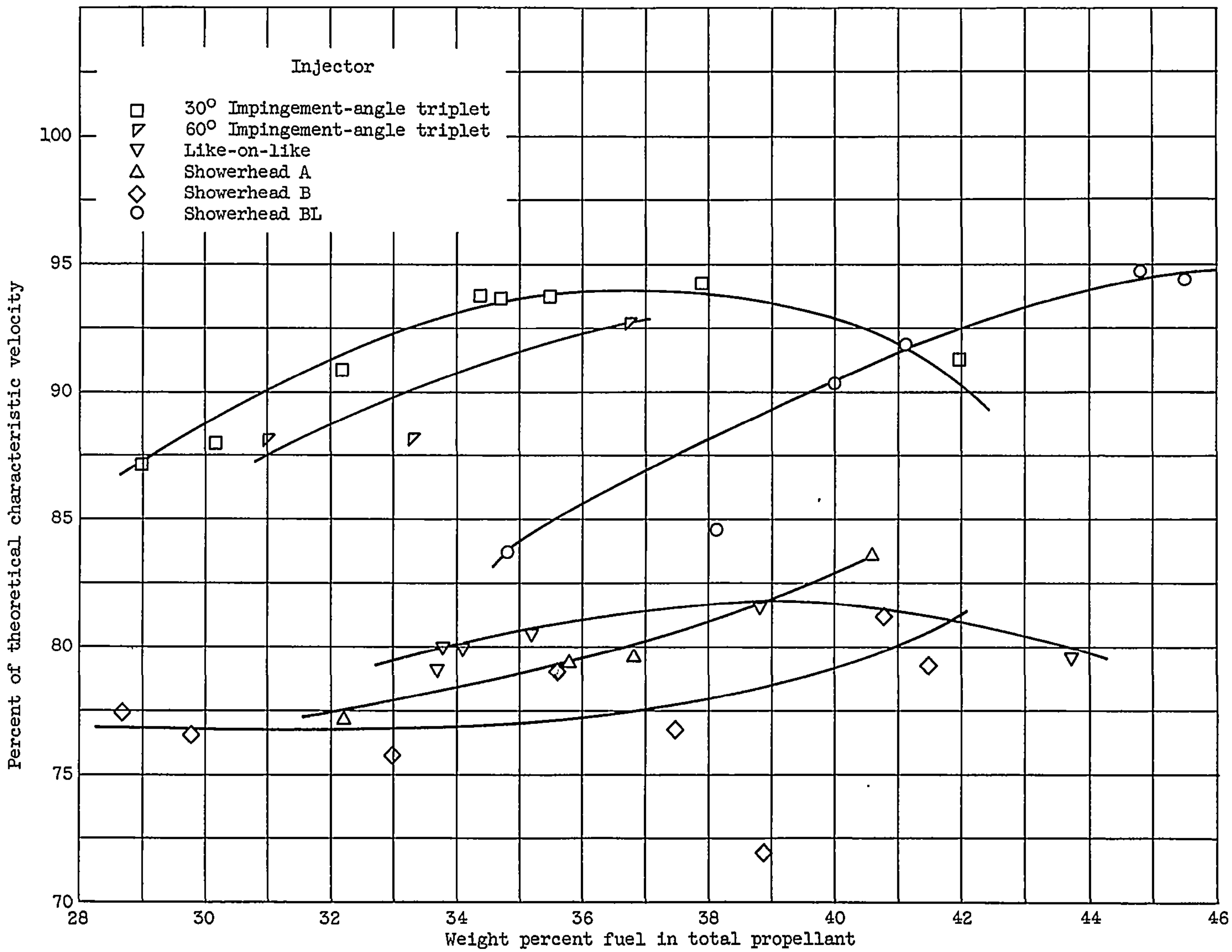


Figure 4. - Performance efficiency of various injectors using liquid hydrazine and liquid fluorine in 300-pound-thrust engine. Chamber pressure, 300 pounds per square inch absolute.

[redacted]

8 FEB 1959