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RESEARCH MEMORANDUM

THEORETICAL PERFORMANCE OF LIQUID HYDROGEN AND LIQUID FLUORINE AS A ROCKET PROPELLANT FOR A CHAMBER PRESSURE OF 600 POUNDS PER SQUARE INCH ABSOLUTE

By Anthony Fortini and Vearl N. Huff

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NATIONAL ADVISORY COMMITTEE
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SUMMARY

Theoretical rocket performance for frozen and equilibrium composition during expansion was calculated for the propellant combination of liquid hydrogen and liquid fluorine at a chamber pressure of 600 pounds per square inch absolute and several pressure ratios and oxidant-fuel ratios.

The parameters included were specific impulse, combustion-chamber temperature, nozzle-exit temperature, molecular weight, characteristic velocity, coefficient of thrust, ratio of nozzle-exit area to throat area, specific heat at constant pressure, isentropic exponent, viscosity, and thermal conductivity. A correlation is given for the effect of chamber pressure on several of the parameters.

INTRODUCTION

A continuing interest in liquid hydrogen and liquid fluorine as a rocket propellant is assured by extremely high specific impulse. Theoretical performance of liquid hydrogen with liquid fluorine has been reported in the literature (e.g., refs. 1 to 3). Reference 2 uses the previously accepted value of dissociation energy for fluorine F_2 (approx. 64 kcal/mole).

Additional computations were made for the hydrogen-fluorine propellant at the NACA Lewis laboratory from 1953 to 1955 as required for theoretical and experimental programs. These data were computed for both frozen and equilibrium composition during expansion and are based on the lower dissociation energy of fluorine F_2 (approx. 34 kcal/mole, ref. 4).

The present report presents the data for frozen and equilibrium composition during expansion for a chamber pressure of 600 pounds per square inch absolute and a wide range of oxidant-fuel ratios and pressure ratios. A correlation is given which permits the determination of specific impulse, characteristic velocity, ratio of nozzle-exit area to throat area, chamber temperature, and nozzle-exit temperature for a wide range of chamber pressure.

SYMBOLS

The following symbols are used in this report:

A nozzle area, sq in.

a local velocity of sound (velocity of flow at throat), ft/sec

C_F coefficient of thrust, $C_F = Ig_c/c^* = F/P_cA_t$

C_p^o molar specific heat at constant pressure, cal/(mole)(^oK)

c_p specific heat at constant pressure, $\frac{\sum_i n_i(C_p^o)_i}{M}$, for frozen composition and $(\partial h/\partial T)_p$ for equilibrium or frozen composition, cal/(g)(^oK)

c^* characteristic velocity, $c^* = g_cP_cA_t/w$, ft/sec

F thrust, lb

g_c gravitational conversion factor, 32.174 (lb mass/lb force)(ft/sec^2)

H_T^o sum of sensible enthalpy and chemical energy, cal/mole

h sum of sensible enthalpy and chemical energy per unit mass, $\frac{\sum_i n_i(H_T^o)_i}{M}$, cal/g

I specific impulse, lb force-sec/lb mass

k coefficient of thermal conductivity, cal/(sec)(cm)(^oK)

M molecular weight, $\sum_i n_iM_i$, g/g-mole or lb/lb-mole

4346

CX-1 back

n_{c^*} characteristic-velocity exponent, $\left(\frac{\Delta \log c^*}{\Delta \log P_c}\right)$ and $\frac{\partial \ln c^*}{\partial \ln P_c}$ for frozen and equilibrium composition, respectively

n_I specific-impulse exponent for fixed pressure ratio, $\left(\frac{\Delta \log I}{\Delta \log P_c}\right)_{P_c/P}$ and $\left(\frac{\partial \ln I}{\partial \ln P_c}\right)_{P_c/P}$ for frozen and equilibrium composition, respectively

n_i mole fraction of gaseous substance, i

n_T temperature exponent for fixed pressure ratio, $\left(\frac{\Delta \log T}{\Delta \log P_c}\right)_{P_c/P}$ and $\left(\frac{\partial \ln T}{\partial \ln P_c}\right)_{P_c/P}$ for frozen and equilibrium composition, respectively

n_ε area-ratio exponent for fixed pressure ratio, $\left(\frac{\Delta \log \varepsilon}{\Delta \log P_c}\right)_{P_c/P}$ and $\left(\frac{\partial \ln \varepsilon}{\partial \ln P_c}\right)_{P_c/P}$ for frozen and equilibrium composition, respectively

o/f oxidant-to-fuel weight ratio

P pressure, lb/sq in.

p partial pressure, lb/sq in.

R universal gas constant (consistent units)

r equivalence ratio, ratio of fluorine atoms to hydrogen atoms, F/H

S_T^o entropy at 1 atmosphere pressure, cal/(mole)(°K)

s entropy per unit mass, $\frac{\sum_i n_i (S_T^o)_i}{M} - \frac{R \sum_i p_i \ln p_i/14.696}{PM}$, cal/(g)(°K)

T temperature, °K

w mass-flow rate, lb/sec

γ isentropic exponent, $\left(\frac{\partial \ln P}{\partial \ln \rho}\right)_s$

ε ratio of nozzle area to throat area, A/A_t

μ dynamic viscosity, g/(cm)(sec) = poise

ξ molecular-weight derivative, $\left(\frac{\partial \ln M}{\partial \ln T}\right)_s$

ρ density, lb/cu in.

Subscripts:

c combustion chamber

e nozzle exit

i gaseous product of combustion

P constant pressure

P_c/P constant pressure ratio

s constant entropy

t nozzle throat

4346

CALCULATION OF PERFORMANCE DATA

Performance data were obtained at a chamber pressure of 600 pounds per square inch absolute for a range of equivalence ratios and pressure ratios. These data were calculated assuming frozen and equilibrium composition during expansion.

The computations were carried out by means of the method described in reference 5 with modifications to adapt it for use with an IBM Card-Programmed Electronic Calculator. The machine was operated with floating-decimal-point notation and eight significant figures. The successive approximation process used in the calculations was continued until seven-figure accuracy was reached in the desired values of the assigned parameters (mass balance and pressure or entropy).

Assumptions

The calculations were based on the following usual assumptions: perfect gas law, adiabatic combustion at constant pressure, isentropic expansion, no friction, homogeneous mixing, and one-dimensional flow.

The products of combustion were assumed to be ideal gases: atomic hydrogen H, hydrogen H_2, atomic fluorine F, fluorine F_2, and hydrogen fluoride HF. The combustion products were assumed to be completely expanded within the exit nozzle; that is, ambient pressure equals exit pressure.

Initial Data

Thermodynamic data. - The thermodynamic data for all combustion products were taken from reference 5, which uses the lower dissociation energy of 35.6 kilocalories per mole for F_2. The base used in this report for assigning absolute values to enthalpy is the same as in reference 5.

Physical and thermochemical data. - The properties of the fuel used in these calculations were obtained from references 4 to 8 and are given in table I.

Viscosity data. - The approximate viscosity data for the individual combustion products were taken from reference 3.

Computation of Combustion Conditions

A combustion pressure of 600 pounds per square inch absolute was assigned. At this assigned pressure, the composition n_i, enthalpy h (including both chemical and sensible energy), and entropy s were determined for three temperatures at 100° K intervals. The temperatures were chosen to band the value of enthalpy for the propellant mixture h_c. The formulas used to calculate h and s are

$$h = \frac{\sum_i n_i (H_T^o)_i}{M} \tag{1}$$

$$s = \frac{\sum_i n_i (S_T^o)_i}{M} - \frac{1.98718 \sum_i p_i \ln p_i/14.696}{PM} \tag{2}$$

Combustion composition corresponding to h_c was obtained by ordinary three-point interpolation of composition as a function of h. Entropy s_c corresponding to h_c was obtained by means of a three-point - three-slope interpolation of s as a function of h. The slope was obtained by means of the thermodynamic relation

$$\left(\frac{\partial s}{\partial h}\right)_P = \frac{1}{T} \tag{3}$$

The molecular weight of the combustion products M is defined and computed by the following equation:

$$M = \sum_i n_i M_i \tag{4}$$

This value of M is suitable for use in the gas law

$$P = \rho RT/M \tag{5}$$

4346

Computation of Exit Conditions

Calculation of parameters at assigned temperatures. - Exit temperatures were selected at 200°, 300°, or 400° K intervals to cover the range of pressure ratios from 1 to 1500. At these selected temperatures, the following data were computed assuming isentropic expansion and frozen or equilibrium composition: pressure, enthalpy, molecular weight, molecular-weight derivative, specific heat at constant pressure, isentropic exponent, absolute viscosity, thermal conductivity, nozzle-area ratio, coefficient of thrust, and specific impulse.

Interpolation of throat pressure, enthalpy, temperature, and molecular weight. - The interpolation technique and the functions used are the same as in references 3, 9, and 10.

The errors due to interpolation were checked for several cases. The values presented for enthalpy, entropy, and specific impulse appear to be correctly computed to all figures tabulated. The temperature and molecular weight may in some cases be in error by a few figures in the last place tabulated. However, because of uncertainties in thermodynamic data used, all values are probably tabulated to more places than are entirely significant.

Formulas

The formulas used in computing the various performance parameters are as follows:

Specific impulse, lb force-sec/lb mass:

$$I = 294.98\sqrt{\frac{h_c - h_e}{1000}} \tag{6}$$

4040

Throat area per unit mass-flow rate, (sq in.)(sec)/lb:

$$\frac{A_t}{w} = \frac{2781.6\ T_t}{P_t M_t a} \tag{7}$$

Characteristic velocity, ft/sec:

$$c^* = g_c P_c (A_t/w) = 32.174\ P_c (A_t/w) \tag{8}$$

Coefficient of thrust:

$$C_F = \frac{g_c I}{c^*} = \frac{32.174 I}{c^*} \tag{9}$$

Nozzle area per unit mass-flow rate, (sq in.)(sec)/lb:

$$\frac{A}{w} = \frac{86.455T}{PMI} \tag{10}$$

Ratio of nozzle area to throat area:

$$\varepsilon = \frac{A/w}{A_t/w} \tag{11}$$

Specific heat at constant pressure, cal/(g)($^{\circ}$K):

For frozen and equilibrium composition

$$c_p \equiv \left(\frac{\partial h}{\partial T}\right)_P$$

For frozen composition

$$c_p = \frac{\sum_i n_i (C_p^{\circ})_i}{M} \tag{12}$$

Isentropic exponent:

For frozen and equilibrium composition

$$\gamma \equiv \left(\frac{\partial \ln P}{\partial \ln \rho}\right)_s$$

For frozen composition

$$\gamma = \frac{c_p}{c_p - \frac{R}{M}} = \frac{c_p}{c_v} \tag{13}$$

4346

Absolute viscosity, poises:

$$\mu = \frac{PM}{\sum_i \frac{p_i}{\mu_i/M_i}} \tag{14}$$

Coefficient of thermal conductivity, cal/(sec)(cm)($^\circ$K):

$$k = \mu\left(c_p + \frac{5}{4}\frac{R}{M}\right) \tag{15}$$

Molecular-weight derivative for equilibrium composition:

$$\xi = \left(\frac{\partial \ln M}{\partial \ln T}\right)_s = D_A - \frac{\sum_i p_i D_i}{P} \tag{16}$$

where D_A and D_i have the definitions of reference 5.

The values of viscosity and thermal conductivity for mixtures of combustion gases calculated by means of equations (14) and (15) are only approximate. When more reliable transport properties for the various products of combustion become available, a more rigorous procedure for computing the properties of mixtures may also be justified.

THEORETICAL PERFORMANCE DATA

Tables

The calculated values of the performance parameters and equilibrium composition of the combustion products are given in tables II to VII.

The properties of gases in the combustion chamber and the characteristic velocity are given in table II for each equivalence ratio. Table III presents the values of performance parameters at assigned temperatures and constant entropy. These values were computed directly and used to interpolate properties for assigned pressure ratios. The values of viscosity and thermal conductivity of the mixture are also given in this table as a function of temperature.

The performance parameters for small pressure ratios from 1 to 8 are given in table IV. These properties permit computations within the rocket nozzle and for finite combustion-chamber diameters. Properties at the throat may be found where the area ratio is 1.000.

The performance parameters for pressure ratios from 10 to 1500 are given in table V. This table gives sufficient data to permit interpolation of complete data for any pressure ratio within the range tabulated.

The specific-impulse and area-ratio values for expansion from chamber pressure to 1 atmosphere are summarized in table VI. The maximum values calculated for specific impulse for frozen and equilibrium composition are 380.9 and 392.5, respectively.

Table VII presents the composition of the combustion products at the combustion temperature and various assigned temperatures at constant entropy.

Curves

The performance parameters and thermodynamic properties are plotted in figures 1 to 8 for frozen and equilibrium composition.

Curves of specific impulse are presented in figure 1 for pressure ratios from 10 to 1500 as functions of percent by weight of fuel. The maximum values occur at about 19 percent by weight of fuel for frozen composition, whereas the maximum values shift from about 15 percent fuel at the low pressure ratios to about 7 percent fuel at the high pressure ratios for equilibrium composition.

Curves of combustion temperature and exit temperature for pressure ratios from 1 to 1500 are plotted in figure 2 as functions of percent by weight of fuel.

Curves of the ratio of nozzle area to throat area are plotted in figure 3 for pressure ratios from 10 to 1500 as functions of percent by weight of fuel.

Figure 4 gives the curves for coefficient of thrust for pressure ratios from 10 to 1500 as functions of percent by weight of fuel.

Curves of molecular weight for pressure ratios of 1 to 1500 as functions of percent by weight of fuel are presented in figure 5.

Figures 6 and 7 give a comparison of characteristic velocity and specific impulse, respectively, for complete expansion to 1 atmosphere during frozen or equilibrium composition. Also shown is the equilibrium performance for a chamber pressure of 300 pounds per square inch absolute from reference 3.

Figure 8 compares frozen and equilibrium values of specific heat and the isentropic exponent as a function of temperature for a stoichiometric mixture. At the higher temperature the specific heat for equilibrium composition is greater than for frozen composition, indicating that a major part of any energy added goes to dissociate the molecules. The frozen mixture, however, has a slightly higher specific heat at the lowest temperature because the average specific heat of the composition frozen at combustion conditions is greater than that of the equilibrium composition at low temperatures, which is undissociated.

4346

Chamber-Pressure Effect

The logarithmic values of the parameters I, T, ε, and c^* are very nearly linear with the logarithm of chamber pressure for a fixed equivalence ratio and pressure ratio. This linearity permits the data to be represented by means of exponential equations. For frozen composition the exponents can be found from data for two chamber pressures. In the case of equilibrium composition, however, the following analytic expressions that permit the exponents to be computed from data at a single chamber pressure have been derived (ref. 10):

$$n_I = \left(\frac{\partial \ln I}{\partial \ln P_c}\right)_{P_c/P} = 86.4554\,\frac{T}{I^2}\left(\frac{1}{M_c} - \frac{1}{M}\right) \tag{16}$$

$$n_T = \left(\frac{\partial \ln T}{\partial \ln P_c}\right)_{P_c/P} = \left(\frac{\gamma-1}{\gamma}\right)\left(\frac{1}{1-\xi}\right) - \frac{R}{M_c c_p} \tag{17}$$

$$n_\varepsilon = \left(\frac{\partial \ln \varepsilon}{\partial \ln P_c}\right)_{P_c/P} = (n_{A/w})_e - (n_{A/w})_t \tag{18}$$

where

$$n_{A/w} = \left(\frac{\partial \ln A/w}{\partial \ln P_c}\right)_{P_c/P} = -\left(\frac{M}{M_c}\right)\left(\frac{\gamma-1}{\gamma}\right)\left(\frac{1}{1-\xi}\right) - \frac{1}{\gamma} - n_I$$

$$n_{c^*} = \frac{\partial \ln c^*}{\partial \ln P_c} = 1 + (n_{A/w})_t \tag{19}$$

Equations (16) to (19) may be written as

$$I = I_1 \left(\frac{P_c}{600}\right)^{n_{I,1}} \tag{20}$$

$$T = T_1 \left(\frac{P_c}{600}\right)^{n_{T,1}} \tag{21}$$

$$\varepsilon = \varepsilon_1 \left(\frac{P_c}{600}\right)^{n_{\varepsilon,1}} \tag{22}$$

$$c^* = c_1^* \left(\frac{P_c}{600}\right)^{n_{c^*,1}} \tag{23}$$

4346

CX-2 back

where I_1, T_1, ε_1, and c_1^* are the values of the parameter for a chamber pressure of 600 pounds per square inch.

To illustrate the use of these relations, suppose it is desired to obtain the value of specific impulse for a chamber pressure of 300 pounds per square inch absolute and a pressure ratio of 40.83 (exit pressure, 0.5 atm) for an equivalence ratio r of 1.00 (percent by weight of fuel, 5.038). From tables II and VI, the values obtained for use in equation (16) were $T = 3285$, $I = 374.7$, $M_c = 17.12$, and $M = 19.24$. Therefore,

$$n_I = 86.4554 \frac{3285}{(374.7)^2}\left(\frac{1}{17.12} - \frac{1}{19.24}\right)$$

$$n_I = 0.01305$$

From equation (20),

$$I = 374.7 \left(\frac{300}{600}\right)^{0.01305}$$

$$I = 371.3$$

The value of I for these conditions from reference 3, table III (chamber pressure, 300 lb/sq in. abs.; pressure ratio, 40.83; altitude, 17,971 ft; and equivalence ratio, 1.00) was 371.2; hence, the error by the use of the exponent equation is about 0.1 of an impulse unit.

Further detailed discussions with examples and comparisons for the use of these exponents are given in references 9 and 10.

SUMMARY OF RESULTS

A theoretical investigation of the performance of liquid hydrogen fuel with liquid fluorine as an oxidant was made for the following conditions: 4346

(1) Equivalence ratios from 1.20 to 0.15

(2) Chamber pressure of 600 pounds per square inch absolute

(3) Pressure ratios from 1 to 1500

(4) Both frozen and equilibrium composition during expansion

The results of the investigation are as follows:

1. The maximum values of specific impulse for chamber pressures of 600 pounds per square inch absolute and an exit pressure of 1 atmosphere were 381.5 at a weight percent fuel of 18.5, and 392.5 at a weight percent fuel of 12.5 for frozen and equilibrium composition, respectively.

2. The data presented in this report permit interpolation of complete performance data for any equivalence ratio from 1.20 to 0.15, chamber pressure from 300 to 1200 pounds per square inch absolute, and pressure ratios up to 1500.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, December 11, 1956

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4346

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TABLE I. - PROPERTIES OF LIQUID PROPELLANTS

Properties	Hydrogen	Fluorine
Molecular weight, M	2.016	38.00
Density, g/cc	[a]0.0709 (at -252.7° C)	[b]1.54 (at -196° C)
Freezing point, °C	[c]-259.20	[c]-217.96
Boiling point, °C	[c]-252.77	[c]-187.92
Viscosity, centipoises	[d]0.0215 (at -258.33° C)	---------------
Enthalpy of formation at boiling point from elements at 25° C, ΔH_f, kcal/mole	[e]-1.895	[e]-3.030
Enthalpy of vaporization ΔH, kcal/mole	[c]0.216 (at -252.77° C)	[c]1.51 (at -187.92° C)
Enthalpy of fusion, ΔH, kcal/mole	[c]0.028 (at -259.20° C)	[c]0.372 (at -217.96° C)

[a]Ref. 6.

[b]Ref. 7.

[c]Ref. 4.

[d]Ref. 8.

[e]Ref. 5.

TABLE II. - THERMODYNAMIC PROPERTIES OF COMBUSTION GASES

FOR HYDROGEN AND FLUORINE

[Chamber pressure, 600 lb/sq in. abs]

Equivalence ratio, r, $\frac{F}{H}$	Percent fuel by weight	Oxidant-to-fuel weight ratio, o/f	Temperature, T, °K	Molecular weight, M_C	Enthalpy h, cal/g (a)	Entropy, s, $\frac{cal}{(g)(^{\circ}K)}$	Characteristic velocity, c*, ft/sec	
							Equilibrium composition (b)	Frozen composition (b)
1.20	4.233	22.62	4730	18.12	2931.6	2.909	7533	7163
1.10	4.601	20.73	4747	17.65	3048.9	2.984	7656	7278
1.00	5.038	18.85	4740	17.11	3188.4	3.072	7774	7396
.90	5.567	16.96	4703	16.49	3357.1	3.176	7887	7513
.80	6.219	15.08	4629	15.77	3565.4	3.301	7989	7630
.70	7.045	13.19	4505	14.95	3829.1	3.455	8075	7741
.60	8.124	11.31	4326	14.01	4173.5	3.648	8151	7846
.50	9.593	9.42	4090	12.93	4642.4	3.902	8234	7955
.40	11.710	7.54	3793	11.65	5318.4	4.251	8334	8084
.30	15.027	5.65	3388	10.06	6377.3	4.770	8427	8232
.20	20.965	3.77	2736	7.98	8273.1	5.635	8360	8292
.15	26.128	2.83	2242	6.71	9921.2	6.324	8169	8158

[a]The base used for enthalpy is given in ref. 5.

[b]Parameter includes energy due to change in composition.

TABLE III. - THEORETICAL ROCKET PERFORMANCE AT ASSIGNED TEMPERATURES FOR HYDROGEN AND FLUORINE

(a) Frozen composition during isentropic expansion or compression from combustion conditions at a chamber pressure of 600 pounds per square inch absolute

Temperature, T, °K	Pressure, P, lb/sq in. abs	Enthalpy, h, cal/g	Isentropic exponent, γ	Specific heat, c_p, cal/(g)(°K)	Absolute viscosity, μ, micropoises	Thermal conductivity, K, cal/(cm)(sec)(°K)	Area ratio, ε	Thrust coefficient, C_F	Specific impulse, I, lb-sec/lb
r = 1.20; percent fuel = 4.233; o/f = 22.62									
4800	636.076	2962.2	1.336	0.4356	2315	0.00133	-----	-----	-----
4400	451.147	2788.9	1.342	.4306	2143	.00122	1.13	0.501	111.4
4000	310.915	2617.6	1.346	.4262	1969	.00111	1.00	.743	165.3
3600	206.917	2448.0	1.352	.4216	1792	.00100	1.09	.921	205.1
3200	131.946	2280.4	1.358	.4163	1614	.00089	1.31	1.069	238.1
2800	79.778	2115.0	1.365	.4101	1432	.00078	1.69	1.197	266.6
2400	45.065	1952.5	1.375	.4025	1247	.00067	2.35	1.311	291.9
2000	23.266	1793.3	1.387	.3928	1058	.00056	3.51	1.414	314.7
1600	10.596	1638.6	1.405	.3805	865	.00045	5.79	1.507	335.4
1200	3.983	1489.3	1.428	.3660	686	.00035	10.94	1.591	354.3
900	1.546	1381.0	1.444	.3565	512	.00025	20.38	1.650	367.3
600	.418	1274.7	1.451	.3527	353	.00017	48.64	1.706	379.7
r = 1.10; percent fuel = 4.601; o/f = 20.73									
4800	627.318	3072.8	1.332	0.4516	2321	0.00138	-----	-----	-----
4400	443.409	2893.2	1.337	.4463	2147	.00126	1.11	0.514	116.4
4000	304.473	2715.6	1.342	.4417	1971	.00115	1.00	.753	170.3
3600	201.843	2539.9	1.347	.4367	1793	.00104	1.10	.930	210.4
3200	128.173	2366.3	1.353	.4312	1613	.00092	1.33	1.077	243.7
2800	77.147	2195.1	1.361	.4248	1429	.00081	1.73	1.205	272.6
2400	43.365	2026.8	1.370	.4166	1243	.00069	2.41	1.318	298.2
2000	22.267	1862.1	1.383	.4063	1053	.00058	3.63	1.420	321.3
1600	10.080	1702.1	1.401	.3933	859	.00046	6.02	1.513	342.3
1200	3.765	1547.9	1.424	.3779	660	.00034	11.45	1.598	361.4
900	1.454	1436.1	1.441	.3678	507	.00026	21.46	1.656	374.6
600	.390	1326.6	1.449	.3635	348	.00018	51.56	1.711	387.1
r = 1.00; percent fuel = 5.038; o/f = 18.85									
4800	631.303	3216.5	1.327	0.4707	2325	0.00143	-----	-----	-----
4400	444.625	3029.4	1.333	.4651	2149	.00131	1.11	0.512	117.6
4000	304.145	2844.3	1.337	.4601	1971	.00119	1.00	.753	173.0
3600	200.808	2661.3	1.343	.4549	1792	.00108	1.10	.932	214.1
3200	126.961	2480.5	1.349	.4490	1610	.00096	1.34	1.080	248.2
2800	76.059	2302.3	1.356	.4420	1425	.00084	1.75	1.208	277.7
2400	42.534	2127.1	1.366	.4334	1238	.00072	2.45	1.322	303.9
2000	21.719	1955.8	1.379	.4225	1047	.00059	3.71	1.426	327.5
1600	9.772	1789.5	1.397	.4086	853	.00047	6.19	1.518	348.9
1200	3.626	1629.3	1.420	.3923	654	.00035	11.85	1.602	368.3
900	1.392	1513.3	1.438	.3814	501	.00026	22.33	1.661	381.8
600	.372	1399.8	1.446	.3766	343	.00017	53.97	1.716	394.5
r = 0.90; percent fuel = 5.567; o/f = 16.96									
4800	652.068	3404.8	1.323	0.4940	2325	0.00150	-----	-----	-----
4400	457.480	3208.4	1.328	.4879	2147	.00137	1.14	0.487	113.7
4000	311.665	3014.3	1.333	.4826	1968	.00125	1.00	.740	172.7
3600	204.882	2822.4	1.338	.4770	1786	.00112	1.10	.924	215.7
3200	128.937	2632.8	1.344	.4706	1603	.00100	1.33	1.075	251.0
2800	76.856	2446.0	1.352	.4631	1418	.00087	1.74	1.206	281.6
2400	42.761	2262.6	1.361	.4539	1230	.00074	2.45	1.322	308.6
2000	21.699	2083.2	1.375	.4422	1039	.00062	3.73	1.426	332.9
1600	9.700	1909.2	1.393	.4273	845	.00049	6.26	1.520	354.9
1200	3.574	1741.8	1.417	.4098	646	.00036	12.06	1.605	374.9
900	1.364	1620.7	1.434	.3980	494	.00027	22.86	1.665	388.7
600	.362	1502.3	1.443	.3926	337	.00018	55.62	1.720	401.7
r = 0.80; percent fuel = 6.219; o/f = 15.08									
4800	697.497	3654.9	1.317	0.5228	2315	0.00158	-----	-----	-----
4400	487.243	3447.1	1.323	.5163	2136	.00144	1.23	0.428	101.5
4000	330.432	3241.7	1.328	.5105	1957	.00131	1.00	.708	167.8
3600	216.171	3038.7	1.333	.5043	1775	.00118	1.08	.903	214.1
3200	135.342	2838.3	1.339	.4974	1592	.00104	1.30	1.061	251.5
2800	80.229	2641.0	1.347	.4893	1406	.00091	1.71	1.196	283.6
2400	44.357	2447.2	1.357	.4793	1218	.00078	2.41	1.315	311.9
2000	22.370	2257.9	1.370	.4667	1028	.00064	3.68	1.422	337.3
1600	9.929	2074.3	1.388	.4505	834	.00051	6.20	1.519	360.2
1200	3.630	1897.9	1.412	.4315	637	.00038	12.03	1.606	380.9
900	1.377	1770.4	1.430	.4188	486	.00028	22.94	1.667	395.2
600	.362	1645.9	1.440	.4126	331	.00019	56.20	1.723	408.7
r = 0.70; percent fuel = 7.045; o/f = 13.19									
4800	782.623	3993.4	1.312	0.5596	2288	0.00166	-----	-----	-----
4400	543.899	3771.0	1.317	.5525	2111	.00152	1.64	0.296	71.1
4000	366.857	3551.3	1.322	.5460	1933	.00138	1.01	.646	155.5
3600	238.628	3334.2	1.327	.5392	1752	.00124	1.05	.862	207.5
3200	148.495	3120.1	1.334	.5315	1570	.00110	1.25	1.032	248.4
2800	87.454	2909.2	1.341	.5225	1387	.00096	1.63	1.176	282.9
2400	48.014	2702.4	1.351	.5115	1201	.00082	2.30	1.301	313.1
2000	24.031	2500.4	1.364	.4976	1012	.00067	3.53	1.413	340.0
1600	10.579	2304.8	1.383	.4799	821	.00053	5.99	1.514	364.2
1200	3.833	2116.9	1.408	.4591	626	.00039	11.70	1.604	386.0
900	1.443	1981.4	1.426	.4451	477	.00029	22.44	1.666	401.0
600	.376	1849.1	1.436	.4381	325	.00020	55.43	1.725	415.1

4346

4346

CX-3

TABLE III. - Continued. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED TEMPERATURES FOR HYDROGEN AND FLUORINE

(a) Concluded. Frozen composition during isentropic expansion or compression from combustion conditions at a chamber pressure of 600 pounds per square inch absolute

Temperature, T, °K	Pressure, P, lb/sq in. abs	Enthalpy, h, cal/g	Isentropic exponent, γ	Specific heat, c_p, $\frac{cal}{(g)(^{o}K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, K, cal/(cm)(sec)(°K)	Area ratio, ε	Thrust coefficient, C_F	Specific impulse, I, $\frac{lb\text{-}sec}{lb}$
r = 0.60; percent fuel = 8.124; o/f = 11.31									
4400	644.830	4,218.1	1.310	0.6000	2062	0.00160	-----	-----	-----
4000	431.929	3,979.5	1.315	.5927	1888	.00145	1.08	0.533	129.9
3600	278.912	3,744.0	1.320	.5848	1712	.00131	1.01	.793	193.3
3200	172.227	3,511.8	1.327	.5761	1535	.00116	1.18	.984	240.0
2800	100.600	3,283.3	1.334	.5660	1356	.00101	1.52	1.141	278.3
2400	54.744	3,059.3	1.344	.5536	1174	.00086	2.14	1.277	311.4
2000	27.138	2,840.9	1.358	.5380	990	.00071	3.29	1.396	340.5
1600	11.823	2,629.5	1.377	.5182	803	.00056	5.60	1.503	366.5
1200	4.235	2,426.8	1.402	.4950	613	.00041	11.03	1.599	389.9
900	1.578	2,280.8	1.420	.4794	467	.00031	21.33	1.664	405.8
600	.407	2,138.3	1.430	.4715	318	.00021	53.24	1.726	420.8
r = 0.50; percent fuel = 9.593; o/f = 9.42									
4400	821.444	4,847.3	1.300	0.6651	1982	0.00170	-----	-----	-----
4000	545.243	4,583.0	1.306	.6565	1816	.00154	1.65	0.291	71.9
3600	348.730	4,322.2	1.311	.6472	1649	.00138	1.00	.675	166.9
3200	213.178	4,065.3	1.318	.6370	1480	.00123	1.09	.906	224.1
2800	123.191	3,812.8	1.326	.6251	1309	.00107	1.37	1.087	268.7
2400	66.271	3,565.5	1.336	.6108	1135	.00091	1.92	1.238	306.1
2000	32.447	3,324.7	1.350	.5929	959	.00075	2.95	1.370	338.6
1600	13.946	3,091.9	1.369	.5701	779	.00059	5.07	1.486	367.3
1200	4.922	2,869.1	1.394	.5436	596	.00044	10.07	1.589	392.8
900	1.811	2,708.8	1.413	.5258	455	.00033	19.66	1.659	410.2
600	.459	2,552.6	1.423	.5168	310	.00022	49.75	1.725	426.4
r = 0.40; percent fuel = 11.710; o/f = 7.54									
4000	757.340	5,473.1	1.295	0.7487	1712	0.00165	-----	-----	-----
3600	478.590	5,175.9	1.301	.7373	1557	.00148	1.20	0.443	111.4
3200	288.873	4,883.4	1.308	.7248	1400	.00131	1.01	.774	194.5
2800	164.700	4,596.3	1.316	.7105	1241	.00115	1.20	.998	250.7
2400	87.332	4,315.4	1.326	.6933	1079	.00098	1.65	1.176	295.4
2000	42.098	4,042.2	1.340	.6719	915	.00081	2.53	1.326	333.2
1600	17.791	3,778.7	1.360	.6449	746	.00064	4.35	1.457	366.0
1200	6.162	3,527.0	1.385	.6136	573	.00047	8.74	1.571	394.8
900	2.231	3,346.1	1.404	.5927	439	.00035	17.26	1.649	414.3
600	.554	3,170.2	1.414	.5821	301	.00024	44.42	1.721	432.3
r = 0.30; percent fuel = 15.027; o/f = 5.65									
3600	785.462	6,563.2	1.290	0.8789	1427	0.00161	-----	-----	-----
3200	467.366	6,214.8	1.297	.8628	1288	.00143	1.16	0.465	118.9
2800	262.461	5,873.2	1.305	.8446	1146	.00125	1.03	.819	209.4
2400	136.932	5,539.5	1.316	.8230	1001	.00107	1.31	1.055	270.0
2000	64.867	5,215.5	1.330	.7961	852	.00089	1.95	1.243	317.9
1600	26.901	4,903.6	1.350	.7626	699	.00071	3.35	1.400	358.1
1200	9.125	4,606.2	1.375	.7240	541	.00053	6.75	1.534	392.6
900	3.244	4,393.1	1.394	.6984	417	.00039	13.46	1.624	415.5
r = 0.20; percent fuel = 20.965; o/f = 3.77									
2800	663.203	8,342.1	1.297	1.0866	1005	0.00141	-----	-----	-----
2400	341.520	7,913.1	1.308	1.0574	884	.00121	1.00	0.687	177.0
2000	159.550	7,497.1	1.322	1.0214	758	.00101	1.22	1.008	259.8
1600	65.185	7,097.2	1.342	.9766	628	.00081	1.94	1.241	319.9
1200	21.754	6,716.8	1.368	.9255	491	.00061	3.78	1.428	368.0
900	7.623	6,444.4	1.387	.8919	383	.00046	7.46	1.548	398.9
600	1.814	6,179.7	1.398	.8751	269	.00032	19.54	1.656	426.8
r = 0.15; percent fuel = 26.128; o/f = 2.83									
2400	800.365	10,119.3	1.307	1.2630	802	0.00131	-----	-----	-----
2000	372.891	9,622.5	1.321	1.2195	692	.00110	1.01	0.636	161.2
1600	151.925	9,145.2	1.341	1.1654	576	.00089	1.24	1.025	259.9
1200	50.557	8,691.3	1.367	1.1040	455	.00067	2.21	1.290	327.1
900	17.671	8,366.4	1.386	1.0638	358	.00051	4.22	1.451	367.8
600	4.191	8,050.7	1.396	1.0438	254	.00036	10.82	1.591	403.4

TABLE III. - Continued. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED TEMPERATURES FOR HYDROGEN AND FLUORINE

(b) Equilibrium composition during isentropic expansion or compression from combustion conditions at a chamber pressure of 600 pounds per square inch absolute

Temperature, T, °K	Pressure, P, lb/sq in. abs	Enthalpy, h, cal/g	Molecular weight, M	Partial derivative, $\left(\frac{\partial \ln M}{\partial \ln T}\right)_S$	Isentropic exponent, γ $\left(\frac{\partial \ln P}{\partial \ln \rho}\right)_S$	Specific heat, c_p, $\frac{cal}{(g)(^{o}K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, K, cal/(cm)(sec)(°K)	Area ratio, ε	Thrust coefficient, C_F	Specific impulse, I, $\frac{lb\text{-}sec}{lb}$
r = 1.20; percent fuel = 4.233; o/f = 22.62											
4800	689.065	3,004.2	18.03	-0.3502	1.169	1.9793	2308	0.00489	------	-----	-----
4400	302.778	2,593.5	18.57	-.3263	1.163	1.7928	2171	.00418	1.01	0.733	171.5
4000	124.489	2,199.9	19.11	-.2710	1.164	1.4475	2019	.00319	1.48	1.078	252.3
3600	51.766	1,857.0	19.56	-.1637	1.186	.9486	1852	.00199	2.58	1.306	305.8
3200	24.977	1,606.2	19.79	-.0451	1.258	.5425	1667	.00111	4.22	1.450	339.6
2800	13.711	1,425.6	19.84	-.0043	1.320	.4168	1473	.00080	6.30	1.546	362.0
2400	7.377	1,264.4	19.84	-.0002	1.339	.3956	1276	.00067	9.54	1.627	380.9
2000	3.629	1,108.5	19.84	-.0001	1.353	.3843	1076	.00055	15.45	1.701	398.3
1600	1.565	957.4	19.84	-.0010	1.370	.3717	872	.00043	27.54	1.770	414.5
1200	.537	808.6	19.88	-.0256	1.351	.4079	665	.00035	57.95	1.836	429.8
r = 1.10; percent fuel = 4.601; o/f = 20.73											
4800	667.861	3,106.6	17.58	-0.3640	1.165	2.1873	2316	0.00539	------	-----	-----
4400	284.019	2,669.3	18.14	-.3514	1.157	2.0683	2180	.00481	1.02	0.764	181.7
4000	109.095	2,236.4	18.73	-.3195	1.152	1.8230	2031	.00397	1.60	1.117	265.9
3600	39.074	1,828.9	19.31	-.2503	1.156	1.3999	1866	.00285	3.19	1.369	325.8
3200	14.794	1,492.5	19.75	-.1208	1.192	.8222	1684	.00160	6.49	1.547	368.0
2800	7.028	1,268.1	19.90	-.0168	1.284	.4682	1486	.00088	11.09	1.654	393.6
2400	3.647	1,097.9	19.92	-.0006	1.324	.4085	1283	.00068	17.48	1.731	412.0
2000	1.753	937.5	19.92	-.0000	1.339	.3946	1077	.00056	29.14	1.801	428.6
1600	.738	782.6	19.92	-.0001	1.357	.3794	870	.00044	53.45	1.866	444.1
1200	.253	633.9	19.92	-.0040	1.375	.3692	660	.00033	113.28	1.926	458.4
r = 1.00; percent fuel = 5.038; o/f = 18.85											
4800	678.343	3,256.5	17.04	-0.3659	1.163	2.3166	2319	0.00571	------	-----	-----
4400	285.596	2,799.9	17.58	-.3573	1.155	2.2243	2183	.00516	1.02	0.761	183.8
4000	107.262	2,343.1	18.17	-.3345	1.148	2.0297	2034	.00441	1.62	1.122	271.2
3600	36.195	1,899.4	18.78	-.2891	1.145	1.7088	1871	.00345	3.39	1.386	334.9
3200	11.513	1,493.6	19.35	-.2111	1.153	1.2726	1691	.00237	8.03	1.589	384.0
2800	3.867	1,160.8	19.77	-.1077	1.184	.8227	1496	.00142	18.72	1.738	420.0
2400	1.526	918.6	19.96	-.0291	1.251	.5287	1290	.00084	38.06	1.839	444.4
2000	.662	735.9	20.00	-.0034	1.311	.4217	1079	.00059	70.17	1.912	462.0
1600	.268	574.5	20.01	-.0001	1.341	.3908	866	.00045	134.39	1.974	476.9
1200	.089	422.4	20.01	-.0000	1.387	.3700	653	.00032	294.43	2.050	490.6
r = 0.90; percent fuel = 5.567; o/f = 16.96											
4800	729.803	3,469.6	16.37	-0.3551	1.165	2.3410	2314	0.00577	------	-----	-----
4400	312.068	3,002.9	16.88	-.3434	1.157	2.2179	2177	.00515	1.01	0.716	175.6
4000	120.572	2,540.4	17.42	-.3152	1.152	1.9768	2026	.00429	1.51	1.088	266.6
3600	42.990	2,100.3	17.96	-.2615	1.154	1.5977	1859	.00323	2.98	1.349	330.7
3200	15.139	1,712.8	18.44	-.1803	1.170	1.1422	1675	.00214	6.41	1.543	378.3
2800	5.728	1,401.2	18.78	-.0998	1.204	.7852	1477	.00136	13.35	1.683	412.5
2400	2.350	1,157.1	18.97	-.0400	1.252	.5693	1272	.00089	26.04	1.785	437.5
2000	1.000	960.7	19.05	-.0082	1.304	.4555	1064	.00062	48.67	1.863	456.6
1600	.400	789.3	19.06	-.0006	1.340	.4118	856	.00046	93.89	1.928	472.7
1200	.133	629.4	19.06	-.0000	1.367	.3884	646	.00034	205.50	1.987	487.2
r = 0.80; percent fuel = 6.219; o/f = 15.08											
4400	373.397	3,297.9	16.03	-0.3168	1.163	2.1023	2157	0.00487	------	-----	-----
4000	153.261	2,841.3	16.50	-.2838	1.161	1.8260	2002	.00396	1.32	1.011	251.0
3600	59.591	2,415.0	16.96	-.2340	1.167	1.4770	1830	.00297	2.35	1.274	316.4
3200	22.772	2,036.3	17.37	-.1745	1.180	1.1403	1644	.00211	4.63	1.469	364.8
2800	8.795	1,712.9	17.70	-.1099	1.204	.8557	1448	.00144	9.36	1.617	401.5
2400	3.535	1,448.3	17.91	-.0466	1.246	.6239	1248	.00095	18.45	1.729	429.2
2000	1.481	1,236.5	17.99	-.0098	1.301	.4877	1046	.00066	34.83	1.813	450.2
1600	.591	1,054.3	18.01	-.0007	1.339	.4364	843	.00048	67.23	1.883	467.4
1200	.196	885.1	18.01	-.0000	1.367	.4112	637	.00035	146.84	1.945	482.9
r = 0.70; percent fuel = 7.045; o/f = 13.19											
4400	487.839	3,707.0	15.05	-0.2890	1.172	1.9845	2119	0.00456	------	-----	-----
4000	213.015	3,253.8	15.45	-.2603	1.172	1.7402	1960	.00373	1.12	0.891	223.7
3600	88.053	2,827.8	15.85	-.2224	1.176	1.4698	1787	.00291	1.81	1.176	295.2
3200	34.904	2,438.2	16.23	-.1743	1.185	1.1969	1604	.00217	3.36	1.386	347.9
2800	13.598	2,095.2	16.54	-.1120	1.204	.9183	1414	.00151	6.62	1.548	388.4
2400	5.458	1,811.7	16.74	-.0474	1.245	.6697	1220	.00100	12.96	1.669	419.0
2000	2.283	1,584.7	16.82	-.0099	1.301	.5225	1025	.00069	24.36	1.761	441.9
1600	.910	1,389.7	16.83	-.0007	1.339	.4670	827	.00051	46.86	1.836	460.7
1200	.302	1,208.6	16.83	-.0000	1.367	.4399	627	.00037	102.02	1.902	477.5

TABLE III. - Concluded. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED TEMPERATURES FOR HYDROGEN AND FLUORINE

(b) Concluded. Equilibrium composition during isentropic expansion or compression from combustion conditions at a chamber pressure of 600 pounds per square inch absolute

Temperature, T, $^{\circ}K$	Pressure, P, lb/sq in. abs	Enthalpy, h, cal/g	Molecular weight, M	Partial derivative, $\left(\frac{\partial \ln M}{\partial \ln T}\right)_S$	Isentropic exponent, γ $\left(\frac{\partial \ln P}{\partial \ln \rho}\right)_S$	Specific heat, c_p, $\frac{cal}{(g)(^{\circ}K)}$	Absolute viscosity, μ, micropoises	Thermal conductivity, K, $\frac{cal}{(cm)(sec)(^{\circ}K)}$	Area ratio, ε	Thrust coefficient, C_F	Specific impulse, I, $\frac{lb\text{-}sec}{lb}$
r = 0.60; percent fuel = 8.124; o/f = 11.31											
4400	690.427	4,260.5	13.95	-0.2667	1.182	1.9273	2059	0.00434	------	------	------
4000	316.412	3,799.6	14.29	-.2447	1.181	1.7333	1900	.00362	1.00	0.712	180.4
3600	136.135	3,359.6	14.64	-.2138	1.183	1.5117	1730	.00291	1.39	1.050	266.1
3200	55.431	2,950.0	14.98	-.1687	1.189	1.2563	1553	.00221	2.42	1.288	326.3
2800	22.004	2,585.7	15.26	-.1069	1.208	.9706	1371	.00155	4.59	1.467	371.7
2400	8.962	2,283.2	15.43	-.0444	1.249	.7143	1185	.00104	8.76	1.601	405.6
2000	3.777	2,039.0	15.50	-.0092	1.302	.5642	997	.00072	16.23	1.701	431.0
1600	1.508	1,827.7	15.51	-.0006	1.339	.5066	807	.00054	31.01	1.783	451.8
1200	.501	1,631.2	15.51	-.0000	1.367	.4774	614	.00039	67.21	1.856	470.3
900	.175	1,490.7	15.51	-.0000	1.386	.4598	466	.00029	140.32	1.907	483.2
r = 0.50; percent fuel = 9.593; o/f = 9.42											
4000	504.249	4,534.7	13.00	-0.2292	1.188	1.7688	1818	0.00356	------	------	------
3600	224.479	4,070.2	13.30	-.2002	1.188	1.5646	1656	.00290	1.10	0.872	223.2
3200	94.382	3,634.8	13.58	-.1555	1.195	1.3084	1488	.00222	1.71	1.157	296.1
2800	38.712	3,247.0	13.81	-.0957	1.214	1.0180	1316	.00158	3.05	1.362	348.5
2400	16.215	2,923.1	13.95	-.0385	1.255	.7646	1141	.00108	5.56	1.511	386.8
2000	6.930	2,657.3	14.00	-.0078	1.304	.6186	963	.00077	10.05	1.624	415.6
1600	2.774	2,424.1	14.01	-.0005	1.339	.5604	781	.00058	18.99	1.717	439.3
1200	.922	2,206.6	14.01	-.0000	1.367	.5285	597	.00042	40.89	1.799	460.4
900	.322	2,051.1	14.01	-.0000	1.386	.5091	455	.00031	85.04	1.856	474.9
r = 0.40; percent fuel = 11.710; o/f = 7.54											
4000	887.979	5,580.3	11.53	-0.2075	1.195	1.8213	1709	0.00348	------	------	------
3600	410.882	5,080.9	11.76	-.1783	1.196	1.6174	1558	.00285	1.04	0.555	143.8
3200	180.482	4,613.1	11.98	-.1342	1.203	1.3572	1403	.00222	1.20	.956	247.7
2800	77.604	4,196.3	12.16	-.0791	1.224	1.0714	1244	.00159	1.90	1.206	312.5
2400	33.785	3,844.3	12.26	-.0306	1.264	.8322	1082	.00112	3.24	1.383	358.1
2000	14.705	3,548.3	12.29	-.0061	1.308	.6960	917	.00082	5.65	1.515	392.5
1600	5.910	3,283.8	12.30	-.0004	1.340	.6379	747	.00063	10.48	1.624	420.8
1200	1.965	3,036.0	12.30	-.0000	1.367	.6022	574	.00046	22.32	1.721	445.6
900	.687	2,858.8	12.30	-.0000	1.386	.5801	440	.00034	46.13	1.786	462.6
r = 0.30; percent fuel = 15.027; o/f = 5.65											
3600	896.621	6,655.7	9.98	-0.1458	1.206	1.6788	1426	0.00275	------	------	------
3200	417.649	6,142.3	10.12	-.1049	1.216	1.4216	1272	.00212	1.05	0.546	143.0
2800	190.753	5,683.6	10.23	-.0586	1.238	1.1542	1146	.00160	1.16	.938	245.7
2400	86.908	5,288.0	10.30	-.0217	1.275	.9405	1002	.00118	1.73	1.175	307.9
2000	38.599	4,944.2	10.32	-.0042	1.312	.8181	853	.00090	2.82	1.348	353.1
1600	15.576	4,630.5	10.32	-.0003	1.340	.7594	700	.00070	5.06	1.488	389.9
1200	5.179	4,335.3	10.32	-.0000	1.367	.7176	541	.00052	10.55	1.609	421.5
r = 0.20; percent fuel = 20.965; o/f = 3.77											
2800	673.496	8,352.7	7.97	-0.0359	1.257	1.3243	1005	0.00164	------	------	------
2400	321.796	7,875.4	8.00	-.0127	1.287	1.1468	884	.00129	1.00	0.716	186.0
2000	145.768	7,443.7	8.01	-.0024	1.315	1.0399	758	.00102	1.27	1.034	268.6
1600	59.046	7,041.6	8.01	-.0002	1.340	.9771	628	.00081	2.06	1.260	327.3
1200	19.636	6,661.4	8.01	-.0000	1.367	.9242	491	.00061	4.07	1.441	374.5
r = 0.15; percent fuel = 26.128; o/f = 2.83											
2400	808.762	10,126.5	6.70	-0.0085	1.293	1.3344	802	0.00137	------	------	------
2000	369.676	9,617.1	6.71	-.0016	1.317	1.2347	692	.00111	1.01	0.641	162.7
1600	149.993	9,137.7	6.71	-.0001	1.340	1.1665	576	.00089	1.24	1.028	261.1
1200	49.883	8,683.7	6.71	-.0000	1.367	1.1038	455	.00067	2.23	1.292	328.1
1000	25.515	8,465.8	6.71	-.0000	1.380	1.0756	391	.00057	3.35	1.402	355.9
900	17.429	8,358.9	6.71	-.0000	1.386	1.0636	358	.00061	4.26	1.452	368.7

TABLE IV. - THEORETICAL ROCKET PERFORMANCE AT ASSIGNED PRESSURE RATIOS FROM 1 TO 8

FOR HYDROGEN AND FLUORINE

(a) Frozen composition during isentropic expansion or compression for a chamber pressure of 600 pounds per square inch absolute

Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Area ratio, ε	Thrust coefficient, C_F	Specific impulse, I, lb-sec/lb	Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature T, °K	Enthalpy, h, cal/g	Area ratio, ε	Thrust coefficient, C_F	Specific impulse, I, lb-sec/lb
r = 1.20; percent fuel = 4.233; o/f = 22.62							r = 0.60; percent fuel = 8.124; o/f = 11.31						
1.000	600.00	4730	2931.6	-----	-----	-----	1.000	600.00	4326	4173.5	-----	-----	-----
1.010	594.06	4718	2926.5	4.822	0.095	21.2	1.010	594.06	4315	4167.4	4.788	0.094	23.0
1.020	588.24	4706	2921.4	3.446	.134	29.9	1.020	588.24	4305	4161.4	3.421	.133	32.6
1.040	576.92	4683	2911.4	2.487	.189	42.0	1.040	576.92	4288	4149.5	2.470	.187	45.7
1.100	545.45	4617	2882.8	1.670	.293	65.2	1.100	545.45	4229	4115.7	1.659	.291	70.9
1.200	500.00	4517	2839.2	1.295	.403	89.7	1.200	500.00	4142	4064.0	1.289	.400	97.6
1.431	419.17	4318	2753.8	1.065	.559	124.4	1.418	423.01	3980	3967.7	1.067	.549	133.6
1.551	386.93	4231	2716.3	1.027	.615	136.9	1.537	390.47	3904	3923.0	1.028	.605	147.6
1.692	354.68	4138	2678.3	1.007	.670	149.0	1.676	357.93	3824	3875.3	1.007	.661	161.1
[a]1.861	322.44	4036	2633.6	1.000	.723	161.0	[a]1.844	325.39	3737	3824.2	1.000	.715	174.3
2.068	290.19	3930	2587.6	1.006	.777	173.0	2.049	292.85	3643	3769.1	1.007	.769	187.6
2.326	257.95	3812	2537.6	1.026	.832	185.2	2.305	260.31	3540	3709.1	1.027	.824	201.0
2.658	225.71	3682	2482.7	1.062	.888	197.6	2.634	227.78	3427	3643.1	1.063	.881	214.8
4.000	150.00	3310	2326.2	1.236	1.031	229.5	4.000	150.00	3093	3450.1	1.248	1.029	250.9
6.000	100.00	2974	2186.6	1.502	1.144	254.6	6.000	100.00	2798	3280.9	1.523	1.143	276.7
8.000	75.00	2754	2096.2	1.752	1.211	269.6	8.000	75.00	2600	3170.9	1.782	1.211	295.4
r = 1.10; percent fuel = 4.601; o/f = 20.73							r = 0.50; percent fuel = 9.593; o/f = 9.42						
1.000	600.00	4747	3048.9	-----	-----	-----	1.000	600.00	4090	4642.4	-----	-----	-----
1.010	594.06	4735	3043.6	4.817	0.095	21.5	1.010	594.06	4081	4636.2	4.780	0.094	23.3
1.020	588.24	4724	3038.3	3.442	.134	30.3	1.020	588.24	4072	4630.0	3.416	.133	32.9
1.040	576.92	4701	3028.0	2.484	.188	42.6	1.040	576.92	4055	4617.9	2.467	.187	46.2
1.100	545.45	4635	2998.5	1.668	.293	66.2	1.100	545.45	4000	4583.2	1.657	.290	71.6
1.200	500.00	4535	2953.6	1.294	.402	91.0	1.200	500.00	3920	4530.2	1.287	.400	98.8
1.429	419.82	4340	2866.3	1.065	.557	126.0	1.416	423.8	3770	4432.6	1.068	.546	135.1
1.548	387.52	4253	2827.6	1.027	.613	138.7	1.534	391.28	3699	4386.7	1.028	.603	149.2
1.689	355.23	4160	2786.4	1.007	.668	151.1	1.673	358.63	3624	4337.7	1.007	.659	162.8
[a]1.858	322.94	4060	2742.3	1.000	.722	163.3	[a]1.840	326.03	3543	4285.2	1.000	.713	176.3
2.064	290.64	3953	2694.8	1.006	.776	175.5	2.045	293.42	3456	4228.6	1.007	.768	189.8
2.322	258.35	3836	2643.2	1.026	.831	187.9	2.300	260.82	3359	4166.9	1.027	.823	203.4
2.654	226.06	3706	2586.5	1.062	.887	200.6	2.629	228.22	3253	4099.1	1.064	.879	217.4
4.000	150.00	3334	2424.1	1.238	1.031	233.2	4.000	150.00	2938	3899.6	1.250	1.028	254.2
6.000	100.00	2999	2279.8	1.506	1.144	258.7	6.000	100.00	2660	3725.4	1.527	1.143	282.5
8.000	75.00	2779	2186.2	1.757	1.211	274.0	8.000	75.00	2476	3611.9	1.788	1.211	299.5
r = 1.00; percent fuel = 5.038; o/f = 18.86							r = 0.40; percent fuel = 11.710; o/f = 7.54						
1.000	600.00	4740	3188.4	-----	-----	-----	1.000	600.00	3793	5318.4	-----	-----	-----
1.010	594.06	4728	3182.9	4.811	0.095	21.8	1.010	594.06	3784	5312.0	4.772	0.094	23.7
1.020	588.24	4717	3177.5	3.438	.134	30.8	1.020	588.24	3775	5305.6	3.411	.133	33.3
1.040	576.92	4694	3166.9	2.482	.188	43.2	1.040	576.92	3759	5293.1	2.463	.187	46.9
1.100	545.45	4630	3136.5	1.666	.292	67.2	1.100	545.45	3710	5257.4	1.655	.290	72.8
1.200	500.00	4531	3090.2	1.293	.402	92.4	1.200	500.00	3637	5202.9	1.286	.399	100.2
1.427	420.44	4339	3001.0	1.066	.555	127.7	1.413	424.70	3502	5103.5	1.069	.544	136.7
1.546	388.10	4253	2961.1	1.028	.612	140.6	1.531	392.03	3437	5056.2	1.029	.601	151.1
1.687	355.76	4161	2918.6	1.007	.667	153.2	1.670	359.36	3368	5005.7	1.007	.657	165.0
[a]1.855	323.42	4062	2873.1	1.000	.721	165.6	[a]1.837	326.69	3294	4951.5	1.000	.711	178.7
2.061	291.08	3956	2824.0	1.007	.775	178.0	2.041	294.02	3213	4893.1	1.007	.766	192.4
2.319	258.75	3840	2770.7	1.027	.829	190.6	2.296	261.35	3125	4829.4	1.027	.821	206.3
2.650	226.39	3712	2712.2	1.062	.886	203.5	2.624	228.68	3028	4759.3	1.064	.876	220.6
4.000	150.00	3341	2543.8	1.240	1.030	236.8	4.000	150.00	2738	4552.1	1.253	1.028	258.2
6.000	100.00	3008	2394.5	1.509	1.143	262.8	6.000	100.00	2481	4371.8	1.532	1.142	287.0
8.000	75.00	2790	2297.7	1.762	1.211	278.4	8.000	75.00	2312	4254.3	1.795	1.211	304.5
r = 0.90; percent fuel = 5.567; o/f = 16.96							r = 0.30; percent fuel = 15.027; o/f = 5.65						
1.000	600.00	4703	3357.1	-----	-----	-----	1.000	600.00	3388	6677.3	-----	-----	-----
1.010	594.06	4692	3351.5	4.805	0.095	22.1	1.010	594.06	3380	6570.6	4.767	0.094	24.1
1.020	588.24	4681	3345.9	3.434	.134	31.2	1.020	588.24	3372	6564.1	3.407	.133	33.9
1.040	576.92	4658	3335.0	2.479	.188	45.9	1.040	576.92	3357	6551.2	2.460	.186	47.7
1.100	545.45	4595	3303.7	1.665	.292	68.2	1.100	545.45	3316	6514.2	1.653	.290	74.1
1.200	500.00	4498	3256.1	1.292	.402	93.8	1.200	500.00	3250	6257.6	1.288	.399	102.0
1.425	421.05	4311	3164.9	1.066	.554	129.3	1.411	425.25	3131	6155.7	1.069	.543	138.9
1.544	388.67	4226	3123.7	1.028	.610	142.5	1.529	392.54	3074	6106.6	1.029	.600	153.5
1.684	356.28	4136	3079.9	1.007	.665	155.3	1.667	359.82	3013	6054.3	1.007	.655	167.6
[a]1.852	323.89	4039	3032.9	1.000	.719	168.0	[a]1.834	327.11	2947	5998.2	1.000	.710	181.6
2.058	291.50	3934	2982.3	1.007	.773	180.6	2.038	294.40	2876	5937.6	1.007	.765	195.6
2.316	259.11	3819	2927.3	1.027	.828	193.4	2.293	261.69	2798	5871.6	1.027	.820	209.8
2.646	226.72	3693	2866.9	1.062	.884	206.5	2.620	228.98	2712	5798.9	1.064	.877	224.5
4.000	150.00	3326	2692.3	1.242	1.030	240.5	4.000	150.00	2453	5563.2	1.254	1.027	262.9
6.000	100.00	2998	2538.0	1.512	1.143	267.0	6.000	100.00	2224	5396.0	1.534	1.142	292.2
8.000	75.00	2782	2437.8	1.767	1.211	282.8	8.000	75.00	2073	5273.9	1.796	1.211	309.6
r = 0.80; percent fuel = 6.219; o/f = 15.08							r = 0.20; percent fuel = 20.865; o/f = 3.77						
1.000	600.00	4629	3565.4	-----	-----	-----	1.000	600.00	2736	8273.1	-----	-----	-----
1.010	594.06	4617	3559.6	4.800	0.095	22.5	1.010	594.06	2730	8266.3	4.775	0.094	24.3
1.020	588.24	4606	3553.9	3.430	.134	31.7	1.020	588.24	2724	8259.6	3.412	.133	34.2
1.040	576.92	4585	3542.7	2.476	.188	44.5	1.040	576.92	2712	8246.5	2.464	.187	48.1
1.100	545.45	4523	3510.5	1.663	.292	69.1	1.100	545.45	2677	8208.6	1.656	.290	74.8
1.200	500.00	4428	3461.4	1.291	.401	95.1	1.200	500.00	2624	8151.4	1.286	.399	102.9
1.423	421.66	4247	3368.3	1.067	.552	131.0	1.414	424.27	2525	8046.1	1.068	.545	140.5
1.542	389.23	4165	3325.9	1.028	.609	144.4	1.532	391.63	2478	7996.3	1.028	.602	155.2
1.682	356.79	4076	3280.8	1.007	.664	157.4	1.671	359.00	2428	7943.1	1.007	.657	169.4
[a]1.850	324.36	3982	3232.4	1.000	.718	170.2	[a]1.838	326.36	2374	7886.1	1.000	.712	183.5
2.055	291.92	3879	3180.2	1.007	.772	183.1	2.043	293.73	2316	7824.6	1.007	.766	197.5
2.312	259.49	3768	3123.5	1.027	.827	196.1	2.298	261.09	2252	7757.6	1.027	.822	211.6
2.643	227.05	3644	3061.1	1.063	.883	209.5	2.626	228.45	2181	7683.9	1.064	.878	226.4
4.000	150.00	3284	2880.3	1.244	1.030	244.2	4.000	150.00	1970	7466.6	1.250	1.028	264.9
6.000	100.00	2965	2720.9	1.516	1.143	271.1	6.000	100.00	1782	7277.3	1.527	1.142	294.4
8.000	75.00	2752	2617.4	1.772	1.211	287.2	8.000	75.00	1658	7154.1	1.787	1.211	312.0
r = 0.70; percent fuel = 7.045; o/f = 13.19							r = 0.15; percent fuel = 26.128; o/f = 2.85						
1.000	600.00	4505	3829.1	-----	-----	-----	1.000	600.00	2242	9921.2	-----	-----	-----
1.010	594.06	4494	3823.1	4.794	0.095	22.8	1.010	594.06	2237	9914.6	4.782	0.095	24.0
1.020	588.24	4484	3817.3	3.426	.133	32.1	1.020	588.24	2232	9908.1	3.425	.133	33.8
1.040	576.92	4463	3805.7	2.473	.187	45.1	1.040	576.92	2221	9895.3	2.472	.187	47.5
1.100	545.45	4403	3772.7	1.661	.291	70.1	1.100	545.45	2192	9858.6	1.661	.291	73.8
1.200	500.00	4312	3722.3	1.290	.401	96.4	1.200	500.00	2147	9802.7	1.290	.401	101.6
1.421	422.30	4139	3627.4	1.067	.551	132.5	1.421	422.13	2061	9697.1	1.067	.551	139.6
1.539	389.81	4059	3583.8	1.028	.607	146.1	1.540	389.65	2021	9646.7	1.028	.607	154.0
1.679	357.33	3974	3537.4	1.007	.662	159.3	1.680	357.18	1979	9597.2	1.007	.662	167.9
[a]1.847	324.84	3883	3487.6	1.000	.718	172.4	[a]1.848	324.71	1934	9541.9	1.000	.716	181.7
2.052	292.36	3784	3433.9	1.007	.771	185.4	2.053	292.24	1884	9482.3	1.007	.771	195.4
2.309	259.88	3676	3376.6	1.027	.826	198.7	2.310	259.77	1830	9417.5	1.027	.826	209.4
2.639	227.39	3557	3311.3	1.063	.882	212.3	2.640	227.30	1771	9346.3	1.063	.882	223.7
4.000	150.00	3208	3124.4	1.246	1.029	247.6	4.000	150.00	1595	9139.1	1.243	1.029	260.9
6.000	100.00	2897	2960.0	1.519	1.143	275.0	6.000	100.00	1437	8957.2	1.515	1.142	289.6
8.000	75.00	2692	2853.2	1.777	1.211	291.4	8.000	75.00	1333	8839.1	1.767	1.210	306.6

[a]At throat.

4346

TABLE IV. - Concluded. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED PRESSURE RATIOS

FROM 1 TO 8 FOR HYDROGEN AND FLUORINE

(b) Equilibrium composition during isentropic expansion or compression for a chamber pressure of 600 pounds per square inch absolute

Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, M	Area ratio, ε	Thrust coefficient, C_F	Specific impulse, I, lb-sec/lb
r = 1.20; percent fuel = 4.233; o/f = 22.62							
1.000	600.00	4730	2931.6	18.12	——	——	——
1.010	594.06	4725	2926.5	18.12	4.589	0.090	21.2
1.020	588.24	4720	2921.4	18.13	3.281	.128	29.9
1.040	576.92	4710	2911.3	18.14	2.372	.179	42.0
1.100	545.45	4682	2882.5	18.18	1.600	.279	65.4
1.200	500.00	4639	2838.3	18.24	1.250	.385	90.1
1.345	446.01	4583	2781.0	18.32	1.086	.489	114.5
1.457	411.70	4545	2741.4	18.37	1.035	.549	128.7
1.590	377.39	4503	2698.9	18.42	1.008	.608	142.3
[a]1.749	343.08	4458	2653.0	18.49	1.000	.665	155.7
1.943	308.77	4409	2602.8	18.55	1.008	.722	169.2
2.186	274.47	4355	2547.6	18.63	1.032	.781	182.8
2.498	240.16	4294	2486.2	18.71	1.075	.841	196.9
4.000	150.00	4083	2278.4	19.00	1.331	1.018	238.4
6.000	100.00	3903	2110.1	19.23	1.682	1.142	267.4
8.000	75.00	3774	1996.5	19.38	2.016	1.218	285.3
r = 1.10; percent fuel = 4.601; o/f = 20.73							
1.000	600.00	4747	3048.9	17.65	——	——	——
1.010	594.06	4742	3045.5	17.66	4.583	0.090	21.5
1.020	588.24	4737	3038.3	17.67	3.277	.127	30.3
1.040	576.92	4728	3028.0	17.68	2.369	.179	42.6
1.100	545.45	4701	2998.3	17.72	1.598	.279	66.3
1.200	500.00	4659	2952.7	17.77	1.249	.384	91.5
1.343	446.82	4606	2894.6	17.85	1.087	.487	115.9
1.455	412.45	4569	2853.7	17.90	1.035	.548	130.3
1.587	378.08	4529	2809.9	17.96	1.008	.606	144.2
[a]1.746	343.71	4485	2762.4	18.02	1.000	.665	157.9
1.940	309.34	4438	2710.7	18.09	1.008	.721	171.5
2.182	274.97	4386	2653.7	18.16	1.032	.779	185.4
2.484	240.60	4328	2590.2	18.25	1.076	.840	199.8
4.000	150.00	4129	2374.4	18.54	1.336	1.018	242.3
6.000	100.00	3965	2199.7	18.78	1.693	1.142	271.8
8.000	75.00	3852	2081.2	18.95	2.036	1.219	290.2
r = 1.00; percent fuel = 5.038; o/f = 18.85							
1.000	600.00	4740	3188.3	17.11	——	——	——
1.010	594.06	4735	3182.9	17.12	4.580	0.090	21.8
1.020	588.24	4730	3177.5	17.13	3.275	.127	30.8
1.040	576.92	4721	3166.8	17.14	2.368	.179	43.3
1.100	545.45	4694	3136.2	17.18	1.597	.279	67.3
1.200	500.00	4653	3089.3	17.23	1.249	.384	92.9
1.342	447.13	4601	3029.8	17.30	1.087	.486	117.5
1.454	412.73	4564	2987.7	17.35	1.035	.547	132.1
1.586	378.34	4524	2942.5	17.41	1.008	.605	146.3
[a]1.744	343.94	4481	2893.6	17.47	1.000	.663	160.2
1.938	309.55	4435	2840.2	17.53	1.008	.720	174.0
2.181	275.16	4384	2781.5	17.60	1.033	.779	188.2
2.492	240.76	4327	2718.0	17.69	1.076	.839	202.7
4.000	150.00	4132	2493.0	17.97	1.337	1.018	246.0
6.000	100.00	3973	2312.6	18.21	1.696	1.142	276.1
8.000	75.00	3884	2190.1	18.38	2.042	1.220	294.7
r = 0.90; percent fuel = 5.567; o/f = 16.96							
1.000	600.00	4703	3357.1	16.49	——	——	——
1.010	594.06	4699	3351.5	16.50	4.581	0.090	22.1
1.020	588.24	4694	3345.9	16.50	3.276	.127	31.2
1.040	576.92	4684	3334.9	16.51	2.369	.179	43.9
1.100	545.45	4657	3303.5	16.55	1.598	.279	68.3
1.200	500.00	4616	3255.1	16.60	1.249	.384	94.2
1.343	446.92	4563	3193.5	16.67	1.087	.487	119.3
1.454	412.54	4526	3150.2	16.72	1.035	.547	134.2
1.587	378.16	4486	3103.7	16.77	1.008	.606	148.5
[a]1.745	343.78	4443	3053.3	16.82	1.000	.663	162.6
1.939	309.40	4396	2998.4	16.88	1.008	.721	176.7
2.182	275.03	4344	2938.0	16.95	1.032	.779	191.0
2.493	240.65	4286	2870.6	17.05	1.076	.839	205.8
4.000	150.00	4088	2641.5	17.30	1.336	1.018	249.5
6.000	100.00	3926	2456.0	17.52	1.693	1.142	280.0
8.000	75.00	3813	2330.4	17.68	2.036	1.219	298.9
r = 0.80; percent fuel = 6.219; o/f = 15.08							
1.000	600.00	4629	3565.4	15.77	——	——	——
1.010	594.06	4624	3559.6	15.78	4.588	0.090	22.5
1.020	588.24	4619	3553.9	15.78	3.281	.128	31.7
1.040	576.92	4609	3542.6	15.79	2.372	.179	44.5
1.100	545.45	4582	3510.2	15.83	1.600	.279	69.3
1.200	500.00	4539	3460.5	15.87	1.250	.385	95.6
1.345	446.06	4484	3398.1	15.94	1.086	.489	121.4
1.457	411.75	4446	3351.6	15.98	1.035	.549	136.4
1.590	377.44	4405	3303.8	16.03	1.008	.608	150.9
[a]1.749	343.13	4361	3252.1	16.08	1.000	.665	165.1
1.943	308.81	4312	3195.7	16.14	1.008	.722	179.4
2.186	274.50	4258	3133.7	16.20	1.032	.781	193.8
2.498	240.19	4198	3064.6	16.27	1.075	.841	208.8
4.000	150.00	3991	2830.9	16.51	1.331	1.018	252.8
6.000	100.00	3817	2641.6	16.71	1.683	1.142	283.5
8.000	75.00	3696	2513.6	16.85	2.020	1.218	302.5
r = 0.70; percent fuel = 7.045; o/f = 13.19							
1.000	600.00	4505	3829.1	14.95	——	——	——
1.010	594.06	4500	3823.1	14.95	4.599	0.091	22.8
1.020	588.24	4495	3817.3	14.96	3.289	.128	32.1
1.040	576.92	4485	3805.7	14.97	2.378	.180	45.1
1.100	545.45	4456	3772.4	15.00	1.603	.280	70.2
1.200	500.00	4412	3721.4	15.04	1.252	.386	96.8
1.349	444.63	4354	3653.5	15.10	1.084	.492	123.6
1.462	410.43	4314	3607.9	15.14	1.034	.553	138.7
1.595	376.23	4271	3559.0	15.18	1.008	.611	153.3
[a]1.754	342.03	4225	3506.1	15.23	1.000	.668	167.7
1.949	307.82	4174	3448.4	15.28	1.008	.725	182.0
2.193	273.62	4118	3385.0	15.33	1.032	.783	196.8
2.506	239.42	4055	3314.5	15.40	1.074	.843	211.6
4.000	150.00	3839	3078.0	15.62	1.325	1.019	255.6
6.000	100.00	3658	2885.8	15.80	1.670	1.141	286.5
8.000	75.00	3530	2756.3	15.92	1.999	1.217	305.5

Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, M	Area ratio, ε	Thrust coefficient, C_F	Specific impulse, I, lb-sec/lb
r = 0.60; percent fuel = 8.124; o/f = 11.31							
1.000	600.00	4326	4173.5	14.01	——	——	——
1.010	594.06	4320	4167.4	14.02	4.611	0.091	23.0
1.020	588.24	4315	4161.4	14.02	3.297	.128	32.5
1.040	576.92	4305	4149.5	14.03	2.384	.180	45.7
1.100	545.45	4276	4115.4	14.05	1.607	.281	71.1
1.200	500.00	4231	4063.2	14.09	1.255	.387	98.0
1.354	443.20	4169	3991.9	14.15	1.083	.496	125.7
1.467	409.11	4128	3945.3	14.18	1.034	.556	140.9
1.600	375.02	4084	3895.3	14.22	1.008	.614	155.6
[a]1.760	340.93	4037	3841.3	14.26	1.000	.671	170.0
1.955	306.83	3985	3782.5	14.31	1.008	.728	184.4
2.200	272.74	3927	3717.9	14.36	1.031	.786	199.1
2.514	238.65	3863	3646.1	14.41	1.073	.846	214.2
4.000	150.00	3645	3407.4	14.60	1.319	1.019	258.2
6.000	100.00	3460	3212.5	14.76	1.660	1.141	289.2
8.000	75.00	3332	3081.4	14.87	1.985	1.217	308.3
r = 0.50; percent fuel = 9.593; o/f = 9.42							
1.000	600.00	4091	4642.4	12.93	——	——	——
1.010	594.06	4085	4636.2	12.94	4.621	0.091	23.3
1.020	588.24	4080	4630.0	12.94	3.304	.129	32.9
1.040	576.92	4070	4617.9	12.95	2.388	.181	46.2
1.100	545.45	4041	4583.0	12.97	1.610	.281	71.9
1.200	500.00	3996	4529.5	13.00	1.257	.387	99.1
1.357	442.15	3933	4455.1	13.05	1.082	.499	127.7
1.470	408.14	3892	4407.5	13.08	1.034	.559	143.0
1.604	374.12	3849	4356.4	13.11	1.008	.617	157.8
[a]1.784	340.11	3801	4301.2	13.15	1.000	.673	172.3
1.980	306.10	3750	4241.2	13.19	1.008	.730	186.9
2.205	272.09	3692	4175.2	13.23	1.031	.788	201.6
2.520	238.08	3626	4102.0	13.28	1.073	.847	216.9
4.000	150.00	3411	3860.1	13.44	1.315	1.020	260.9
6.000	100.00	3226	3662.0	13.56	1.651	1.141	292.1
8.000	75.00	3097	3529.2	13.65	1.970	1.216	311.2
r = 0.40; percent fuel = 11.710; o/f = 7.54							
1.000	600.00	3793	5318.4	11.65	——	——	——
1.010	594.06	3787	5312.0	11.65	4.631	0.091	23.7
1.020	588.24	3782	5305.6	11.66	3.311	.129	33.4
1.040	576.92	3772	5293.1	11.66	2.393	.181	46.9
1.100	545.45	3743	5257.2	11.68	1.613	.282	73.0
1.200	500.00	3699	5202.2	11.71	1.259	.388	100.6
1.361	440.77	3635	5123.8	11.74	1.081	.502	130.1
1.475	406.87	3595	5074.9	11.77	1.033	.562	145.6
1.609	372.96	3552	5022.5	11.79	1.008	.620	160.5
[a]1.770	339.06	3505	4965.9	11.82	1.000	.676	175.1
1.966	305.15	3453	4904.3	11.85	1.008	.733	189.8
2.212	271.25	3396	4836.8	11.88	1.031	.790	204.7
2.528	237.34	3331	4761.8	11.92	1.072	.850	220.1
4.000	150.00	3112	4516.4	12.03	1.308	1.020	264.2
6.000	100.00	2920	4315.1	12.11	1.634	1.141	295.5
8.000	75.00	2784	4180.8	12.16	1.943	1.215	314.6
r = 0.30; percent fuel = 15.027; o/f = 5.65							
1.000	600.00	3388	6377.3	10.06	——	——	——
1.010	594.06	3382	6370.6	10.06	4.658	0.092	24.1
1.020	588.24	3377	6364.1	10.06	3.330	.130	33.9
1.040	576.92	3367	6351.1	10.07	2.407	.182	47.7
1.100	545.45	3338	6314.0	10.08	1.621	.283	74.2
1.200	500.00	3293	6257.2	10.09	1.264	.390	102.2
1.373	436.99	3225	6170.9	10.12	1.077	.512	134.0
1.487	403.38	3182	6120.6	10.13	1.032	.571	149.5
1.623	369.76	3138	6068.7	10.14	1.008	.628	164.4
[a]1.785	336.15	3089	6008.6	10.16	1.000	.684	179.1
1.983	302.53	3035	5945.5	10.18	1.007	.740	193.8
2.231	268.92	2975	5876.5	10.19	1.030	.797	208.7
2.550	235.30	2907	5800.0	10.21	1.069	.856	224.1
4.000	150.00	2678	5555.9	10.26	1.289	1.021	267.3
6.000	100.00	2471	5354.0	10.29	1.594	1.139	298.4
8.000	75.00	2326	5220.9	10.30	1.879	1.211	317.2
r = 0.20; percent fuel = 20.965; o/f = 3.77							
1.000	600.00	2736	8273.1	7.98	——	——	——
1.010	594.06	2731	8266.3	7.98	4.737	0.093	24.3
1.020	588.24	2725	8259.6	7.98	3.386	.132	34.2
1.040	576.92	2715	8246.4	7.98	2.446	.185	48.1
1.100	545.45	2684	8208.8	7.98	1.645	.288	74.8
1.200	500.00	2637	8151.2	7.99	1.280	.396	103.0
1.404	427.32	2551	8049.8	7.99	1.070	.536	139.4
1.521	394.45	2508	7999.5	8.00	1.029	.594	154.3
1.659	361.58	2462	7945.8	8.00	1.007	.649	168.8
[a]1.825	328.70	2411	7888.1	8.00	1.000	.704	183.0
2.028	295.83	2356	7825.8	8.00	1.007	.759	197.3
2.282	262.96	2294	7757.8	8.01	1.028	.815	211.7
2.608	230.09	2226	7682.9	8.01	1.064	.872	226.6
4.000	150.00	2014	7458.0	8.01	1.256	1.025	266.3
6.000	100.00	1825	7265.1	8.01	1.536	1.140	296.2
8.000	75.00	1699	7139.4	8.01	1.797	1.209	314.1
r = 0.15; percent fuel = 26.128; o/f = 2.85							
1.000	600.00	2242	9921.2	6.71	——	——	——
1.010	594.06	2237	9914.6	6.71	4.785	0.094	24.0
1.020	588.24	2232	9908.1	6.71	3.420	.133	33.8
1.040	576.92	2222	9895.2	6.71	2.469	.187	47.5
1.100	545.45	2193	9858.6	6.71	1.659	.291	73.8
1.200	500.00	2149	9802.6	6.71	1.289	.400	101.8
1.420	422.54	2065	9697.5	6.71	1.067	.549	139.5
1.538	390.04	2026	9649.0	6.71	1.028	.606	153.9
1.678	357.53	1984	9597.4	6.71	1.007	.661	167.9
[a]1.846	325.03	1939	9542.0	6.71	1.000	.715	181.6
2.051	292.53	1890	9482.3	6.71	1.007	.770	195.4
2.307	260.02	1836	9417.3	6.71	1.027	.825	209.4
2.637	227.52	1776	9345.8	6.71	1.063	.881	223.7
4.000	150.00	1600	9137.7	6.71	1.244	1.028	261.1
6.000	100.00	1442	8955.2	6.71	1.514	1.142	289.9
8.000	75.00	1337	8836.8	6.71	1.768	1.210	307.2

[a]At throat.

TABLE V. - THEORETICAL ROCKET PERFORMANCE AT ASSIGNED PRESSURE RATIOS FROM 10 TO

1500 FOR HYDROGEN AND FLUORINE

(a) Frozen composition during isentropic expansion or compression from a chamber pressure of 600 pounds per square inch absolute

Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Area ratio, ε	Thrust coefficient, C_F	Specific impulse, I, $\frac{\text{lb-sec}}{\text{lb}}$
r = 120; percent fuel = 4.233; o/f = 22.62						
10	60.00	2594	2030.8	1.99	1.258	280.0
15	40.00	2323	1921.6	2.52	1.332	296.5
20	30.00	2146	1851.1	3.00	1.377	306.6
30	20.00	1917	1760.6	3.86	1.434	319.2
40	15.00	1767	1702.7	4.63	1.469	327.0
60	10.00	1574	1628.5	6.01	1.513	336.7
80	7.50	1447	1580.9	7.24	1.540	342.8
100	6.00	1355	1546.6	8.37	1.559	347.2
150	4.00	1202	1489.8	10.91	1.591	354.2
200	3.00	1102	1453.5	13.17	1.611	358.6
300	2.00	974	1407.4	17.20	1.636	364.2
400	1.50	892	1378.0	20.79	1.652	367.7
600	1.00	787	1340.7	27.19	1.671	372.1
800	.75	720	1317.0	32.82	1.684	374.8
1000	.60	671	1299.9	38.19	1.693	376.8
1500	.40	592	1271.9	50.06	1.707	380.0
r = 1.10; percent fuel = 4.601; o/f = 20.73						
10	60.00	2619	2118.5	1.99	1.258	284.5
15	40.00	2346	2005.2	2.53	1.332	301.3
20	30.00	2171	1932.1	3.02	1.378	311.7
30	20.00	1841	1838.3	3.88	1.435	324.6
40	15.00	1781	1777.9	4.66	1.470	332.6
60	10.00	1596	1700.7	6.05	1.514	342.5
80	7.50	1469	1651.1	7.30	1.542	348.8
100	6.00	1377	1616.3	8.44	1.561	353.2
150	4.00	1222	1556.1	11.01	1.593	360.4
200	3.00	1121	1518.2	13.30	1.613	365.0
300	2.00	992	1470.0	17.36	1.638	370.6
400	1.50	909	1439.3	21.02	1.654	374.2
600	1.00	802	1400.3	27.52	1.674	378.7
800	.75	734	1375.4	33.32	1.687	381.6
1000	.60	685	1357.6	38.87	1.696	383.6
1500	.40	604	1326.2	50.75	1.710	386.9
r = 1.00; percent fuel = 5.038; o/f = 18.85						
10	60.00	2630	2227.5	2.00	1.258	289.1
15	40.00	2361	2110.1	2.54	1.333	306.3
20	30.00	2184	2034.3	3.03	1.379	316.9
30	20.00	1955	1936.9	3.91	1.436	330.0
40	15.00	1805	1874.1	4.69	1.471	338.2
60	10.00	1611	1793.8	6.10	1.518	348.3
80	7.50	1483	1742.2	7.35	1.543	354.7
100	6.00	1391	1704.9	8.51	1.563	359.3
150	4.00	1235	1643.2	11.11	1.595	366.7
200	3.00	1134	1603.6	13.43	1.616	371.3
300	2.00	1004	1553.3	17.56	1.641	377.2
400	1.50	921	1521.2	21.25	1.657	380.9
600	1.00	814	1480.4	27.83	1.677	385.5
800	.75	745	1454.4	33.71	1.690	388.4
1000	.60	695	1435.8	39.14	1.698	390.5
1500	.40	614	1405.0	51.36	1.714	393.9
r = 0.90; percent fuel = 5.567; o/f = 16.96						
10	60.00	2825	2365.1	2.01	1.258	293.8
15	40.00	2358	2245.5	2.55	1.333	311.3
20	30.00	2183	2164.8	3.04	1.379	322.1
30	20.00	1956	2063.8	3.93	1.457	336.5
40	15.00	1807	1996.6	4.72	1.472	343.6
60	10.00	1614	1915.1	6.14	1.517	354.2
80	7.50	1487	1861.4	7.40	1.545	360.6
100	6.00	1395	1822.6	8.57	1.565	365.4
150	4.00	1240	1758.3	11.20	1.597	373.0
200	3.00	1140	1717.1	13.84	1.618	377.8
300	2.00	1010	1664.6	17.72	1.643	383.6
400	1.50	926	1631.1	21.46	1.660	387.6
600	1.00	819	1588.5	28.12	1.680	392.3
800	.75	750	1561.3	34.06	1.693	395.3
1000	.60	701	1541.6	39.56	1.702	397.4
1500	.40	619	1509.7	51.97	1.717	400.9
r = 0.80; percent fuel = 6.219; o/f = 15.08						
10	60.00	2597	2642.2	2.01	1.258	298.4
15	40.00	2356	2416.3	2.56	1.333	316.2
20	30.00	2164	2334.8	3.06	1.380	327.2
30	20.00	1940	2230.1	3.95	1.457	340.9
40	15.00	1794	2162.4	4.75	1.473	349.4
60	10.00	1603	2075.7	6.18	1.518	360.0
80	7.50	1479	2019.9	7.48	1.546	366.7
100	6.00	1388	1979.7	8.63	1.566	371.5
150	4.00	1234	1912.7	11.29	1.599	379.2
200	3.00	1155	1869.8	13.66	1.620	384.1
300	2.00	1006	1815.2	17.88	1.646	390.2
400	1.50	923	1780.3	21.66	1.662	394.1
600	1.00	817	1735.9	28.40	1.682	399.0
800	.75	749	1707.5	34.44	1.698	402.1
1000	.60	700	1687.1	40.01	1.705	404.3
1500	.40	618	1653.5	52.57	1.720	407.9
r = 0.70; percent fuel = 7.046; o/f = 13.19						
10	60.00	2542	2775.5	2.02	1.258	302.8
15	40.00	2288	2645.5	2.57	1.334	320.9
20	30.00	2122	2561.2	3.07	1.380	332.2
30	20.00	1904	2452.6	3.97	1.438	346.1
40	15.00	1761	2382.6	4.77	1.474	354.8
60	10.00	1575	2292.9	6.21	1.520	365.6
80	7.50	1454	2235.0	7.50	1.548	372.4
100	6.00	1363	2193.3	8.69	1.568	377.3
150	4.00	1215	2123.8	11.57	1.601	385.2
200	3.00	1117	2079.2	13.77	1.622	390.2
300	2.00	992	2022.5	18.04	1.648	396.5
400	1.50	911	1986.1	21.86	1.664	400.5
600	1.00	806	1939.9	28.68	1.685	405.4
800	.75	739	1910.4	34.80	1.698	408.6
1000	.60	691	1889.2	40.44	1.708	410.9
1500	.40	611	1854.1	53.17	1.723	414.5
r = 0.60; percent fuel = 8.124; o/f = 11.31						
10	60.00	2457	3090.9	2.03	1.259	306.9
15	40.00	2214	2956.7	2.56	1.334	325.4
20	30.00	2053	2869.7	3.09	1.381	336.8
30	20.00	1844	2757.7	3.95	1.439	351.0
40	15.00	1707	2685.3	4.80	1.476	359.9
60	10.00	1528	2592.3	6.25	1.521	370.9
80	7.50	1411	2532.4	7.56	1.550	377.9
100	6.00	1325	2489.1	8.76	1.570	382.6
150	4.00	1181	2417.2	11.46	1.603	390.9
200	3.00	1086	2371.0	13.88	1.624	396.0
300	2.00	965	2312.0	18.20	1.650	402.5
400	1.50	867	2274.3	22.07	1.667	406.5
600	1.00	786	2226.3	28.98	1.686	411.6
800	.75	721	2195.5	36.18	1.701	414.9
1000	.60	674	2173.5	40.81	1.711	417.2
1500	.45	597	2137.0	53.83	1.726	421.0
r = 0.50; percent fuel = 9.595; o/f = 9.42						
10	60.00	2341	3529.3	2.03	1.259	311.2
15	40.00	2111	3390.6	2.59	1.335	330.0
20	30.00	1960	3300.8	3.10	1.382	341.7
30	20.00	1782	3185.0	4.01	1.440	356.1
40	15.00	1632	3110.0	4.83	1.477	365.2
60	10.00	1462	3015.7	6.30	1.523	376.5
80	7.50	1360	2951.6	7.61	1.551	383.6
100	6.00	1269	2906.7	8.83	1.572	384.6
150	4.00	1131	2832.0	11.56	1.605	398.9
200	3.00	1042	2784.0	14.01	1.626	402.1
300	2.00	926	2722.7	18.39	1.653	408.7
400	1.50	852	2683.5	22.31	1.670	412.9
600	1.00	756	2633.4	29.33	1.691	418.1
800	.75	694	2601.4	35.63	1.704	421.4
1000	.60	650	2578.4	41.46	1.714	423.6
1500	.45	576	2540.2	54.62	1.730	427.7
r = 0.40; percent fuel = 11.710; o/f = 7.54						
10	60.00	2187	4168.7	2.04	1.259	316.3
15	40.00	1974	4024.9	2.61	1.335	335.5
20	30.00	1834	3931.5	3.12	1.363	347.4
30	20.00	1650	3811.1	4.04	1.441	362.1
40	15.00	1529	3733.2	4.86	1.478	371.4
60	10.00	1371	3633.0	6.34	1.524	383.0
80	7.50	1267	3568.3	7.47	1.553	390.2
100	6.00	1191	3521.6	8.90	1.574	395.4
150	4.00	1063	3443.7	11.66	1.608	403.9
200	3.00	980	3393.6	14.14	1.629	409.2
300	2.00	872	3329.6	18.58	1.656	416.0
400	1.50	802	3288.6	22.56	1.673	420.3
600	1.00	713	3236.2	29.69	1.694	425.6
800	.75	656	3202.7	36.11	1.706	429.1
1000	.60	614	3176.5	42.05	1.717	431.5
1500	.40	546	3136.4	55.48	1.733	435.6
r = 0.30; percent fuel = 15.027; o/f = 5.65						
10	60.00	1962	5165.0	2.05	1.259	322.1
15	40.00	1771	5036.6	2.61	1.336	341.7
20	30.00	1646	4938.5	3.13	1.383	353.8
30	20.00	1481	4813.4	4.05	1.442	366.9
40	15.00	1372	4732.3	4.87	1.479	376.3
60	10.00	1230	4628.2	6.36	1.525	390.1
80	7.50	1137	4560.9	7.69	1.554	397.5
100	6.00	1069	4512.3	8.92	1.574	402.6
150	4.00	955	4431.5	11.69	1.608	411.5
200	3.00	880	4379.2	14.16	1.630	417.0
300	2.00	784	4312.6	18.64	1.657	423.9
400	1.50	722	4269.6	22.67	1.674	428.2
600	1.00	642	4215.2	29.67	1.695	433.7
800	.75	592	4180.1	36.37	1.709	437.2
1000	.60	555	4154.9	42.39	1.719	439.7
1500	.40	494	4112.9	56.03	1.736	443.9
r = 0.20; percent fuel = 20.965; o/f = 3.77						
10	60.00	1566	7064.5	2.03	1.258	324.3
15	40.00	1410	6914.4	2.59	1.334	343.6
20	30.00	1308	6817.1	3.09	1.381	358.9
30	20.00	1175	6691.9	3.99	1.439	370.9
40	15.00	1065	6611.0	4.80	1.476	380.3
60	10.00	970	6507.3	6.24	1.521	392.0
80	7.50	896	6440.6	7.54	1.550	399.3
100	6.00	842	6392.2	8.75	1.570	404.6
150	4.00	751	6311.9	11.46	1.603	413.1
200	3.00	692	6260.3	13.90	1.624	418.5
300	2.00	617	6194.3	18.29	1.650	425.3
400	1.50	588	6151.9	22.24	1.667	429.6
600	1.00	506	6097.7	29.35	1.688	435.1
800	.75	466	6062.9	35.76	1.702	438.5
1000	.60	438	6037.8	41.71	1.711	441.0
1500	.40	390	5996.1	55.21	1.727	445.1
r = 0.15; percent fuel = 26.128; o/f = 2.83						
10	60.00	1256	8753.6	2.00	1.257	316.7
15	40.00	1127	8610.6	2.54	1.332	337.7
20	30.00	1042	8518.3	3.03	1.378	349.4
30	20.00	932	8400.0	3.81	1.436	363.8
40	15.00	860	8323.3	4.69	1.471	372.9
60	10.00	767	8225.7	6.09	1.515	384.1
80	7.50	707	8162.9	7.36	1.543	391.1
100	6.00	654	8117.6	8.52	1.563	396.2
150	4.00	592	8042.2	11.17	1.595	404.3
200	3.00	546	7993.6	13.55	1.616	409.5
300	2.00	486	7931.9	17.82	1.641	416.0
400	1.50	446	7892.1	21.68	1.658	420.2
600	1.00	399	7841.3	28.62	1.676	426.4
800	.75	366	7806.6	34.88	1.691	428.7
1000	.60	345	7785.1	40.66	1.701	431.1
1500	.40	307	7746.3	63.83	1.716	436.0

4346

TABLE V. - Continued. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED PRESSURE RATIOS FROM 10 TO 1500 FOR HYDROGEN AND FLUORINE

(b) Equilibrium composition during isentropic expansion or compression from a chamber pressure of 600 pounds per square inch absolute

Pressure ratio, P_o/P	Pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, M	Area ratio, ε	Thrust coefficient, C_F	Specific impulse, I, lb-sec/lb	Pressure ratio, P_o/P	Pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, M	Area ratio, ε	Thrust coefficient, C_F	Specific impulse, I, lb-sec/lb
r = 1.20; percent fuel = 4.233; o/f = 22.62								r = 0.90; percent fuel = 5.567; o/f = 16.96							
10	60.00	3671	1911.6	19.49	2.33	1.272	297.9	10	60.00	3727	2236.1	17.79	2.37	1.274	312.3
15	40.00	3470	1764.6	19.66	3.07	1.361	318.7	15	40.00	3575	2071.8	18.00	3.14	1.364	334.4
20	30.00	3311	1666.2	19.75	3.73	1.417	331.6	20	30.00	3464	1960.4	18.14	3.86	1.422	348.6
30	20.00	3056	1536.4	19.82	4.90	1.488	348.4	30	20.00	3308	1810.6	18.32	5.21	1.496	366.8
40	15.00	2861	1451.1	19.83	5.94	1.533	358.9	40	15.00	3196	1709.6	18.44	6.46	1.545	378.6
60	10.00	2591	1340.4	19.84	7.78	1.588	372.1	60	10.00	3034	1574.0	18.60	8.76	1.607	393.9
80	7.50	2410	1268.4	19.84	9.43	1.625	380.4	80	7.50	2915	1482.8	18.70	10.89	1.647	403.6
100	6.00	2277	1216.0	19.84	10.97	1.650	386.4	100	6.00	2820	1415.0	18.77	12.89	1.677	411.1
150	4.00	2051	1128.2	19.84	14.48	1.692	396.1	150	4.00	2642	1298.0	18.87	17.50	1.727	423.3
200	3.00	1903	1071.3	19.84	17.60	1.718	402.3	200	3.00	2512	1220.1	18.93	21.71	1.759	431.2
300	2.00	1709	998.0	19.84	23.28	1.752	410.2	300	2.00	2325	1117.3	19.00	29.33	1.801	441.6
400	1.50	1582	950.6	19.84	28.36	1.773	415.2	400	1.50	2190	1049.4	19.02	36.24	1.828	448.1
600	1.00	1416	889.8	19.84	37.50	1.800	421.5	600	1.00	2000	960.8	19.05	48.66	1.863	456.6
800	.75	1310	850.5	19.85	45.79	1.817	425.5	800	.75	1869	902.7	19.06	59.88	1.886	462.1
1000	.60	1235	822.1	19.87	55.55	1.830	428.4	1000	.60	1770	860.4	19.06	70.29	1.901	466.1
1500	.40	1117	774.6	19.94	71.63	1.850	433.2	1500	.40	1600	789.2	19.06	93.93	1.928	472.7
r = 1.10; percent fuel = 4.601; o/f = 20.73								r = 0.80; percent fuel = 6.219; o/f = 16.08							
10	60.00	3766	1992.4	19.08	2.37	1.274	303.2	10	60.00	3605	2417.9	16.95	2.34	1.273	316.0
15	40.00	3609	1837.6	19.30	3.14	1.364	324.6	15	40.00	3434	2251.6	17.14	3.10	1.362	338.1
20	30.00	3497	1732.8	19.45	3.86	1.422	338.4	20	30.00	3315	2139.4	17.28	3.80	1.419	352.3
30	20.00	3335	1591.9	19.63	5.20	1.496	356.1	30	20.00	3148	1989.3	17.42	5.09	1.491	370.3
40	15.00	3206	1496.9	19.74	6.42	1.544	367.6	40	15.00	3026	1888.3	17.53	6.29	1.538	382.0
60	10.00	3003	1370.6	19.85	8.63	1.606	382.2	60	10.00	2855	1753.7	17.66	8.50	1.598	397.0
80	7.50	2839	1286.4	19.89	10.59	1.646	391.6	80	7.50	2732	1663.5	17.75	10.54	1.638	406.8
100	6.00	2705	1224.6	19.91	12.38	1.674	398.4	100	6.00	2635	1596.8	17.81	12.45	1.667	415.9
150	4.00	2455	1120.3	19.92	16.40	1.722	409.6	150	4.00	2456	1481.7	17.89	16.83	1.715	425.8
200	3.00	2288	1052.3	19.92	20.02	1.752	416.6	200	3.00	2325	1405.4	17.94	20.82	1.746	433.5
300	2.00	2068	964.3	19.92	26.57	1.790	425.9	300	2.00	2138	1305.2	17.98	26.02	1.786	443.5
400	1.50	1923	907.0	19.92	32.50	1.814	431.7	400	1.50	2006	1239.4	17.99	34.51	1.812	449.9
600	1.00	1732	833.1	19.92	43.18	1.845	439.1	600	1.00	1823	1153.7	18.00	46.18	1.845	458.1
800	.75	1607	785.2	19.92	52.84	1.865	443.8	800	.75	1699	1097.8	18.01	56.71	1.866	463.4
1000	.60	1515	750.5	19.92	61.79	1.879	447.2	1000	.60	1606	1057.1	18.01	66.46	1.881	467.2
1500	.40	1359	692.4	19.92	82.11	1.905	452.8	1500	.40	1448	986.8	18.01	88.69	1.907	473.5
r = 1.00; percent fuel = 5.038; o/f = 18.85								r = 0.70; percent fuel = 7.045; o/f = 13.19							
10	60.00	3782	2098.2	18.61	2.37	1.276	308.0	10	60.00	3432	2659.6	16.01	2.31	1.271	319.0
15	40.00	3636	1937.7	18.73	3.16	1.365	328.9	15	40.00	3258	2492.2	16.18	3.06	1.359	341.1
20	30.00	3534	1826.8	18.88	3.89	1.423	343.9	20	30.00	3136	2379.5	16.28	3.74	1.415	355.1
30	20.00	3392	1681.8	19.09	5.27	1.498	362.1	30	20.00	2964	2229.3	16.42	5.00	1.486	373.1
40	15.00	3292	1582.1	19.23	6.55	1.547	373.9	40	15.00	2842	2128.5	16.51	6.18	1.533	384.7
60	10.00	3151	1445.9	19.41	8.95	1.611	388.4	60	10.00	2668	1994.6	16.62	8.30	1.592	398.5
80	7.50	3048	1355.4	19.53	11.19	1.653	399.4	80	7.50	2542	1905.1	16.69	10.26	1.630	409.2
100	6.00	2967	1287.8	19.62	13.31	1.683	406.6	100	6.00	2443	1839.0	16.73	12.09	1.658	416.1
150	4.00	2813	1170.3	19.76	18.24	1.734	419.0	150	4.00	2258	1725.9	16.78	16.25	1.704	427.8
200	3.00	2698	1080.7	19.83	22.78	1.768	427.2	200	3.00	2126	1651.3	16.80	20.02	1.734	435.5
300	2.00	2524	984.9	19.92	31.06	1.812	437.8	300	2.00	1940	1553.9	16.82	26.78	1.773	444.9
400	1.50	2392	914.4	19.96	38.58	1.841	444.8	400	1.50	1811	1490.2	16.83	32.87	1.797	451.1
600	1.00	2198	821.8	19.99	52.01	1.878	453.8	600	1.00	1659	1407.7	16.83	43.83	1.829	459.0
800	.75	2059	761.0	20.00	64.12	1.902	459.6	800	.75	1523	1354.0	16.83	53.73	1.849	464.1
1000	.60	1954	716.5	20.00	75.34	1.919	463.8	1000	.60	1458	1316.0	16.83	62.91	1.863	467.7
1500	.40	1770	641.6	20.01	100.84	1.948	470.7	1500	.40	1293	1249.7	16.83	83.77	1.888	473.8

TABLE V. - Concluded. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED PRESSURE RATIOS FROM 10 TO 1500 FOR HYDROGEN AND FLUORINE

(b) Concluded. Equilibrium composition during isentropic expansion or compression from a chamber pressure of 600 pounds per square inch absolute

Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, M	Area ratio, ε	Thrust coefficient, C_F	Specific impulse, I, $\frac{\text{lb-sec}}{\text{lb}}$	Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Molecular weight, M	Area ratio, ε	Thrust coefficient, C_F	Specific impulse, I, $\frac{\text{lb-sec}}{\text{lb}}$
r = 0.60; percent fuel = 8.124; o/f = 11.31								r = 0.30; percent fuel = 15.027; o/f = 5.65							
10	60.00	3235	2983.6	14.95	2.29	1.270	321.7	10	60.00	2214	5123.2	10.31	2.15	1.261	330.3
15	40.00	3059	2815.0	15.09	3.02	1.357	343.8	15	40.00	2017	4958.0	10.32	2.75	1.342	351.4
20	30.00	2934	2701.8	15.17	3.69	1.412	357.9	20	30.00	1883	4849.9	10.32	3.30	1.392	364.6
30	20.00	2758	2551.2	15.28	4.92	1.483	375.7	30	20.00	1704	4710.0	10.32	4.29	1.454	380.9
40	15.00	2632	2450.6	15.35	6.05	1.528	387.2	40	15.00	1585	4618.9	10.32	5.18	1.493	391.2
60	10.00	2450	2317.4	15.42	8.10	1.586	401.9	60	10.00	1428	4501.4	10.32	6.78	1.542	404.0
80	7.50	2318	2229.1	15.45	9.96	1.624	411.3	80	7.50	1324	4425.2	10.32	8.22	1.574	412.1
100	6.00	2214	2164.2	15.47	11.68	1.650	418.1	100	6.00	1248	4370.0	10.32	9.55	1.596	417.9
150	4.00	2026	2053.8	15.50	15.59	1.695	429.5	150	4.00	1119	4277.7	10.32	12.56	1.632	427.4
200	3.00	1895	1981.5	15.50	19.10	1.724	436.7	200	3.00	1035	4218.1	10.32	15.27	1.655	433.5
300	2.00	1717	1887.7	15.51	25.42	1.760	446.0	300	2.00	925	4141.6	10.32	20.13	1.684	441.1
400	1.50	1598	1826.6	15.51	31.12	1.784	451.9	400	1.50	854	4092.3	10.32	24.60	1.702	445.9
600	1.00	1440	1747.8	15.51	41.38	1.813	459.4	600	1.00	762	4029.3	10.32	32.35	1.726	452.0
800	.75	1336	1696.6	15.51	50.65	1.832	464.2	800	.75	703	3988.8	10.32	39.43	1.741	455.9
1000	.60	1258	1659.5	15.51	58.23	1.846	467.7	1000	.60	660	3959.5	10.32	45.99	1.751	458.7
1500	.40	1129	1597.6	15.51	78.72	1.869	473.4	1500	.40	588	3910.9	10.33	60.87	1.769	463.3
r = 0.50; percent fuel = 9.593; o/f = 9.42								r = 0.20; percent fuel = 20.965; o/f = 3.77							
10	60.00	2997	3430.4	13.71	2.27	1.269	324.7	10	60.00	1607	7047.9	8.01	2.04	1.257	326.5
15	40.00	2815	3260.2	13.80	2.98	1.355	346.8	15	40.00	1448	6894.5	8.01	2.60	1.333	346.3
20	30.00	2684	3146.6	13.86	3.63	1.410	360.8	20	30.00	1343	6795.0	8.01	3.11	1.380	358.6
30	20.00	2498	2996.3	13.93	4.80	1.479	378.5	30	20.00	1206	6666.9	8.01	4.02	1.439	373.8
40	15.00	2363	2896.6	13.96	5.87	1.523	389.8	40	15.00	1116	6584.3	8.01	4.83	1.475	383.3
60	10.00	2172	2786.9	13.99	7.79	1.579	404.1	60	10.00	999	6478.0	8.01	6.30	1.521	395.2
80	7.50	2037	2679.9	14.00	9.52	1.615	413.2	80	7.50	923	6409.5	8.01	7.61	1.550	402.7
100	6.00	1934	2617.0	14.00	11.11	1.640	419.8	100	6.00	867	6360.0	8.01	8.82	1.570	408.0
150	4.00	1783	2511.1	14.01	14.7[illegible]	1.683	430.6	150	4.00	774	6277.6	8.01	11.56	1.604	418.7
200	3.00	1632	2442.0	14.01	17.99	1.710	437.6	200	3.00	713	6224.6	8.01	14.03	1.625	422.2
300	2.00	1472	2352.8	14.01	23.85	1.744	446.3	300	2.00	636	6156.8	8.01	18.46	1.652	429.1
400	1.50	1365	2295.0	14.01	29.14	1.766	452.0	400	1.50	586	6113.2	8.01	22.45	1.668	433.5
600	1.00	1226	2220.5	14.01	38.65	1.794	459.1	600	1.00	522	6057.6	8.01	29.63	1.690	439.1
800	.75	1135	2172.4	14.01	47.23	1.812	463.6	800	.75	481	6021.8	8.01	36.12	1.703	442.6
1000	.60	1068	2137.5	14.01	55.17	1.824	466.9	1000	.60	451	5996.0	8.01	42.13	1.713	446.1
1500	.40	956	2079.4	14.01	73.18	1.845	472.2	1500	.40	402	5953.1	8.01	55.78	1.729	449.3
r = 0.40; percent fuel = 11.710; o/f = 7.54								r = 0.15; percent fuel = 26.128; o/f = 2.83							
10	60.00	2677	4081.3	12.19	2.23	1.267	328.1	10	60.00	1261	8751.0	6.71	2.00	1.257	319.1
15	40.00	2482	3911.2	12.24	2.90	1.351	349.9	15	40.00	1131	8607.5	6.71	2.55	1.332	338.1
20	30.00	2342	3798.7	12.26	3.51	1.404	363.6	20	30.00	1045	8514.9	6.71	3.05	1.378	349.8
30	20.00	2146	3651.4	12.28	4.59	1.470	380.9	30	20.00	935	8396.2	6.71	3.91	1.435	364.3
40	15.00	2009	3554.7	12.29	5.57	1.512	391.7	40	15.00	863	8319.6	6.71	4.69	1.470	373.3
60	10.00	1824	3429.2	12.30	7.33	1.565	405.4	60	10.00	770	8221.7	6.71	6.10	1.515	384.6
80	7.50	1699	3347.3	12.30	8.91	1.599	414.1	80	7.50	710	8158.6	6.71	7.36	1.542	391.6
100	6.00	1606	3287.7	12.30	10.37	1.623	420.4	100	6.00	667	8113.1	6.71	8.53	1.562	396.6
150	4.00	1448	3187.7	12.30	13.69	1.662	430.6	150	4.00	594	8037.5	6.71	11.17	1.594	404.9
200	3.00	1343	3122.9	12.30	16.68	1.687	437.1	200	3.00	548	7986.8	6.71	13.55	1.615	410.0
300	2.00	1206	3059.6	12.30	22.06	1.718	445.3	300	2.00	488	7926.7	6.71	17.83	1.641	416.6
400	1.50	1116	2985.5	12.30	26.89	1.739	450.5	400	1.50	450	7886.8	6.71	21.69	1.657	420.7
600	1.00	999	2916.4	12.30	35.58	1.765	457.2	600	1.00	401	7835.8	6.71	28.63	1.678	426.0
800	.75	922	2871.7	12.30	43.40	1.781	461.4	800	.75	369	7803.0	6.71	34.90	1.691	429.3
1000	.60	887	2839.5	12.30	50.65	1.793	464.4	1000	.60	346	7779.3	6.71	40.70	1.700	431.7
1500	.40	774	2785.8	12.30	67.08	1.812	469.4	1500	.40	308	7740.1	6.71	53.86	1.716	435.8

4346

CX-4

TABLE VI. - THEORETICAL ROCKET PERFORMANCE FOR COMPLETE EXPANSION TO EXIT PRESSURE OF 1 ATMOSPHERE FOR HYDROGEN AND FLUORINE AT A CHAMBER PRESSURE OF 600 POUNDS PER SQUARE INCH ABSOLUTE

Equivalence ratio, r, $\frac{F}{H}$	Percent fuel by weight	Oxidant-to-fuel weight ratio, o/f	Combustion temperature, T_c, °K	Exit temperature, T_e, °K	Characteristic velocity, c*, ft/sec	Area ratio, ε	Thrust coefficient, C_F	Specific impulse, I, $\frac{\text{lb-sec}}{\text{lb}}$	Molecular weight, M_e
Frozen composition									
1.20	4.234	22.62	4730	1757	7163	4.69	1.471	327.5	18.12
1.10	4.601	20.73	4747	1781	7278	4.73	1.472	333.1	17.65
1.00	5.038	18.85	4740	1795	7396	4.75	1.474	338.7	17.11
.90	5.567	16.96	4703	1797	7513	4.78	1.475	344.4	16.49
.80	6.219	15.08	4629	1784	7630	4.81	1.476	350.0	15.77
.70	7.045	13.19	4505	1751	7741	4.84	1.477	355.3	14.95
.60	8.124	11.31	4326	1698	7846	4.87	1.478	360.4	14.01
.50	9.593	9.42	4090	1623	7955	4.90	1.479	365.8	12.93
.40	11.710	7.54	3793	1521	8084	4.93	1.481	372.0	11.65
.30	15.027	5.65	3388	1365	8232	4.94	1.481	379.0	10.06
.20	20.965	3.77	2736	1079	8292	4.86	1.478	380.9	7.98
.15	26.128	2.83	2242	855	8158	4.75	1.473	373.4	6.71
Equilibrium composition									
1.20	4.234	22.62	4730	2847	7533	6.02	1.536	359.6	19.83
1.10	4.601	20.73	4747	3197	7656	6.52	1.548	368.3	19.75
1.00	5.038	18.85	4740	3285	7774	6.66	1.551	374.7	19.24
.90	5.567	16.96	4703	3188	7887	6.56	1.548	379.4	18.45
.80	6.219	15.08	4629	3017	7989	6.39	1.542	382.8	17.54
.70	7.045	13.19	4505	2833	8075	6.26	1.536	385.5	16.52
.60	8.124	11.31	4326	2620	8151	6.13	1.531	388.0	15.35
.50	9.593	9.42	4090	2354	8234	5.96	1.526	390.5	13.96
.40	11.710	7.54	3793	2000	8334	5.65	1.515	392.5	12.29
.30	15.027	5.65	3388	1577	8427	5.25	1.496	391.8	10.32
.20	20.965	3.77	2736	1110	8360	4.90	1.478	383.9	8.01
.15	26.128	2.83	2242	858	8169	4.74	1.473	373.9	6.71

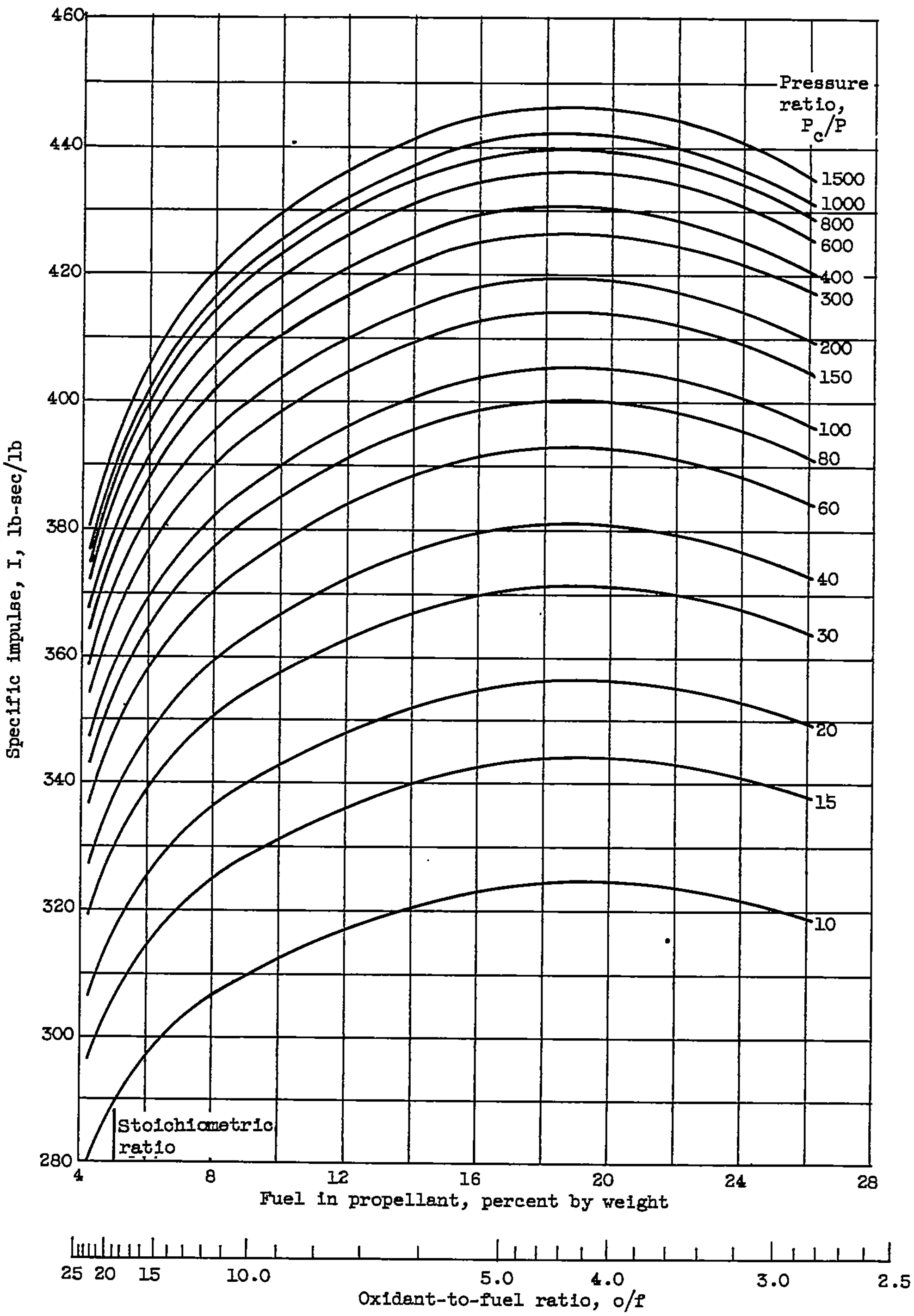
TABLE VII. - EQUILIBRIUM COMPOSITION OF PRODUCTS OF REACTION AT ASSIGNED TEMPERATURES

FOR HYDROGEN AND FLUORINE

[Isentropic expansion or compression from combustion conditions; chamber pressure, 600 lb/sq in. abs]

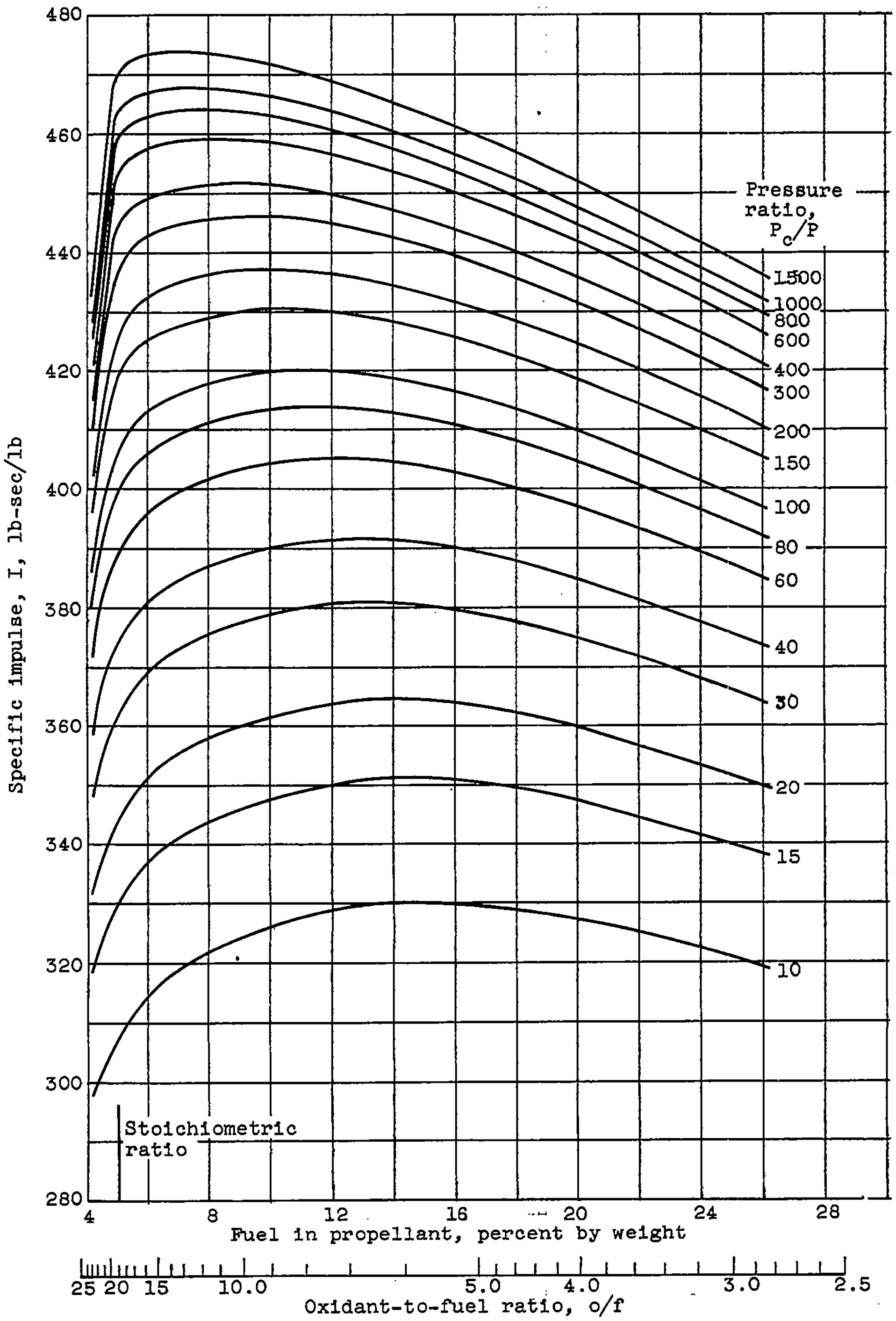
Mole fraction[a] at temperature T												
r = 1.20; percent fuel = 4.233; o/f = 22.62												
T, °K	1200	1600	2000	2400	2800	3200	3600	4000	4400	[b]4730	4800	
F	0.16259	0.16645	0.16662	0.16685	0.16683	0.16901	0.17962	0.20112	0.22759	0.24983	0.25449	
F_2	.00222	.00012	.00002	.00001	.00001	-------	-------	-------	.00001	.00003	.00003	
H	-------	-------	-------	.00001	.00020	.00252	.01309	.03320	.05678	.07593	.07987	
H_2	-------	-------	-------	-------	.00001	.00014	.00112	.00371	.00743	.01088	.01163	
HF	.83519	.83343	.83335	.83333	.83298	.82833	.80616	.76197	.70818	.66334	.65398	
r = 1.10; percent fuel = 4.601; o/f = 20.73												
T, °K	1200	1600	2000	2400	2800	3200	3600	4000	4400	[b]4747	4800	
F	0.09029	0.09088	0.09090	0.09093	0.09169	0.09946	0.12208	0.15275	0.18462	0.21107	0.21494	
F_2	.00032	.00002	-------	-------	-------	-------	-------	-------	.00001	.00002	.00002	
H	-------	-------	-------	.00002	.00077	.00778	.02882	.05157	.07652	.09672	.09964	
H_2	-------	-------	-------	-------	.00004	.00078	.00356	.00784	.01266	.01690	.01754	
HF	.90938	.90911	.90909	.90905	.90750	.89198	.84754	.78783	.72619	.67529	.66785	
r = 1.00; percent fuel = 5.038; o/f = 18.85												
T, °K	1200	1600	2000	2400	2800	3200	3600	4000	4400	[b]4740	4800	
F	-------	0.00001	0.00039	0.00348	0.01531	0.03966	0.07254	0.10811	0.14285	0.17051	0.17518	
F_2	-------	-------	-------	-------	-------	-------	-------	-------	.00001	.00001	.00001	
H	-------	-------	.00009	.00154	.00898	.02607	.04980	.07528	.09966	.11870	.12189	
H_2	-------	.00001	.00015	.00097	.00317	.00679	.01137	.01642	.02160	.02592	.02666	
HF	1.00000	.99998	.99937	.99401	.97256	.92748	.86628	.80019	.73589	.68486	.67626	
r = 0.90; percent fuel = 5.567; o/f = 16.96												
T, °K	1200	1600	2000	2400	2800	3200	3600	4000	4400	[b]4703	4800	
F	-------	-------	0.00002	0.00038	0.00357	0.01517	0.03947	0.07120	0.10457	0.12910	0.13664	
F_2	-------	-------	-------	-------	-------	-------	-------	-------	-------	.00001	.00001	
H	-------	0.00008	.00142	.00871	.02626	.05035	.07591	.10098	.12434	.14055	.14543	
H_2	0.05263	.05259	.05189	.04823	.04041	.03332	.03157	.03321	.03673	.03982	.04083	
HF	.94737	.94733	.94667	.94269	.92996	.90116	.85325	.79461	.73436	.69053	.67710	
r = 0.80; percent fuel = 6.219; o/f = 15.08												
T, °K	1200	1600	2000	2400	2800	3200	3600	4000	4400	[b]4629	4800	
F	-------	-------	0.00001	0.00020	0.00167	0.00756	0.02175	0.04457	0.07232	0.08891	0.10127	
F_2	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	.00001	
H	-------	0.00009	.00170	.01050	.03230	.06332	.09498	.12296	.14712	.15942	.16801	
H_2	0.11111	.11106	.11017	.10537	.09391	.07929	.06803	.06261	.06152	.06206	.06278	
HF	.88889	.88885	.88812	.88394	.87212	.84982	.81527	.76986	.71904	.68961	.66793	
r = 0.70; percent fuel = 7.045; o/f = 13.19												
T, °K	900	1200	1600	2000	2400	2800	3200	3600	4000	4400	[b]4505	4800
F	-------	-------	-------	-------	0.00011	0.00096	0.00429	0.01258	0.02732	0.04762	0.05356	0.07102
F_2	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
H	-------	-------	0.00009	0.00172	.01074	.03360	.06759	0.10396	.13659	.16384	.17017	.18635
H_2	0.17647	0.17647	.17642	.17546	.17020	.15710	.13848	.12050	.10737	.09970	.09843	.09610
HF	.82353	.82353	.82349	.82281	.81895	.80833	.78963	.76296	.72871	.68884	.67784	.64652
r = 0.60; percent fuel = 8.124; o/f = 11.31												
T, °K	900	1200	1600	2000	2400	2800	3200	3600	4000	[b]4326	4400	
F	-------	-------	-------	-------	0.00007	0.00057	0.00253	0.00745	0.01657	0.02728	0.03010	
F_2	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	
H	-------	-------	0.00008	0.00160	.01003	.03198	.06600	.10432	.14038	.16596	.17130	
H_2	0.25000	0.25000	.24995	.24900	.24376	.23023	.20970	.18759	.16847	.15650	.15423	
HF	.75000	.75000	.74997	.74940	.74615	.73722	.72177	.70064	.67458	.65026	.64437	
r = 0.50; percent fuel = 9.593; o/f = 9.42												
T, °K	900	1200	1600	2000	2400	2800	3200	3600	4000	[b]4090	4400	
F	-------	-------	-------	-------	0.00004	0.00033	0.00146	0.00434	0.00978	0.01143	0.01821	
F_2	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	
H	-------	-------	0.00007	0.00136	.00864	.02818	.05988	.09743	.13461	.14256	.16794	
H_2	0.33333	0.33333	.33329	.33243	.32759	.31485	.29390	.26983	.24665	.24210	.22748	
HF	.66667	.66667	.66664	.66621	.66373	.65683	.64475	.62841	.60875	.60391	.58640	
r = 0.40; percent fuel = 11.710; o/f = 7.54												
T, °K	900	1200	1600	2000	2400	2800	3200	3600	[b]3793	4000		
F	-------	-------	-------	-------	0.00002	0.00017	0.00079	0.00237	0.00364	0.00544		
F_2	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------		
H	-------	-------	0.00006	0.00106	.00681	.02279	.05008	.08423	.10146	.11984		
H_2	0.42857	0.42857	.42853	.42781	.42371	.41235	.39303	.36909	.35714	.34453		
HF	.57143	.57143	.57141	.57112	.56946	.56469	.55611	.54431	.53776	.53020		
r = 0.30; percent fuel = 15.027; o/f = 5.65												
T, °K	1200	1600	2000	2400	2800	3200	[b]3388	3600				
F	-------	-------	-------	0.00001	0.00008	0.00037	0.00066	0.00114				
F_2	-------	-------	-------	-------	-------	-------	-------	-------				
H	-------	0.00004	0.00073	.00477	.01641	.03749	.05004	.06558				
H_2	0.53846	.53843	.53790	.53479	.52585	.50971	.50012	.48828				
HF	.46154	.46153	.46137	.46043	.45765	.45243	.44918	.44500				
r = 0.20; percent fuel = 20.965; o/f = 3.77												
T, °K	900	1200	1600	2000	2400	[b]2736	2800					
F	-------	-------	-------	-------	-------	0.00002	0.00003					
F_2	-------	-------	-------	-------	-------	-------	-------					
H	-------	-------	0.00002	0.00042	0.00276	.00824	.00977					
H_2	0.66667	0.66667	.66665	.66632	.66437	.65980	.65853					
HF	.33333	.33333	.33333	.33326	.33287	.33194	.33167					
r = 0.15; percent fuel = 26.126; o/f = 2.83												
T, °K	900	1000	1200	1600	2000	[b]2242	2400					
F	-------	-------	-------	-------	-------	-------	-------					
F_2	-------	-------	-------	-------	-------	-------	-------					
H	-------	-------	-------	0.00001	0.00028	0.00095	0.00184					
H_2	0.73913	0.73913	0.73913	.73912	.73889	.73830	.73753					
HF	.26087	.26087	.26087	.26087	.26083	.26075	.26063					

[a]Mole fractions were computed for all five substances considered in this report but are omitted if less than 5×10^{-6}.
[b]Combustion temperature.



(a) Frozen composition.

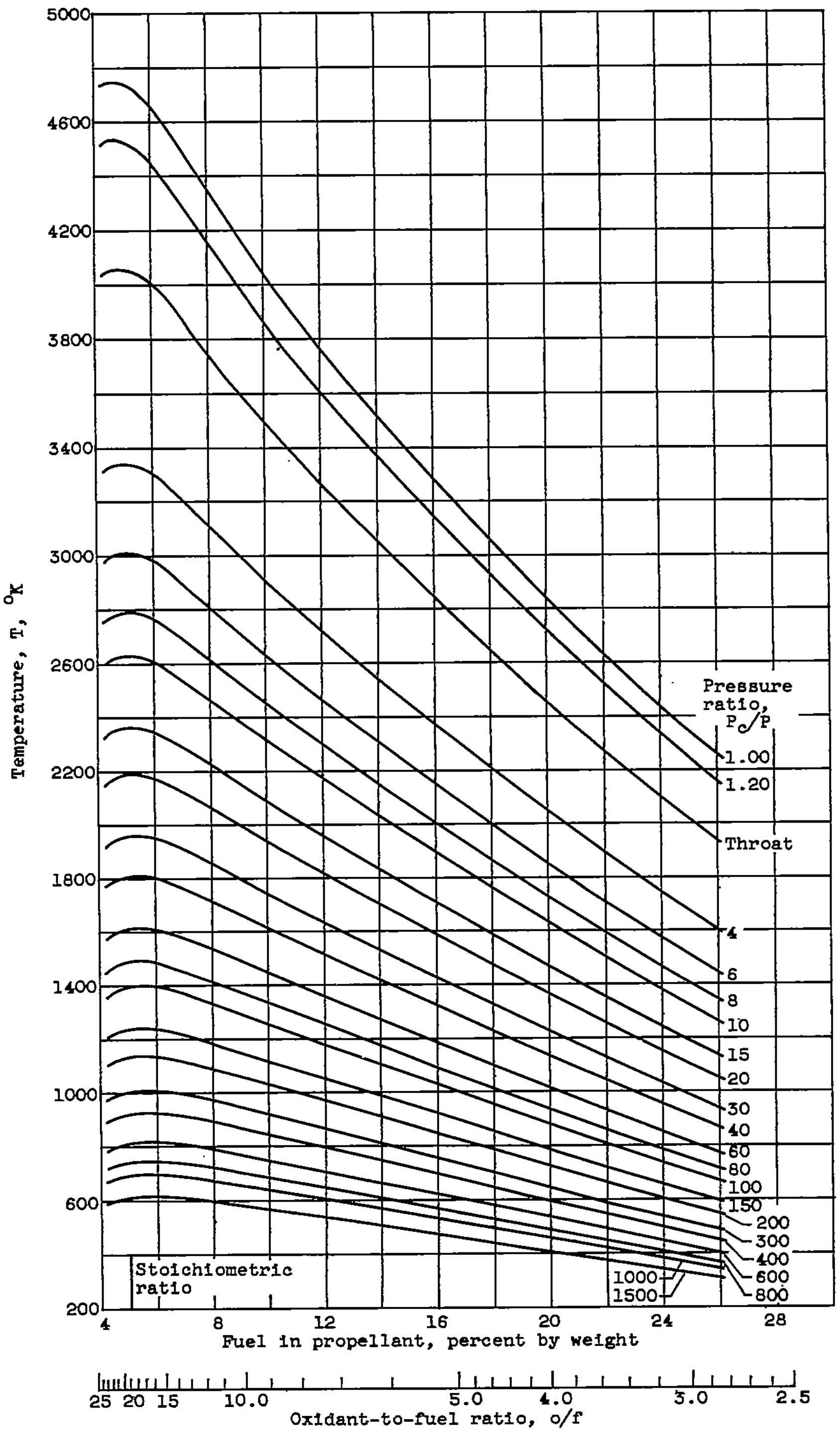
Figure 1. - Theoretical specific impulse for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with isentropic expansion to indicated pressure ratios.



(b) Equilibrium composition.

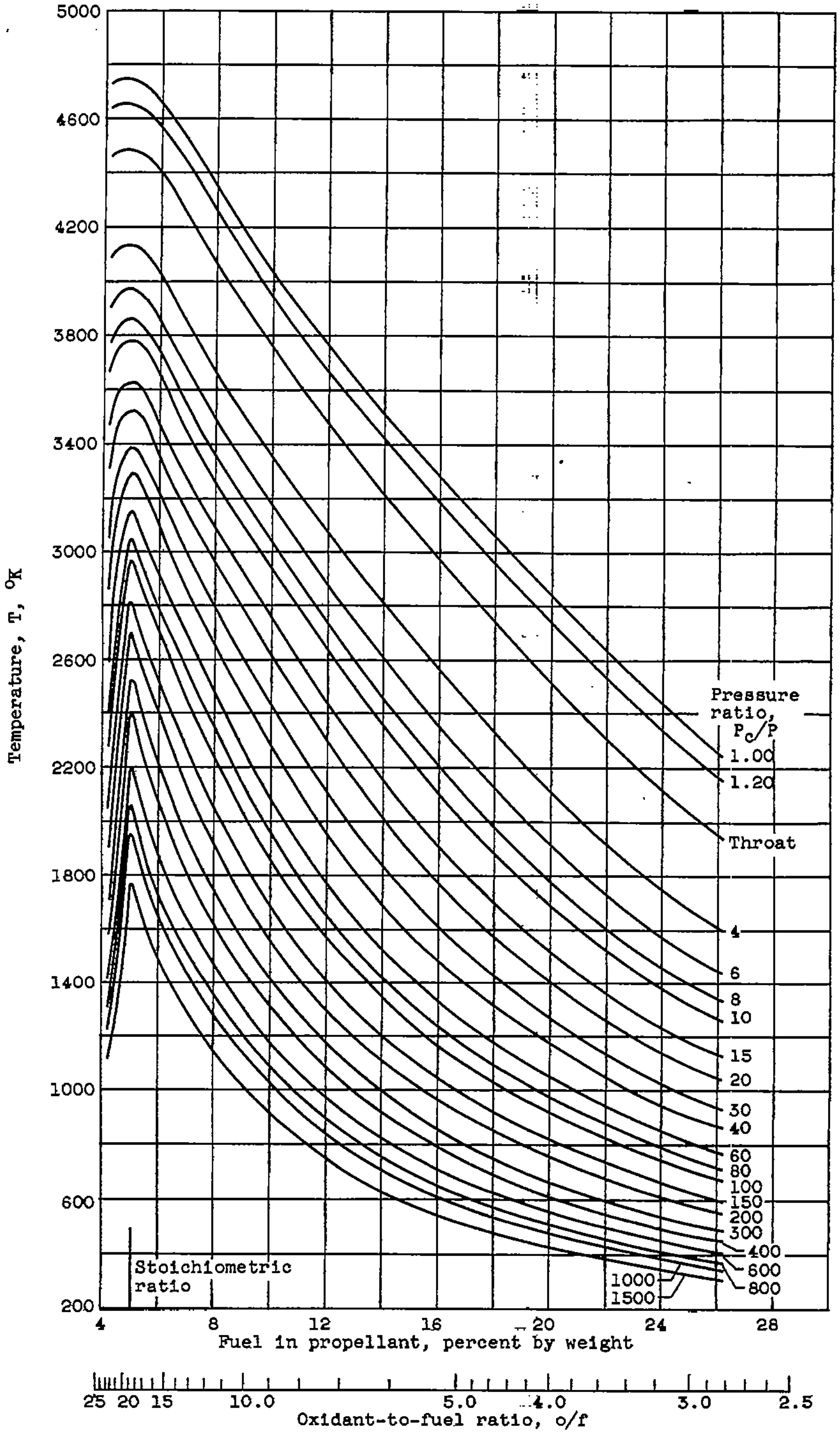
Figure 1. - Concluded. Theoretical specific impulse for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with isentropic expansion to indicated pressure ratios.

4346



(a) Frozen composition.

Figure 2. - Theoretical chamber temperature and nozzle-exit temperature for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with isentropic expansion to indicated pressure ratios.



(b) Equilibrium composition.

Figure 2. - Concluded. Theoretical chamber temperature and nozzle-exit temperature for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with isentropic expansion to indicated pressure ratios.

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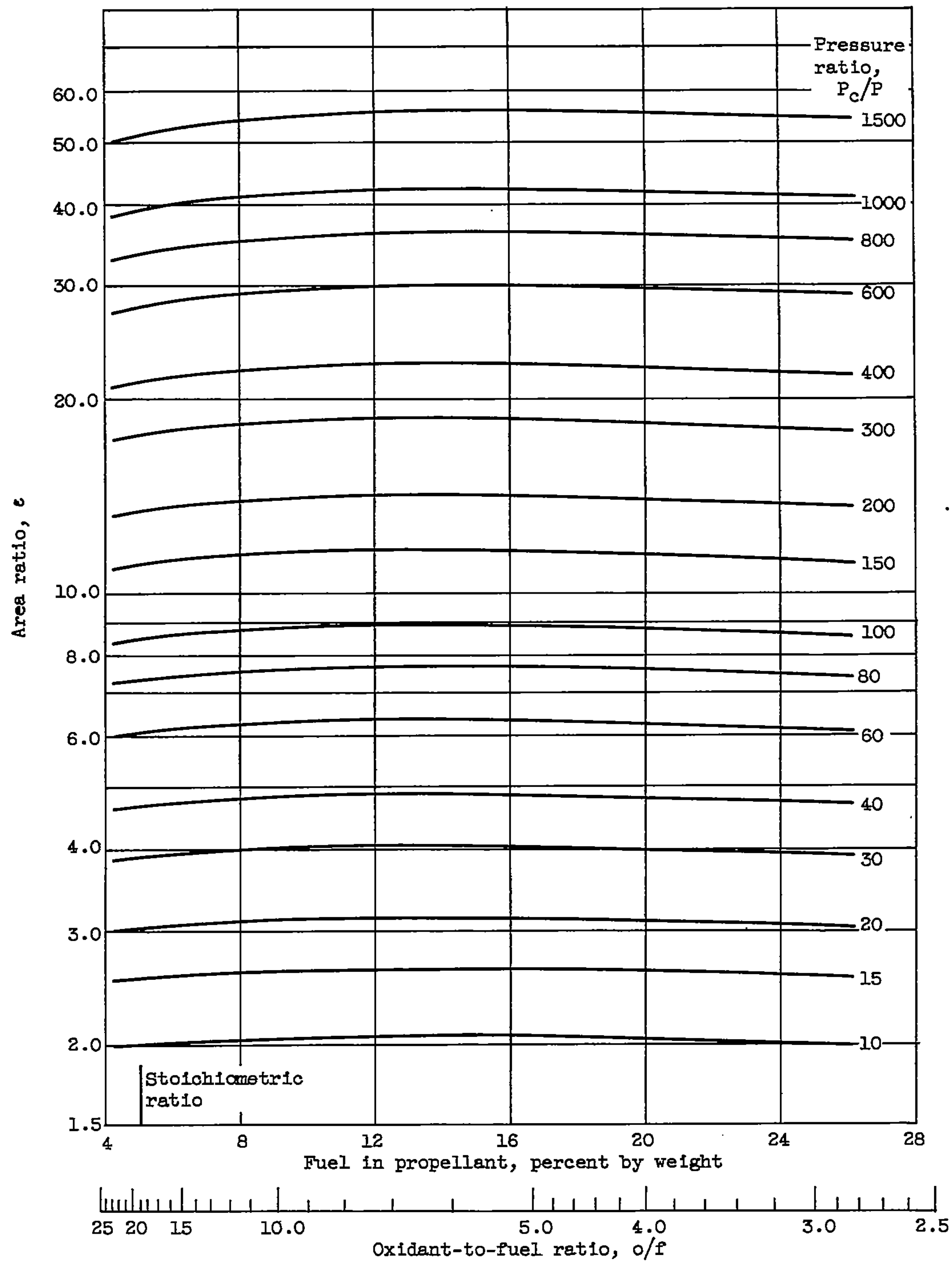
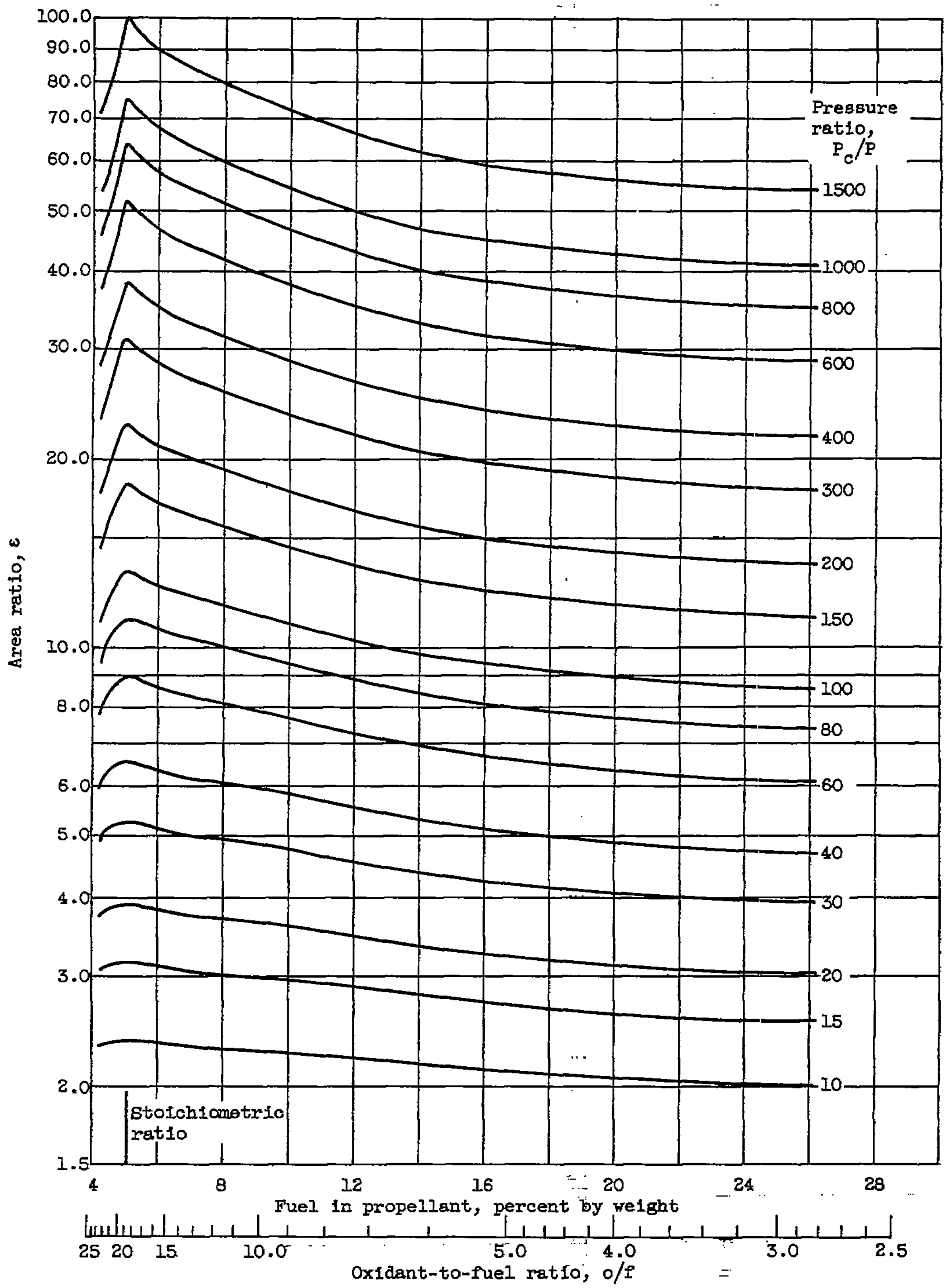


(a) Frozen composition.

Figure 3. - Theoretical ratio of nozzle area to throat area for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with isentropic expansion to indicated pressure ratios.



(b) Equilibrium composition.

Figure 3. - Concluded. Theoretical ratio of nozzle area to throat area for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with isentropic expansion to indicated pressure ratios.

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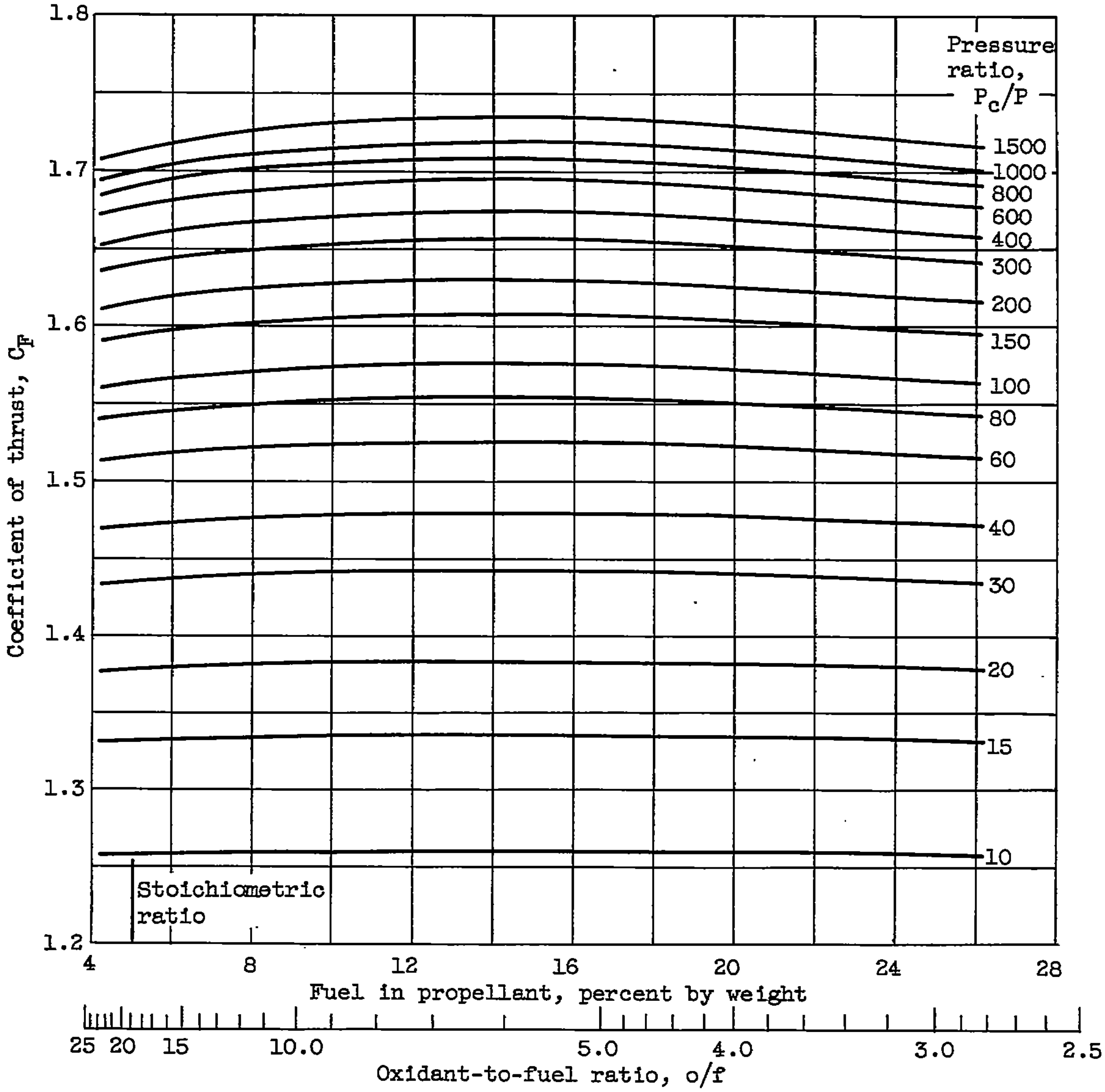
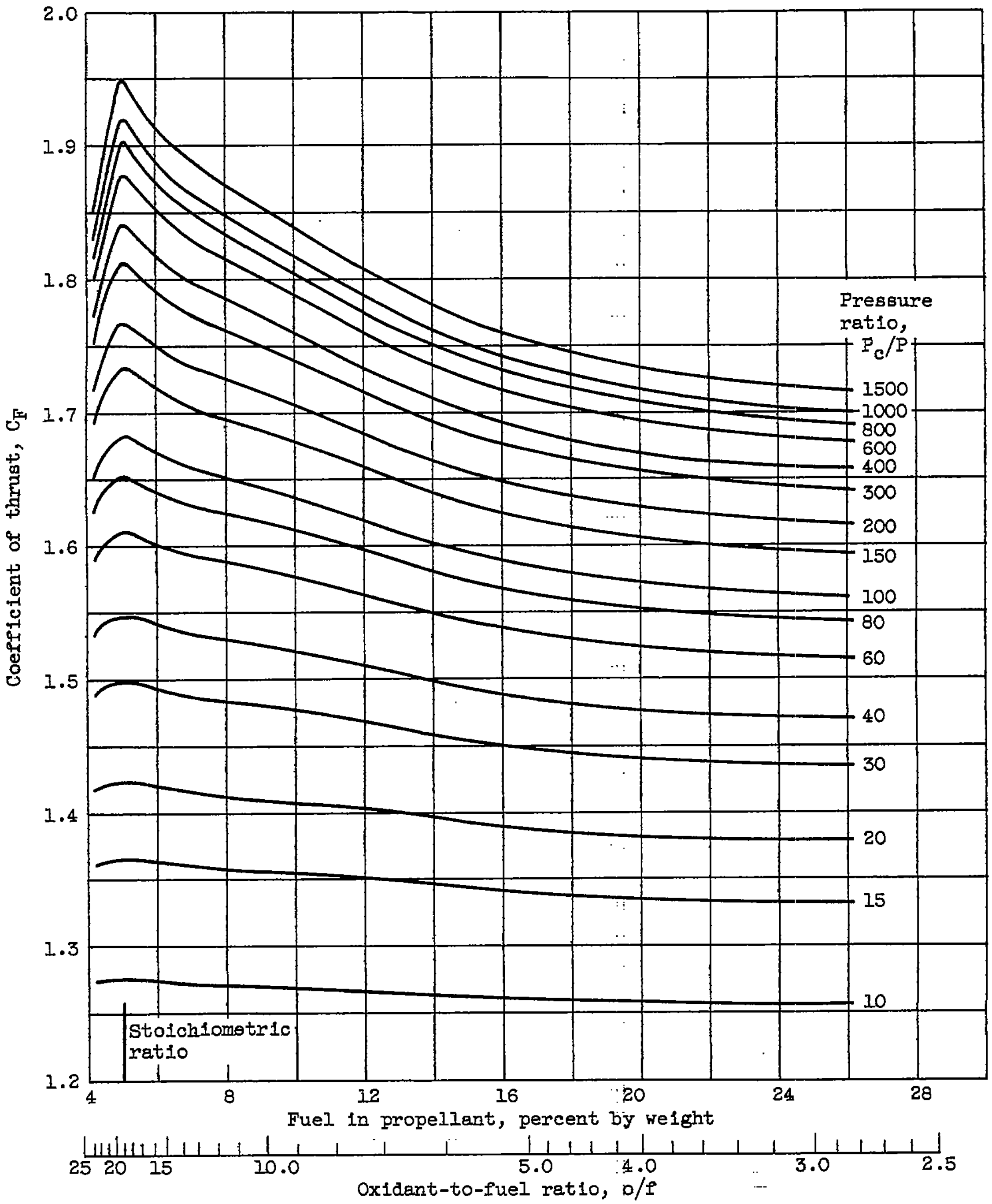


(a) Frozen composition.

Figure 4. - Theoretical coefficient of thrust for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with isentropic expansion to indicated pressure ratios.



(b) Equilibrium composition.

Figure 4. - Concluded. Theoretical coefficient of thrust for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with isentropic expansion to indicated pressure ratios.

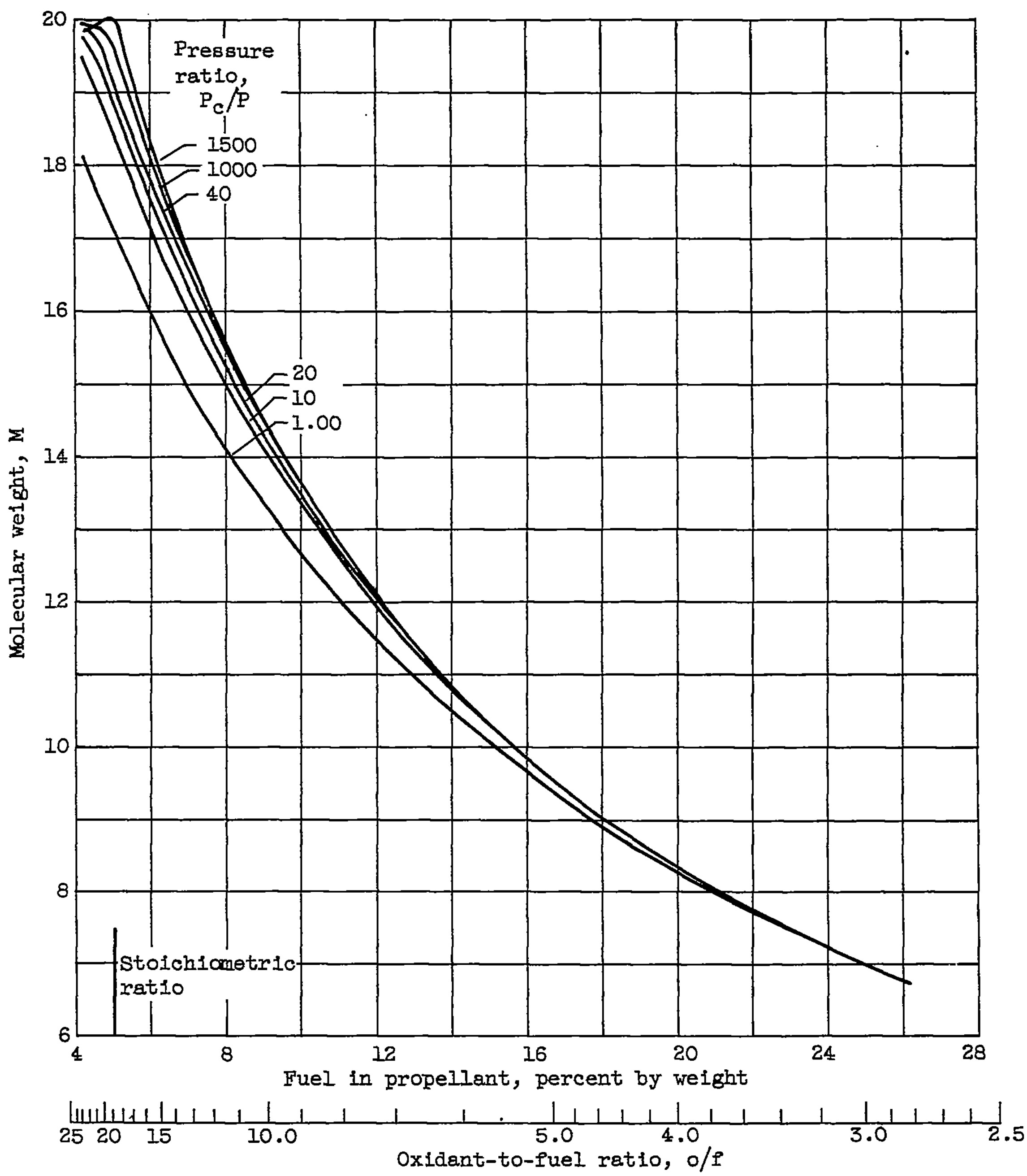


Figure 5. - Theoretical molecular weight for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with equilibrium composition during isentropic expansion to indicated pressure ratios.

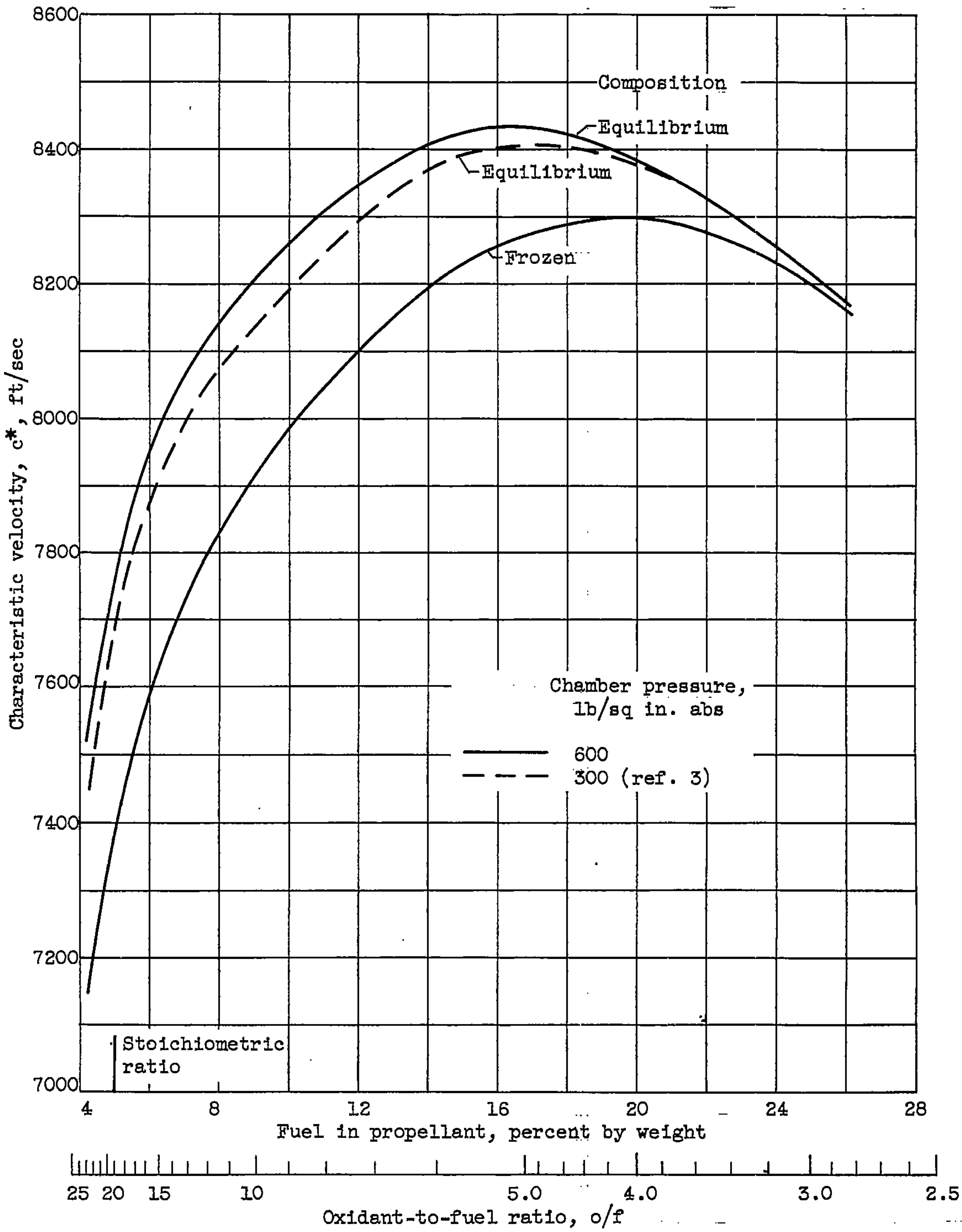


Figure 6. - Comparison of theoretical characteristic velocity assuming frozen and equilibrium composition for liquid hydrogen with liquid fluorine at chamber pressures of 600 and 300 pounds per square inch absolute.

4346

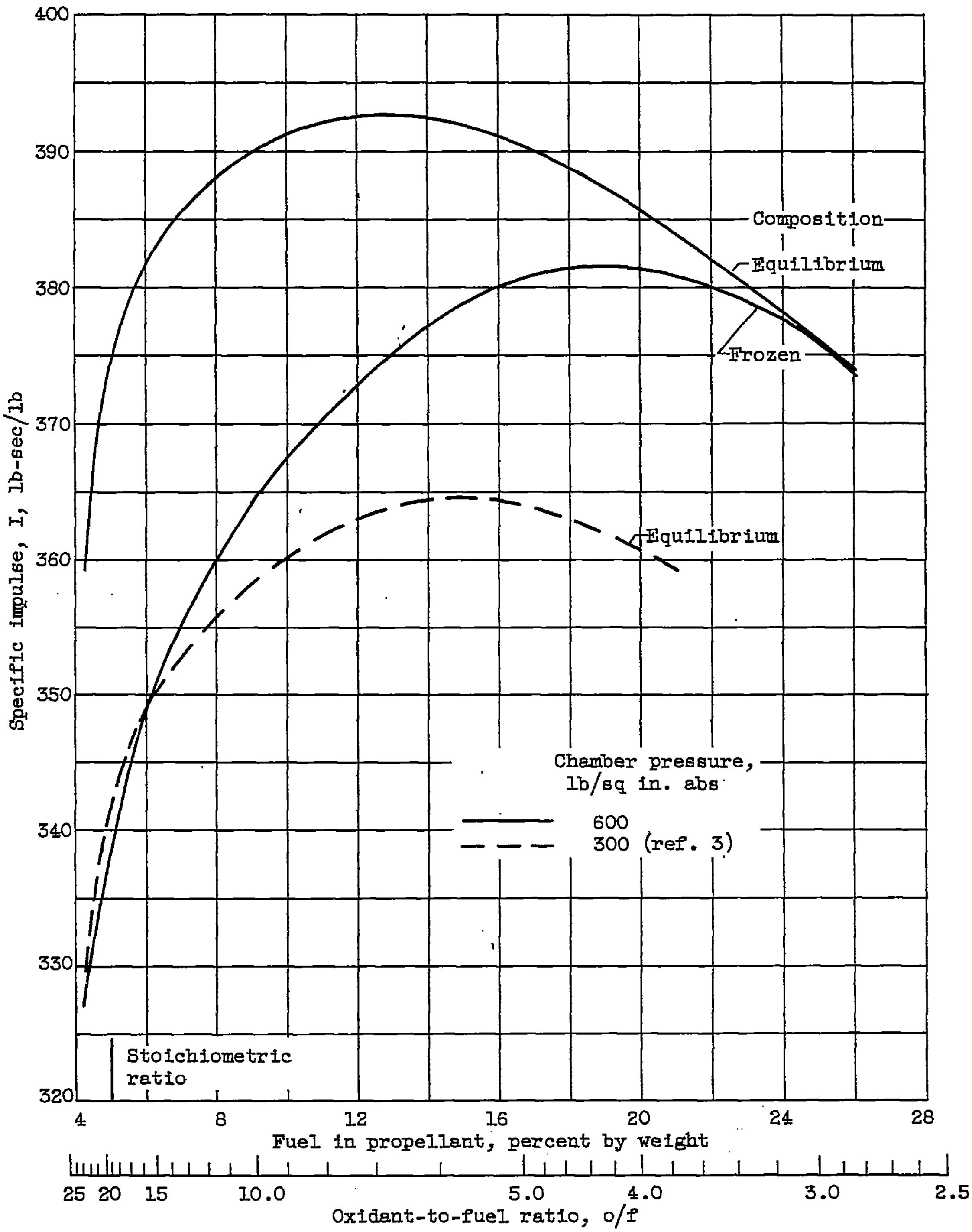


Figure 7. - Comparison of theoretical specific impulse assuming frozen and equilibrium composition. Isentropic expansion to 1 atmosphere; pressure ratio, 40.83 and 20.41 for liquid hydrogen with liquid fluorine.

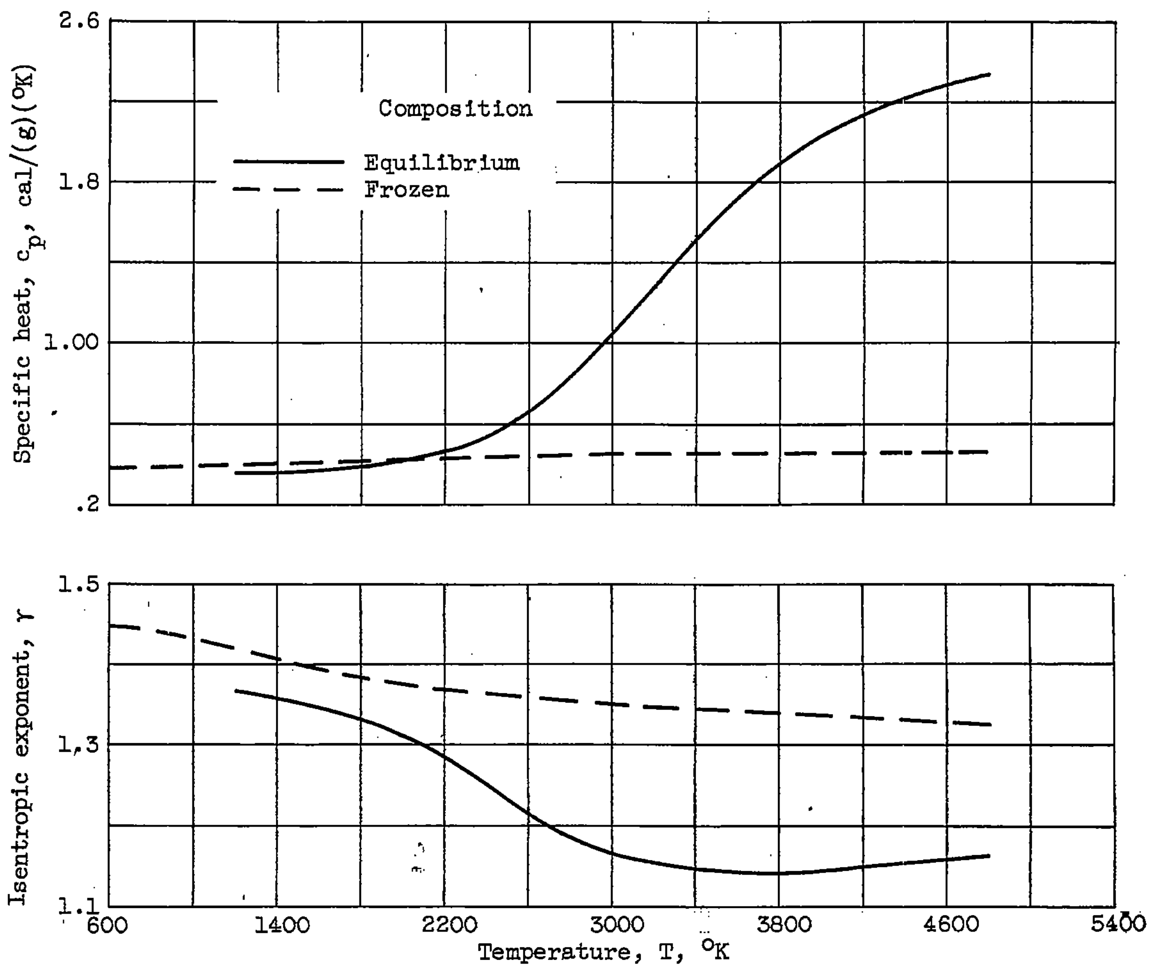


Figure 8. - Variation of theoretical specific heat and isentropic exponent with temperature for both frozen and equilibrium composition. Isentropic expansion; combustion pressure, 600 pounds per square inch absolute; stoichiometric equivalence ratio for liquid hydrogen with liquid fluorine.