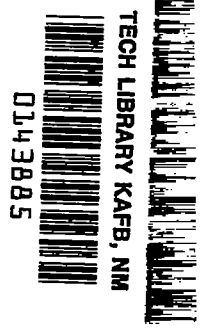
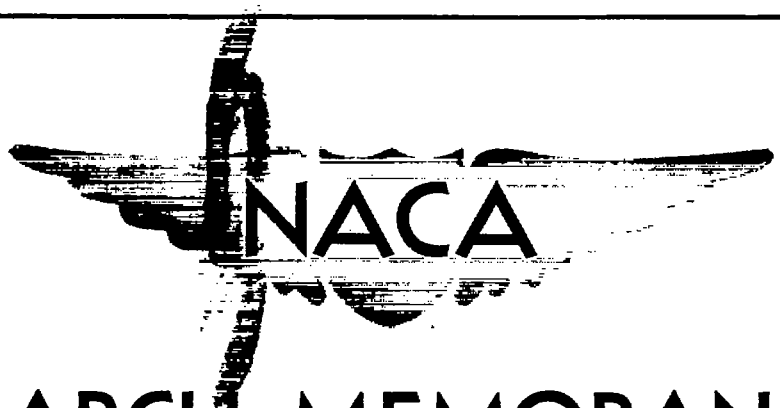


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RESEARCH MEMORANDUM

THEORETICAL ROCKET PERFORMANCE OF LIQUID METHANE WITH
SEVERAL FLUORINE-OXYGEN MIXTURES ASSUMING
FROZEN COMPOSITION

By Sanford Gordon and Michael E. Kastner

Lewis Flight Propulsion Laboratory
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SUMMARY

Theoretical rocket performance for frozen composition during expansion was calculated for liquid methane with several fluorine-oxygen mixtures for a range of pressure ratios and oxidant-fuel ratios. The parameters included are 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.

The maximum calculated value of specific impulse for a chamber pressure of 600 pounds per square inch absolute (40.827 atm) and an exit pressure of 1 atmosphere is 315.3 for 79.67 percent fluorine in the oxidant.

INTRODUCTION

Mixtures of liquid fluorine and liquid oxygen as oxidants with hydrocarbons as fuel have been considered in recent years for possible high-energy rocket propellants. References 1 to 3 present data for JP-4 fuel with several mixtures of oxygen and fluorine. These data show that mixtures of fluorine and oxygen exist that give higher performance with JP-4 fuel than either 100 percent oxygen or fluorine because fluorine burns preferentially with hydrogen, and oxygen with carbon.

A hydrocarbon fuel with a higher hydrogen-carbon atom ratio than that of JP-4 fuel (1.942 hydrogen-carbon atom ratio) might be expected to yield even higher values of specific impulse with mixtures of fluorine and oxygen than were obtained with JP-4 fuel. Calculations were, therefore, made at the NACA Lewis laboratory in order to determine the performance of liquid methane with several mixtures of liquid fluorine and oxygen.

SYMBOLS

The following symbols are used in this report:

- A nozzle area, sq in.
- a local velocity of sound, ft/sec
- C_F coefficient of thrust, $C_F = g_c I / c^* = F / P_c A_t$
- C_p^O molar specific heat at constant pressure, cal/(mole)(°K)
- c_p specific heat at constant pressure, $\frac{\sum_i x_i (C_p^O)_i}{M(1 - x_k)}$, cal/(g)(°K)
- c_v specific heat at constant volume
- c^* characteristic velocity, $g_c P_c A_t / w$, ft/sec
- F thrust, lb
- g_c gravitational conversion factor, 32.174 (lb mass/lb force)(ft/sec²)
- H_T^O sum of sensible enthalpy and chemical energy at temperature T, cal/mole
- h sum of sensible enthalpy and chemical energy per unit mass, $\frac{\sum_i x_i (H_T^O)_i}{M(1 - x_k)}$, cal/g
- I specific impulse, (lb force)(sec)/lb mass
- k coefficient of thermal conductivity, cal/(sec)(cm)(°K)
- M molecular weight, $\frac{\sum_i x_i M_i}{1 - x_k}$, g/g-mole or lb/lb-mole
- O/F oxidant-fuel weight ratio
- P static pressure (sum of partial pressures), lb/sq in.
- p partial pressure, lb/sq in.

- R universal gas constant (consistent units)
- r equivalence ratio, ratio of four times the number of carbon atoms plus the number of hydrogen atoms to two times the number of oxygen atoms plus the number of fluorine atoms, $\frac{4(C) + (H)}{2(O) + (F)}$
- S_T^0 entropy at a pressure of 1 atmosphere, cal/(mole)(°K)
- s entropy per unit mass, $\frac{\sum_i x_i (S_T^0)_i}{M(1 - x_k)} - \frac{R \sum_j p_j \ln(p_j/14.696)}{PM}$, cal/(g)(°K)
- T temperature, °K
- w mass-flow rate, lb/sec
- x mole fraction
- γ isentropic exponent, $\left(\frac{\partial \ln P}{\partial \ln \rho}\right)_s$
- ϵ ratio of nozzle area to throat area
- μ absolute viscosity, g/(cm)(sec) or poises
- ρ density, lb/cu in.

Subscripts:

- c combustion chamber
- e nozzle exit
- i product of combustion including both gaseous and solid phases
- j gaseous product of combustion
- k solid product of combustion (graphite)
- p constant pressure
- s constant entropy

t nozzle throat

Superscript:

o thermodynamic standard reference state

CALCULATION OF PERFORMANCE DATA

Performance data were obtained for liquid methane with several fluorine-oxygen mixtures for a range of equivalence and pressure ratios. Frozen composition during expansion from a chamber pressure of 600 pounds per square inch absolute was assumed.

The computations were carried out by the method described in reference 4 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 graphite and the following ideal gases: atomic carbon C, carbon monofluoride CF, carbon difluoride CF₂, carbon trifluoride CF₃, carbon tetrafluoride CF₄, difluoroacetylene C₂F₂, methane CH₄, carbon monoxide CO, carbon dioxide CO₂, atomic fluorine F, fluorine F₂, atomic hydrogen H, hydrogen H₂, hydrogen fluoride HF, water H₂O, atomic oxygen O, oxygen O₂, and the hydroxyl radical OH. The combustion products are assumed to be completely expanded within the exit nozzle; that is, ambient pressure equals exit pressure.

The graphite was assumed to be finely divided and in temperature and velocity equilibrium with the gases during the flow process.

Initial Data

Thermodynamic data. - The thermodynamic data for all combustion products except graphite, methane, the fluorocarbons, and water were taken from reference 4. Data for graphite were taken from reference 5, for carbon monofluoride from reference 6, for the remainder of the

fluorocarbons from reference 7, and for water from reference 8. Data for methane were determined by the rigid-rotator - harmonic-oscillator approximation using spectroscopic data from reference 9. The base used in this report for assigning absolute values to enthalpy is the same as in reference 4.

The dissociation energy of fluorine was assumed to be 35.6 kilocalories per mole and the heat of sublimation of graphite at 298.16° K was assumed to be 171.698 kilocalories per mole (ref. 10). The heat of solution of oxygen and fluorine was omitted.

Physical, thermochemical, and viscosity data. - Several properties of the propellants taken from references 4, 10, 11, and 12 are listed in table I. The viscosity data for the individual combustion products were either taken from the literature when available, or estimated. The viscosities of F, H, H₂, and HF are given in reference 13. The viscosities of the remaining substances except H₂O were calculated using similar techniques. The viscosity of H₂O was obtained from a modified Sutherland equation (ref. 14).

Formulas

Interpolation formulas and accuracy of results are discussed in reference 15. The formulas used in computing the various performance parameters are as follows:

Specific impulse, (lb force)(sec)/lb mass

$$I = 294.98 \sqrt{\frac{h_c - h_e}{1000}} \quad (1)$$

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

$$\frac{A_t}{w} = \frac{2781.6 T_t}{P_t M_t a} \quad (2)$$

This equation is derived from the continuity equation and the fact that the velocity of flow equals the velocity of sound at the throat.

Characteristic velocity, ft/sec

$$c^* = g_c P_c \frac{A_t}{w} = 32.174 P_c \frac{A_t}{w} \quad (3)$$

Coefficient of thrust

$$C_F = \frac{g_c I}{c^*} = \frac{32.174 I}{c^*} \quad (4)$$

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

$$\frac{A}{w} = \frac{86.455 T}{PMI} \quad (5)$$

Ratio of nozzle area to throat area

$$\epsilon = \frac{A/w}{A_t/w} \quad (6)$$

Specific heat at constant pressure, cal/(g)(°K)

$$c_p = \frac{\sum_i x_i (c_p)_i}{M(1 - x_k)} \quad (7)$$

Isentropic exponent

$$\gamma = \left(\frac{\partial \ln P}{\partial \ln \rho} \right)_s \quad (8)$$

When the composition is frozen,

$$\left(\frac{\partial \ln P}{\partial \ln \rho} \right)_s = \frac{c_p}{c_p - \frac{R}{M}} = \frac{c_p}{c_v}$$

Absolute viscosity, poises

$$\mu = \frac{PM}{\sum_j \frac{P_j}{\mu_j/M_j}} \quad (9)$$

Coefficient of thermal conductivity, cal/(sec)(cm)(°K)

$$k = \mu \left(c_p + \frac{5}{4} \frac{R}{M} \right) \quad (10)$$

THEORETICAL PERFORMANCE DATA

Tables

The calculated values of the various performance parameters for a combustion pressure of 600 pounds per square inch absolute and for a range of oxidant-fuel ratios and exit conditions are given in tables II to V for a range of fluorine-oxygen ratios.

4762 The fluorine-oxygen atom ratios selected are 0 (100 percent oxygen), 0.2, 0.5, 1.0, 2.0, 3.0, 3.3, 3.4, 3.7, and 4.0, which correspond to the following percentages of fluorine in the oxidant by weight: 0, 19.19, 37.25, 54.29, 70.37, 78.08, 79.67, 80.15, 81.46, and 82.61. The range of oxidant-fuel ratios selected for each percentage of fluorine is greater for the fluorine percentages up to 70 than for those over 70. For the fluorine percentages over 70, closely spaced oxidant-fuel ratios were selected primarily to determine maximum specific impulse.

The properties of gases in the combustion chamber and the characteristic velocity are given in table II. Table III presents the values of the performance parameters at assigned temperatures and constant entropy. These values were computed directly and used to interpolate properties at the assigned pressure ratios given in table IV. Properties at the throat in table IV may be found where the ratio of nozzle area to throat area ϵ is 1.000. The values adjacent to the throat correspond to pressures of 1.2 and 0.8 times the throat pressure. Table V presents the equilibrium composition in the combustion chamber. Solid graphite did not appear as a combustion product for any of the conditions considered in this report and is therefore omitted from table V. The mole fractions of carbon tetrafluoride and methane were always less than 5×10^{-6} for all the conditions considered in this report and therefore these substances were also omitted from table V. Performance data for expansion from combustion-chamber pressure to 1 atmosphere are summarized in table VI.

Curves

The performance parameters are plotted in figures 1 to 7. Curves of specific impulse are presented in figure 1 for assigned pressure ratios as functions of percentages of fuel by weight.

Combustion temperature and exit temperature for assigned pressure ratios are plotted in figure 2 as functions of percentages of fuel by weight.

In figure 2(f) the combustion temperatures for 78.08, 79.67, 80.15, 81.46, and 82.61 percent fluorine in the oxidant by weight are presented as separate curves. However, the exit curves coincided so closely that only one curve is given for each pressure ratio covering the range of 78.08 to 82.61 percent fluorine.

Curves of the ratio of nozzle area to throat area are plotted in figure 3 as functions of percentages of fuel by weight for assigned pressure ratios.

Figures 4 and 5 present curves of molecular weight and characteristic velocity, respectively, as functions of percentages of fuel by weight.

Effect of fluorine-oxygen ratio. - The specific-impulse data for expansion from chamber pressure to 1 atmosphere (table VI) are plotted in figure 6 to show the effect of fluorine-oxygen ratios on performance. Specific impulse increases with increasing percentages of fluorine to about 80 percent fluorine in the oxidant. Increasing the amount of fluorine in the oxidant above 80 percent results in a decrease in specific impulse.

Maximum values of specific impulse calculated for a chamber pressure of 600 pounds per square inch absolute (40.827 atm) and an exit pressure of 1 atmosphere are shown in the following table:

Fluorine in oxidant, percent by weight	Maximum specific impulse, $\frac{\text{lb-sec}}{\text{lb}}$
0	282.8
19.19	289.0
37.25	295.3
54.29	301.8
70.37	310.0
78.08	315.1
79.67	315.3
80.15	315.2
81.46	314.2
82.61	312.7

The data of the preceding table are plotted in figure 7; it may be seen from this figure that a specific impulse value of about 315 may be obtained from about 77 to 81 percent fluorine in the oxidant. Specific impulse increases from 282.8 to 315.3 for 0 to 79.67 percent fluorine in the oxidant and decreases from 315.3 to 312.7 for 79.67 to 82.61 percent fluorine in the oxidant. A curve for JP-4 fuel with mixtures of fluorine

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and oxygen (fig. 8 of ref. 2) is also given in figure 7 for comparison. The maximum value of specific impulse for JP-4 fuel is 301.6 at about 70 percent fluorine in the oxidant as compared with 315.3 at 79.67 percent fluorine in the oxidant for liquid methane.

Effect of finite chamber area. - The use of a combustion chamber of finite cross-sectional area leads to a pressure change across the combustion process. Reference 15 illustrates how the data for low pressure ratios may be used to calculate the pressure at the injector face.

SUMMARY OF RESULTS

A theoretical investigation of the performance of liquid methane with fluorine-oxygen mixtures was made for the following conditions: fluorine in oxidant by weight from 0 to 82.61 percent for various equivalence ratios, pressure ratios from 1 to 300, and frozen composition during expansion from 600 pounds per square inch absolute in the combustion chamber. The maximum values of specific impulse calculated for an exit pressure of 1 atmosphere (pressure ratio, 40.827) ranged from 282.8 to 315.3 for 0 to 79.67 percent fluorine in the oxidant and from 315.3 to 312.7 for 79.67 to 82.61 percent fluorine in the oxidant.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, February 27, 1958

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TABLE I. - PROPERTIES OF LIQUID PROPELLANTS

Property	Propellant		
	Oxygen, O ₂	Fluorine, F ₂	Methane, CH ₄
Molecular weight, M	32.00	38.00	16.042
Density, g/cc	^a 1.1415	^b 1.54	^c 0.4245
Freezing point, °C	^{d,e} -218.76	^d -217.96	^{d,f} -182.48
Boiling point, °C	^d -182.97	^d -187.92	^d -161.49
Enthalpy of formation at boiling point from elements at 25° C, kcal/mole	^g -3.080	^g -3.030	^{d,h} -21.352
Enthalpy of vaporization, kcal/mole	^{d,i} 1.630	^{d,j} 1.51	^{d,k} 1.955
Enthalpy of fusion, kcal/mole	^{d,l} 0.106	^{d,m} 0.372	^{d,n} 0.225

^aAt -182.0° C; ref. 11.^bAt -196° C; ref. 12.^cAt -161.5° C; ref. 11.^dRef. 10.^eAt 1.1 mm Hg.^fAt 87.7 mm Hg.^gRef. 4.^hUnpublished NACA calculations based on data of ref. 9.ⁱAt -182.97° C.^jAt -187.92° C.^kAt -161.49° C.^lAt -218.76° C.^mAt -217.96° C.ⁿAt -182.48° C.

TABLE II. - THERMODYNAMIC PROPERTIES OF COMBUSTION-CHAMBER GASES AND CHARACTERISTIC VELOCITY FOR LIQUID METHANE WITH SEVERAL MIXTURES OF FLUORINE AND OXYGEN

Equivalence ratio, $\frac{r}{\frac{4(O) + (H)}{2(O) + (F)}}$	Fuel, percent by weight	Oxidant-to-fuel weight ratio, O/F	Temperature, T, °K	Molecular weight, M	Enthalpy, h, cal/g (a)	Entropy, s, cal/(g)(°K)	Specific heat, c_p , cal/(g)(°K)	Isentropic exponent, γ (b)	Characteristic velocity, c^* , ft/sec (b)
Percent fluorine in oxidant, 0 (100 percent oxygen)									
1.00	20.04	3.990	3497	22.87	2645.8	2.8259	0.519	1.201	5700
1.30	24.58	3.089	3444	20.54	3237.1	3.0420	.565	1.207	5959
1.40	25.98	2.850	3372	19.80	3419.6	3.1038	.578	1.210	5998
1.50	27.32	2.660	3272	19.08	3595.5	3.1604	.590	1.215	6011
1.60	28.62	2.493	3147	18.39	3765.0	3.2121	.600	1.220	5996
1.80	31.09	2.216	2855	17.10	4086.6	3.3011	.618	1.231	5901
Percent fluorine in oxidant by weight, 19.19									
1.20	21.10	3.740	3622	20.83	3017.6	2.9809	0.521	1.224	6036
1.40	23.78	3.206	3536	19.59	3359.2	3.1015	.548	1.227	6145
1.50	25.05	2.992	3460	18.99	3521.4	3.1556	.560	1.230	6169
1.60	26.28	2.805	3362	18.40	3678.2	3.2056	.571	1.233	6172
1.80	28.62	2.493	3119	17.28	3977.0	3.2936	.591	1.242	6118
Percent fluorine in oxidant by weight, 37.25									
1.30	20.35	3.913	3753	19.88	3145.8	3.0158	0.505	1.247	6248
1.50	22.77	3.391	3650	18.86	3447.2	3.1221	.530	1.248	6324
1.60	23.93	3.179	3572	18.36	3591.2	3.1701	.541	1.250	6336
1.70	25.05	2.992	3479	17.87	3730.9	3.2147	.552	1.252	6333
1.90	27.19	2.677	3258	16.95	3998.3	3.2945	.571	1.258	6282
Percent fluorine in oxidant by weight, 54.29									
1.30	18.26	4.475	3957	19.60	3100.6	2.9706	0.476	1.271	6416
1.40	19.40	4.156	3917	19.16	3238.7	3.0222	.488	1.270	6459
1.50	20.50	3.879	3864	18.73	3373.1	3.0708	.499	1.270	6489
1.60	21.57	3.636	3798	18.30	3503.9	3.1165	.511	1.270	6506
1.80	23.63	3.232	3628	17.48	3755.1	3.1994	.531	1.272	6503
Percent fluorine in oxidant by weight, 70.37									
1.40	17.22	4.809	4209	19.08	3178.8	2.9530	0.458	1.294	6664
1.50	18.22	4.488	4157	18.69	3299.0	2.9988	.469	1.293	6694
1.60	19.20	4.208	4091	18.30	3416.3	3.0419	.480	1.292	6711
1.70	20.16	3.960	4014	17.93	3530.8	3.0823	.490	1.292	6717
Percent fluorine in oxidant by weight, 78.08									
1.55	17.55	4.697	4333	18.59	3317.5	2.9700	0.460	1.303	6833
1.60	18.02	4.551	4298	18.40	3372.4	2.9890	.465	1.303	6841
1.65	18.48	4.413	4228	18.31	3426.7	3.0041	.470	1.300	6807
Percent fluorine in oxidant by weight, 79.67									
1.48	16.66	5.003	4418	18.89	3232.1	2.9282	0.450	1.305	6840
1.51	16.94	4.904	4402	18.78	3265.2	2.9399	.453	1.305	6848
1.55	17.31	4.777	4351	18.70	3309.0	2.9531	.457	1.303	6827
Percent fluorine in oxidant by weight, 80.15									
1.46	16.40	5.098	4440	18.98	3207.7	2.9157	0.447	1.308	6839
1.48	16.59	5.029	4431	18.91	3229.8	2.9236	.449	1.306	6846
1.50	16.77	4.962	4408	18.86	3251.8	2.9306	.451	1.305	6838
Percent fluorine in oxidant by weight, 81.46									
1.38	15.45	5.471	4498	19.32	3113.3	2.8700	0.436	1.309	6817
1.40	15.64	5.393	4493	19.25	3135.6	2.8783	.438	1.308	6828
1.42	15.83	5.317	4476	19.20	3157.7	2.8859	.440	1.308	6825
Percent fluorine in oxidant by weight, 82.61									
1.30	14.53	5.882	4527	19.65	3019.9	2.8241	0.425	1.312	6776
1.33	14.85	5.735	4528	19.53	3057.2	2.8386	.429	1.311	6799
1.40	15.48	5.462	4480	19.41	3131.0	2.8633	.436	1.307	6793
1.50	16.40	5.098	4395	19.23	3239.7	2.8965	.448	1.300	6772

^aThe base used for enthalpy is given in ref. 4.

^bParameters based on frozen composition.

TABLE III. - THEORETICAL ROCKET PERFORMANCE AT ASSIGNED EXIT TEMPERATURES FOR LIQUID METHANE WITH SEVERAL FLUORINE-OXYGEN MIXTURES

[Frozen composition assumed during isentropic expansion or compression from combustion-chamber pressure of 600 lb/sq in. abs.]

(a) Percent fluorine in oxidant, 0 (100 percent oxygen)

Temperature, T, °K	Static pressure, P, lb/sq in. abs	Enthalpy, h, cal/g	Isentropic exponent, γ	Specific heat, c_p , cal/(g)(°K)	Absolute viscosity, μ , micro-poise	Thermal conductivity, k , cal/(cm)(sec)(°K)	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, lb-sec/lb
r, 1.00; percent fuel, 20.04; O/F, 3.990									
3600	714.07	2699.4	1.200	0.5212	895	0.00056	-----	-----	-----
3200	354.07	2249.2	1.204	.5138	829	.00052	1.00	0.652	115.5
2800	161.89	2088.6	1.208	.5047	761	.00047	1.26	.995	176.3
2400	66.7996	2009.0	1.214	.4933	688	.00041	2.09	1.242	220.1
2000	24.0997	1894.4	1.222	.4783	609	.00036	4.16	1.443	255.7
1600	7.240	1707.1	1.234	.4578	523	.00030	9.90	1.613	285.8
1200	1.668	1529.4	1.254	.4289	427	.00023	29.56	1.759	311.7
900	.423	1404.4	1.277	.4008	346	.00018	82.96	1.855	328.6
600	.071	1289.4	1.309	.3684	252	.00012	317.07	1.939	343.5
r, 1.30; percent fuel, 24.58; O/F, 3.089									
3600	777.80	3325.6	1.205	0.5679	870	0.00049	-----	-----	-----
3200	391.56	3100.0	1.209	.5597	807	.00045	1.02	0.590	109.2
2800	182.10	2878.0	1.214	.5497	740	.00041	1.19	.954	176.8
2400	76.607	2660.6	1.220	.5372	669	.00036	1.91	1.209	224.0
2000	28.272	2448.0	1.228	.5206	593	.00031	3.68	1.414	261.9
1600	8.733	2244.9	1.241	.4978	510	.00025	8.50	1.587	293.8
1200	2.085	2051.9	1.262	.4657	417	.00019	24.44	1.734	321.1
900	.647	1916.7	1.286	.4350	337	.00015	66.20	1.830	339.0
600	.095	1791.2	1.318	.4013	245	.00010	242.19	1.915	354.7
r, 1.40; percent fuel, 25.98; O/F, 2.850									
3600	875.72	3551.9	1.208	0.5825	864	0.00061	-----	-----	-----
3200	444.25	3320.5	1.212	.5740	802	.00056	1.09	0.498	92.9
2800	208.39	3092.9	1.217	.5637	736	.00051	1.12	.904	168.6
2400	88.535	2869.9	1.223	.5508	665	.00045	1.74	1.173	218.7
2000	33.048	2652.8	1.232	.5338	590	.00039	3.29	1.386	258.3
1600	10.348	2443.8	1.245	.5103	507	.00032	7.46	1.563	291.4
1200	2.612	2245.8	1.266	.4775	415	.00025	21.01	1.714	319.6
900	.669	2107.2	1.290	.4463	336	.00019	55.96	1.813	337.9
600	.118	1978.3	1.322	.4124	244	.00013	200.88	1.900	354.1
r, 1.50; percent fuel, 27.32; O/F, 2.660									
3600	1034.4	3790.2	1.211	0.5967	860	0.00062	-----	-----	-----
3200	529.34	3553.2	1.215	.5880	798	.00057	1.45	0.324	60.6
2800	250.76	3320.1	1.220	.5774	732	.00052	1.05	.629	154.8
2400	107.73	3091.7	1.226	.5641	663	.00046	1.55	1.121	209.4
2000	40.739	2869.9	1.235	.5466	587	.00040	2.84	1.345	251.3
1600	12.952	2655.3	1.249	.5226	505	.00033	6.29	1.531	285.0
1200	3.202	2452.2	1.270	.4892	413	.00026	17.30	1.688	315.3
900	.868	2310.5	1.295	.4578	335	.00020	45.21	1.790	334.4
600	.156	2178.2	1.326	.4239	244	.00014	158.99	1.880	351.2
r, 1.60; percent fuel, 28.62; O/F, 2.493									
3600	658.21	3799.8	1.219	0.6016	795	0.00059	-----	-----	-----
3200	315.14	3558.3	1.224	.5907	730	.00053	1.00	0.720	134.1
2800	137.03	3320.1	1.230	.5771	660	.00047	1.35	1.050	195.5
2400	58.543	3092.4	1.240	.5592	586	.00041	2.39	1.293	241.1
2000	16.978	2869.7	1.253	.5346	504	.00034	5.14	1.491	277.8
1600	4.278	2655.0	1.275	.5009	413	.00026	13.76	1.656	308.6
1200	1.177	2452.5	1.299	.4693	335	.00020	35.24	1.762	328.5
900	.401	2310.5	1.330	.4357	244	.00014	121.26	1.856	346.0
600	.071	2178.2	1.362	.4013	152	.00009	481.14	1.939	360.0
r, 1.80; percent fuel, 31.09; O/F, 2.216									
3600	1105.3	4301.3	1.227	0.6279	792	0.00061	-----	-----	-----
3200	540.68	4052.2	1.232	.6164	727	.00055	1.57	0.297	54.6
2800	240.90	3809.9	1.239	.6022	658	.00049	1.06	.848	155.5
2400	94.990	3571.2	1.249	.5837	584	.00043	1.64	1.155	211.8
2000	31.710	3344.2	1.263	.5585	503	.00035	3.28	1.387	254.5
1600	8.301	3129.5	1.285	.5242	412	.00028	8.27	1.577	289.2
1200	2.359	2917.3	1.309	.4926	335	.00021	20.27	1.797	311.3
900	.659	2703.0	1.338	.4598	246	.00015	66.74	1.863	330.6

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TABLE III. - Continued. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED EXIT TEMPERATURES FOR LIQUID METHANE WITH SEVERAL FLUORINE-OXYGEN MIXTURES

[Frozen composition assumed during isentropic expansion or compression from combustion-chamber pressure of 600 lb/sq in. abs.]

(b) Percent fluorine in oxidant by weight, 19.19

Temperature, T, °K	Static pressure, P, lb/sq in. abs	Enthalpy, h, cal/g	Isentropic exponent, γ	Specific heat, c_p , cal/(g)(°K)	Absolute viscosity, μ , micro-poise	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, 21.10; O/F, 3.740									
4000	1034.9	3215.7	1.221	0.5270	1046	0.00068			
3600	580.20	3006.1	1.224	.5209	975	.00062	2.60	0.169	31.7
3200	306.35	2799.1	1.228	.5136	901	.00057	1.01	.735	137.9
2800	150.21	2595.4	1.233	.5047	823	.00051	1.29	1.022	191.7
2400	67.048	2395.7	1.240	.4936	740	.00045	3.04	1.240	232.6
2000	26.464	2201.1	1.249	.4796	652	.00039	3.74	1.421	266.6
1600	8.830	2013.2	1.262	.4609	557	.00033	6.14	1.674	295.6
1200	2.304	1834.7	1.283	.4319	452	.00025	21.55	1.710	320.8
900	.651	1708.9	1.307	.4065	363	.00019	54.35	1.799	337.5
r, 1.40; percent fuel, 23.78; O/F, 3.208									
3600	660.58	3194.0	1.227	0.5492	956	0.00065			
3200	350.70	3175.8	1.231	.5414	883	.00059	1.00	0.651	126.3
2800	173.03	2961.1	1.236	.5320	807	.00053	1.21	.974	186.1
2400	77.787	2750.5	1.242	.5202	727	.00047	1.86	1.205	230.1
2000	30.965	2545.4	1.252	.5047	641	.00040	3.37	1.393	266.1
1600	10.440	2347.6	1.266	.4835	548	.00033	7.16	1.553	296.7
1200	2.761	2159.7	1.287	.4545	445	.00026	18.65	1.692	321.2
900	.791	2027.3	1.311	.4277	358	.00020	46.34	1.782	340.4
r, 1.50; percent fuel, 25.05; O/F, 2.992									
3600	742.44	3600.1	1.228	0.5629	948	0.00066			
3200	395.86	3376.5	1.233	.5548	877	.00060	1.03	0.586	112.3
2800	196.27	3156.5	1.238	.5451	802	.00054	1.24	.929	178.2
2400	88.732	2940.8	1.244	.5328	722	.00048	1.71	1.172	224.8
2000	32.654	2730.0	1.254	.5170	637	.00042	3.06	1.370	262.3
1600	12.088	2528.0	1.268	.4953	544	.00034	6.42	1.533	294.0
1200	3.225	2335.5	1.290	.4656	442	.00026	16.50	1.675	321.2
900	.932	2199.9	1.314	.4384	356	.00020	40.57	1.769	339.1
r, 1.60; percent fuel, 26.28; O/F, 2.805									
3600	852.51	3814.7	1.231	0.5762	942	0.00067			
3200	462.25	3585.8	1.235	.5679	871	.00061	1.13	0.468	89.7
2800	230.51	3360.6	1.240	.5578	797	.00055	1.07	.867	166.2
2400	104.91	3139.9	1.247	.5453	718	.00049	1.53	1.128	216.4
2000	42.363	2924.9	1.257	.5290	634	.00043	2.71	1.335	256.0
1600	14.528	2717.5	1.271	.5068	542	.00035	5.60	1.507	289.1
1200	3.922	2520.6	1.293	.4766	441	.00027	14.17	1.655	317.4
900	1.144	2351.6	1.317	.4491	355	.00021	34.42	1.751	335.9
r, 1.80; percent fuel, 28.62; O/F, 2.495									
3600	684.23	4024.8	1.241	0.5931	864	0.00064			
3200	345.76	3789.6	1.246	.5824	790	.00057	1.00	0.672	127.7
2800	159.76	3559.7	1.253	.5693	712	.00051	1.24	1.003	190.7
2400	65.650	3333.1	1.261	.5533	629	.00044	2.03	1.243	236.4
2000	23.980	3118.1	1.278	.5293	538	.00036	4.02	1.338	273.4
1600	6.356	2912.3	1.300	.4983	438	.00028	9.79	1.501	304.4
900	1.893	2766.9	1.323	.4706	354	.00022	23.13	1.706	324.5

(c) Percent fluorine in oxidant by weight, 37.25

r, 1.30; percent fuel, 20.38; O/F, 3.913									
4000	828.94	3271.0	1.244	0.5088	1163	0.00074			
3600	486.36	3068.7	1.248	.5029	1080	.00068	1.21	0.422	81.9
3200	270.01	2868.9	1.252	.4960	994	.00062	1.03	.799	155.2
2800	139.97	2672.1	1.258	.4876	904	.00055	1.32	1.045	203.0
2400	66.513	2479.0	1.265	.4773	809	.00049	2.01	1.240	240.9
2000	28.21	2290.7	1.275	.4638	708	.00042	3.49	1.405	272.8
1600	8.215	2108.6	1.289	.4446	601	.00034	7.01	1.547	300.4
1200	2.935	1935.1	1.311	.4218	483	.00026	16.92	1.671	324.6
900	.908	1811.9	1.334	.3994	366	.00020	39.35	1.754	340.7
r, 1.40; percent fuel, 22.77; O/F, 3.581									
4000	913.46	3653.8	1.245	0.5353	1136	0.00076			
3600	559.97	3440.9	1.249	.5292	1056	.00070	1.28	0.574	117.9
3200	311.26	3210.7	1.253	.5218	973	.00064	1.00	.730	143.6
2800	161.39	3003.7	1.259	.5129	885	.00057	1.23	1.000	196.5
2400	76.929	2800.7	1.266	.5018	793	.00050	1.84	1.207	237.2
2000	32.684	2602.7	1.276	.4875	695	.00043	3.16	1.379	271.1
1600	11.882	2411.4	1.291	.4681	590	.00035	6.28	1.528	300.2
1200	3.413	2229.1	1.313	.4422	476	.00027	15.04	1.657	325.6
900	1.060	2049.9	1.336	.4193	360	.00021	34.72	1.742	342.4
r, 1.50; percent fuel, 23.93; O/F, 3.178									
3600	684.14	3606.5	1.250	0.5418	1047	0.00071			
3200	347.56	3391.3	1.254	.5342	964	.00065	1.00	0.670	131.9
2800	180.83	3179.9	1.260	.5250	878	.00058	1.17	.961	189.3
2400	86.307	2971.6	1.267	.5137	787	.00051	1.79	1.179	232.2
2000	36.781	2768.6	1.277	.4993	690	.00044	2.92	1.358	267.6
1600	13.420	2573.1	1.292	.4790	586	.00036	5.75	1.511	297.6
1200	3.893	2386.6	1.314	.4525	473	.00028	13.66	1.644	323.8
900	1.207	2215.3	1.337	.4292	379	.00021	31.36	1.732	341.1
r, 1.70; percent fuel, 25.06; O/F, 2.992									
3600	711.74	3798.1	1.251	0.5542	1039	0.00072			
3200	397.32	3578.0	1.256	.5463	957	.00066	1.03	0.586	115.4
2800	207.32	3361.3	1.261	.5369	872	.00059	1.11	.911	179.3
2400	99.279	3148.8	1.269	.5258	782	.00052	1.58	1.143	225.1
2000	42.477	2941.6	1.279	.5101	686	.00045	2.65	1.331	262.1
1600	15.572	2741.4	1.294	.4897	583	.00037	5.16	1.491	293.4
1200	4.572	2548.6	1.316	.4627	470	.00028	11.86	1.628	320.6
900	1.416	2415.4	1.339	.4391	377	.00022	27.70	1.719	338.3
r, 1.90; percent fuel, 27.19; O/F, 2.677									
3600	979.22	4195.1	1.254	0.5782	1027	0.00074			
3200	530.10	3965.5	1.259	.5698	946	.00068	1.01	0.774	153.5
2800	289.12	3739.5	1.265	.5598	862	.00061	1.01	.769	150.4
2400	139.61	3518.0	1.272	.5475	774	.00054	1.22	1.047	204.4
2000	60.317	3308.0	1.283	.5317	679	.00046	2.11	1.261	246.1
1600	28.367	3093.4	1.298	.5108	578	.00038	4.00	1.437	280.6
1200	6.614	2894.5	1.321	.4828	467	.00029	9.18	1.587	309.9
900	2.085	2753.2	1.343	.4588	376	.00023	20.55	1.686	329.2
600	.445	2619.0	1.368	.4361	272	.00016	60.97	1.774	346.4

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TABLE III. - Continued. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED EXIT TEMPERATURES FOR LIQUID

METHANE WITH SEVERAL FLUORINE OXYGEN MIXTURES

[Frozen composition assumed during isentropic expansion or compression from combustion-chamber pressure of 800 lb/sq in. abs.]

(d) Percent fluorine in oxidant by weight, 54.29

Temperature, T, °K	Static pressure, P, lb/sq in. abs	Enthalpy, h, cal/g	Isentropic exponent, γ	Specific heat, C_p , cal/(°K)	Absolute viscosity, μ , micro-poise	Thermal conductivity, k , cal/(cm)(sec)(°K)	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, lb-sec/lb
r, 1.50; percent fuel, 18.26; Q/F, 4.475									
4000	631.23	3121.1	1.270	0.4764	1320	0.00080	1.02	0.608	121.3
3600	385.83	2851.6	1.274	0.4709	1221	0.00073	1.08	0.883	176.0
3200	294.06	2744.4	1.279	0.4646	1117	0.00068	1.14	1.087	216.9
2800	182.09	2560.0	1.285	0.4571	1010	0.00059	1.40	1.286	250.6
2400	61.331	2479.0	1.293	0.4479	898	0.00052	2.07	1.408	279.1
2000	27.708	2403.1	1.303	0.4359	781	0.00044	3.43	1.530	305.8
1600	10.800	2050.8	1.318	0.4080	653	0.00036	6.44	1.643	327.7
1200	3.433	1749.7	1.362	0.3992	523	0.00028	14.38	1.719	342.9
900	1.117	1637.6	1.384	0.3816	415	0.00021	31.19	1.789	356.8
600	0.251			0.3686	296	0.00015	68.76		
r, 1.40; percent fuel, 19.40; Q/F, 4.156									
4000	662.09	3279.2	1.269	0.4690	1302	0.00081	1.04	0.577	115.8
3600	404.03	3084.7	1.273	0.4634	1204	0.00074	1.06	0.865	173.5
3200	234.21	2898.6	1.278	0.4569	1103	0.00067	1.37	1.077	213.8
2800	127.33	2703.4	1.284	0.4491	997	0.00060	1.64	1.248	250.3
2400	53.873	2517.5	1.291	0.4396	887	0.00052	2.02	1.396	280.3
2000	28.782	2436.1	1.302	0.4278	772	0.00045	3.34	1.526	306.3
1600	11.192	2160.4	1.317	0.4077	649	0.00036	6.29	1.644	329.3
1200	3.453	1892.2	1.340	0.3902	518	0.00028	14.07	1.718	344.8
900	1.133	1757.5	1.383	0.3909	411	0.00021	30.54	1.788	359.0
600	0.259			0.3743	293	0.00015	67.01		
r, 1.50; percent fuel, 20.50; Q/F, 3.879									
4000	706.24	3441.1	1.268	0.5014	1385	0.00081	1.07	0.530	106.9
3600	430.53	3241.7	1.272	0.4955	1189	0.00075	1.04	0.838	169.9
3200	249.30	3044.8	1.277	0.4888	1089	0.00068	1.33	1.057	213.0
2800	135.43	2850.5	1.283	0.4809	986	0.00060	1.61	1.233	249.0
2400	67.83	2666.0	1.291	0.4710	878	0.00053	2.32	1.387	279.6
2000	30.528	2474.5	1.301	0.4582	764	0.00045	3.82	1.519	306.4
1600	11.856	2294.4	1.317	0.4412	643	0.00037	6.05	1.636	329.9
1200	3.696	2123.2	1.339	0.4190	513	0.00028	13.52	1.709	345.7
900	1.219	1959.4	1.381	0.4002	407	0.00021	29.44	1.786	360.2
600	0.274	1881.9	1.383	0.3831	291	0.00015	63.57		
r, 1.60; percent fuel, 21.57; Q/F, 3.638									
4000	786.30	3607.4	1.268	0.5135	1470	0.00082	1.15	0.463	93.6
3600	466.93	3403.2	1.272	0.5075	1176	0.00076	1.02	0.808	162.2
3200	270.26	3201.6	1.277	0.5005	1078	0.00069	1.28	1.032	208.8
2800	146.77	3008.9	1.283	0.4923	976	0.00061	1.68	1.217	246.1
2400	73.482	2808.0	1.291	0.4821	869	0.00054	2.14	1.384	279.7
2000	35.83	2607.7	1.300	0.4709	757	0.00047	3.55	1.509	305.2
1600	12.809	2403.3	1.317	0.4524	638	0.00037	5.78	1.629	329.4
1200	4.003	2257.3	1.339	0.4286	509	0.00029	12.76	1.709	345.7
900	1.320	2131.6	1.361	0.4094	405	0.00022	27.65	1.789	360.4
600	0.297	2011.4	1.383	0.3920	290	0.00015	70.68		
r, 1.80; percent fuel, 23.63; Q/F, 3.232									
4000	949.09	3853.8	1.268	0.5371	1544	0.00085	1.24	0.418	86.0
3600	578.65	3740.2	1.273	0.5306	1154	0.00078	1.00	0.693	140.1
3200	338.21	3529.2	1.278	0.5232	1059	0.00070	1.28	0.961	194.2
2800	182.25	3321.9	1.284	0.5144	959	0.00063	1.64	1.165	235.4
2400	91.383	3118.2	1.292	0.5036	855	0.00055	2.14	1.333	269.7
2000	41.197	2919.4	1.302	0.4917	746	0.00047	3.44	1.480	299.1
1600	16.039	2727.0	1.318	0.4713	629	0.00037	5.90	1.607	324.7
1200	5.017	2543.1	1.341	0.4475	504	0.00030	10.81	1.692	341.9
900	1.659	2411.8	1.362	0.4276	401	0.00023	23.30	1.692	341.9
600	0.374	2286.3	1.384	0.4099	288	0.00016	65.93	1.769	357.3

(e) Percent fluorine in oxidant by weight, 70.37

Temperature, T, °K	Static pressure, P, lb/sq in. abs	Enthalpy, h, cal/g	Isentropic exponent, γ	Specific heat, C_p , cal/(°K)	Absolute viscosity, μ , micro-poise	Thermal conductivity, k , cal/(cm)(sec)(°K)	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I, lb-sec/lb
r, 1.40; percent fuel, 17.22; Q/F, 4.809									
4400	730.04	3266.7	1.292	0.4606	1593	0.00094	1.20	0.440	91.1
3600	479.98	3073.2	1.297	0.4532	1478	0.00087	1.00	0.749	155.2
3200	303.43	2908.0	1.300	0.4458	1361	0.00079	1.28	0.962	199.2
2800	182.83	2722.8	1.305	0.4383	1239	0.00071	1.64	1.165	235.4
2400	103.78	2546.1	1.312	0.4303	1124	0.00063	2.14	1.333	269.7
2000	54.588	2378.0	1.320	0.4218	1007	0.00055	2.85	1.480	299.1
1600	20.745	2202.6	1.331	0.4129	850	0.00047	4.40	1.607	324.7
1200	7.445	2037.7	1.347	0.4047	709	0.00038	6.20	1.521	315.1
900	3.605	1879.4	1.369	0.3865	560	0.00029	13.00	1.623	336.3
600	0.864	1765.6	1.389	0.3720	440	0.00022	26.61	1.692	350.7
	0.308	1655.9	1.407	0.3602	312	0.00015	70.88	1.759	364.0
r, 1.50; percent fuel, 18.22; Q/F, 4.488									
4400	771.99	3413.6	1.291	0.4723	1573	0.00095	1.32	0.384	79.9
3600	506.72	3219.4	1.295	0.4651	1440	0.00080	1.00	0.728	150.2
3200	319.27	3039.8	1.299	0.4578	1329	0.00070	1.28	0.944	196.3
2800	192.27	2856.1	1.304	0.4502	1225	0.00072	1.64	1.180	233.0
2400	108.91	2675.0	1.310	0.4421	1102	0.00064	2.14	1.277	264.2
2000	57.15	2497.0	1.318	0.4340	974	0.00057	2.85	1.401	291.4
1600	21.117	2324.8	1.329	0.4258	841	0.00047	4.40	1.517	315.0
1200	7.743	2154.2	1.345	0.4144	702	0.00038	6.04	1.621	337.2
900	3.711	1992.0	1.368	0.3957	555	0.00029	12.69	1.692	351.9
600	0.915	1875.6	1.388	0.3806	437	0.00022	26.03	1.692	351.9
	0.315	1763.3	1.406	0.3685	309	0.00016	69.48	1.757	365.5
r, 1.80; percent fuel, 19.30; Q/F, 4.208									
4400	828.45	3564.9	1.289	0.4837	1554	0.00096	1.42	0.326	61.7
3600	542.17	3372.1	1.293	0.4762	1423	0.00081	1.00	0.684	142.0
3200	320.47	3194.0	1.298	0.4687	1329	0.00072	1.28	0.919	191.7
2800	192.20	2994.0	1.303	0.4610	1211	0.00073	1.60	1.108	229.9
2400	116.20	2808.6	1.309	0.4537	1090	0.00065	2.14	1.255	262.2
2000	60.878	2626.4	1.317	0.4458	964	0.00057	2.94	1.391	290.2
1600	28.834	2448.3	1.328	0.4378	833	0.00048	4.35	1.501	315.0
1200	11.875	2275.6	1.344	0.4240	696	0.00039	5.81	1.616	337.2
900	5.963	2109.7	1.367	0.4047	550	0.00030	12.20	1.688	352.2
600	1.386	1990.7	1.387	0.3892	433	0.00023	25.06	1.688	352.2
	0.333	1875.9	1.405	0.3767	307	0.00016	66.97	1.758	366.1
r, 1.70; percent fuel, 20.18; Q/F, 3.980									
4400	901.95	3720.8	1.289	0.4950	1537	0.00097	1.51	0.278	52.4
3600	580.64	3523.8	1.293	0.4877	1427	0.00090	1.01	0.635	132.5
3200	371.81	3339.0	1.297	0.4801	1315	0.00082	1.01	0.887	185.2
2800	223.04	3136.7	1.302	0.4727	1199	0.00074	1.07	1.080	225.4
2400	128.01	2947.1	1.308	0.4651	1079	0.00066	1.37	1.240	258.8
2000	65.947	2760.8	1.317	0.4570	955	0.00057	1.95	1.379	287.8
1600	31.201	2578.7	1.328	0.4490	826	0.00049	3.09	1.501	313.4
1200	12.835	2402.1	1.344	0.4333	690	0.00039	5.51	1.610	336.1
900	4.279	2238.6	1.366	0.4135	546	0.00030	11.57	1.684	351.5
600	1.494	2111.0	1.386	0.3977	431	0.00023	23.75	1.684	351.5
	0.358	1993.7	1.404	0.3850	306	0.00016	63.51	1.752	365.7

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TABLE III. - Continued. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED EXIT TEMPERATURES FOR LIQUID

METHANE WITH SEVERAL FLUORINE-OXYGEN MIXTURES

[Frozen composition assumed during isentropic expansion or compression from combustion-chamber pressure of 600 lb/sq in. abs.]

(f) Percent fluorine in oxidant by weight, 78.08

Temperature, T, °K	Static pressure, P, lb/sq in. abs.	Enthalpy, h, cal/g	Isentropic exponent, γ	Specific heat, c_p , cal/(g)(°K)	Absolute viscosity, μ , micro-poise	Thermal conductivity, k , cal/(cm)(sec)(°K)	Area ratio, τ	Thrust coefficient, C_F	Specific impulse, I_{sp} , lb-sec/lb
r, 1.85; percent fuel, 17.85; O/F, 4.897									
4400	641.13	3748.4	1.302	0.4606	1638	0.00099	-----	-----	-----
4000	426.10	3165.1	1.306	0.4560	1536	0.00091	1.07	0.548	115.1
3600	272.54	2883.7	1.311	0.4510	1411	0.00083	1.09	0.808	170.4
3200	186.34	2684.4	1.316	0.4453	1283	0.00074	1.20	1.095	211.3
2800	95.771	2453.7	1.322	0.4383	1152	0.00065	1.37	1.434	254.7
2400	51.182	2233.6	1.331	0.4304	1016	0.00057	2.25	1.891	277.0
2000	24.473	2023.3	1.348	0.4197	875	0.00048	3.53	1.412	299.9
1600	10.473	1818.4	1.358	0.4083	727	0.00039	5.27	1.521	308.2
1200	3.600	1659.5	1.380	0.3888	529	0.00030	12.50	1.618	313.7
900	1.291	1485.1	1.399	0.3745	449	0.00233	25.59	1.688	317.9
r, 1.60; percent fuel, 16.02; O/F, 4.551									
4400	665.55	3419.7	1.302	0.4661	1650	0.00099	-----	-----	-----
4000	440.71	3234.2	1.306	0.4613	1529	0.00091	1.10	0.516	109.7
3600	281.71	3050.7	1.310	0.4563	1405	0.00083	1.01	0.787	167.3
3200	186.71	2869.3	1.315	0.4513	1278	0.00074	1.12	1.084	209.8
2800	98.847	2659.4	1.322	0.4437	1147	0.00065	1.30	1.414	251.2
2400	52.784	2451.4	1.330	0.4353	1011	0.00058	2.21	1.885	273.8
2000	25.543	2242.8	1.341	0.4265	871	0.00049	3.47	1.408	299.3
1600	10.473	2034.8	1.354	0.4150	718	0.00040	5.27	1.518	308.2
1200	3.702	1824.8	1.380	0.3926	570	0.00030	12.50	1.604	313.7
900	1.287	1619.9	1.399	0.3787	447	0.00233	25.59	1.684	317.9
r, 1.65; percent fuel, 16.45; O/F, 4.413									
4400	713.12	3507.6	1.298	0.4723	1632	0.00099	-----	-----	-----
4000	478.09	3319.6	1.303	0.4673	1512	0.00091	1.13	0.456	96.5
3600	310.70	3132.7	1.307	0.4621	1390	0.00083	1.00	0.753	159.7
3200	187.72	2945.9	1.312	0.4568	1264	0.00074	1.04	1.037	202.0
2800	104.79	2759.0	1.319	0.4491	1135	0.00066	1.20	1.393	249.7
2400	55.666	2571.9	1.327	0.4405	1001	0.00058	2.14	1.875	269.7
2000	26.900	2384.9	1.337	0.4307	863	0.00049	3.37	1.401	296.4
1600	11.250	2197.9	1.354	0.4180	718	0.00040	5.27	1.518	308.2
1200	3.702	2010.8	1.380	0.3969	565	0.00030	12.50	1.615	314.5
900	1.287	1823.8	1.399	0.3827	444	0.00233	25.59	1.684	317.9
600	0.335	1636.8	1.418	0.3719	313	0.0016	67.64	1.748	328.0

(g) Percent fluorine in oxidant by weight, 79.87

Temperature, T, °K	Static pressure, P, lb/sq in. abs.	Enthalpy, h, cal/g	Isentropic exponent, γ	Specific heat, c_p , cal/(g)(°K)	Absolute viscosity, μ , micro-poise	Thermal conductivity, k , cal/(cm)(sec)(°K)	Area ratio, τ	Thrust coefficient, C_F	Specific impulse, I_{sp} , lb-sec/lb
r, 1.48; percent fuel, 16.85; O/F, 5.005									
4800	857.06	3404.5	1.301	0.4544	1808	0.00106	-----	-----	-----
4400	589.77	3224.1	1.306	0.4498	1686	0.00098	3.66	0.184	26.3
4000	393.28	3048.6	1.310	0.4450	1562	0.00090	1.03	0.600	127.6
3600	252.88	2873.2	1.315	0.4401	1434	0.00082	1.04	0.837	177.9
3200	154.68	2693.3	1.321	0.4347	1304	0.00074	1.23	1.174	218.4
2800	89.437	2518.5	1.328	0.4283	1169	0.00065	1.43	1.470	248.8
2400	43.379	2348.4	1.337	0.4200	1031	0.00057	2.33	1.933	276.9
2000	19.936	2182.3	1.348	0.4100	887	0.00048	3.66	1.420	301.9
1600	7.439	2020.3	1.361	0.3966	737	0.00040	5.27	1.518	314.5
1200	2.447	1862.7	1.383	0.3797	579	0.00030	13.08	1.621	324.5
900	0.847	1709.9	1.407	0.3658	454	0.00233	26.15	1.688	328.4
600	0.309	1567.5	1.431	0.3527	320	0.0016	67.64	1.747	331.3
r, 1.51; percent fuel, 16.94; O/F, 4.904									
4800	870.94	3446.5	1.301	0.4577	1803	0.00106	-----	-----	-----
4400	599.02	3264.4	1.305	0.4527	1681	0.00098	1.49	0.184	26.3
4000	399.84	3084.2	1.309	0.4482	1557	0.00090	1.04	0.600	127.6
3600	256.84	2905.9	1.314	0.4433	1430	0.00082	1.03	0.831	176.8
3200	159.79	2729.7	1.320	0.4379	1300	0.00074	1.23	1.174	218.4
2800	90.689	2555.8	1.325	0.4313	1166	0.00066	1.43	1.470	248.8
2400	48.688	2384.8	1.333	0.4235	1028	0.00057	2.31	1.933	276.9
2000	21.652	2217.7	1.345	0.4139	888	0.00048	3.67	1.420	301.9
1600	10.035	2054.5	1.360	0.4027	733	0.00040	5.27	1.518	314.5
1200	3.473	1898.5	1.383	0.3823	578	0.00030	13.08	1.621	324.5
900	1.252	1748.9	1.407	0.3685	454	0.00233	26.15	1.688	328.4
600	0.309	1607.5	1.432	0.3557	320	0.0016	67.64	1.747	331.3

(h) Percent fluorine in oxidant by weight, 80.18

Temperature, T, °K	Static pressure, P, lb/sq in. abs.	Enthalpy, h, cal/g	Isentropic exponent, γ	Specific heat, c_p , cal/(g)(°K)	Absolute viscosity, μ , micro-poise	Thermal conductivity, k , cal/(cm)(sec)(°K)	Area ratio, τ	Thrust coefficient, C_F	Specific impulse, I_{sp} , lb-sec/lb
r, 1.46; percent fuel, 16.40; O/F, 5.098									
4800	838.04	3769.2	1.302	0.4511	1817	0.00106	-----	-----	-----
4400	577.23	3589.8	1.307	0.4462	1694	0.00098	2.48	0.186	27.5
4000	385.31	3419.8	1.311	0.4418	1569	0.00090	1.02	0.614	130.4
3600	247.60	3256.4	1.315	0.4370	1441	0.00082	1.04	0.846	179.7
3200	151.89	3098.6	1.320	0.4317	1305	0.00074	1.24	1.024	217.8
2800	81.934	2945.9	1.326	0.4259	1174	0.00066	1.44	1.305	249.7
2400	47.280	2798.6	1.335	0.4174	1038	0.00057	2.35	1.785	276.9
2000	23.055	2656.2	1.346	0.4078	890	0.00048	3.69	1.432	302.3
1600	8.816	2517.7	1.360	0.3973	740	0.00040	5.27	1.527	314.5
1200	3.404	2384.9	1.384	0.3854	581	0.00030	13.08	1.631	324.5
900	1.230	2259.7	1.403	0.3728	456	0.00233	26.15	1.688	328.4
600	0.307	2142.0	1.429	0.3606	321	0.0016	67.77	1.746	331.3
r, 1.42; percent fuel, 16.89; O/F, 5.029									
4800	845.74	3392.2	1.302	0.4533	1813	0.00106	-----	-----	-----
4400	582.33	3212.3	1.306	0.4484	1691	0.00098	2.80	0.163	34.7
4000	390.60	3038.9	1.310	0.4439	1568	0.00090	1.03	0.608	129.4
3600	249.60	2868.8	1.315	0.4391	1446	0.00082	1.04	0.846	179.7
3200	153.05	2699.2	1.320	0.4337	1307	0.00074	1.24	1.028	217.8
2800	88.387	2534.0	1.326	0.4273	1172	0.00065	1.44	1.305	249.7
2400	48.387	2372.6	1.334	0.4199	1033	0.00057	2.34	1.785	276.9
2000	23.177	2214.8	1.344	0.4108	889	0.00048	3.64	1.430	302.3
1600	9.970	2060.7	1.362	0.3997	739	0.00040	5.44	1.528	314.5
1200	3.420	1909.7	1.384	0.3889	580	0.00030	13.12	1.631	324.5
900	1.235	1762.0	1.403	0.3783	458	0.00233	26.18	1.688	328.4
600	0.308	1618.8	1.429	0.3661	321	0.0016	67.77	1.746	331.3
r, 1.50; percent fuel, 16.77; O/F, 4.982									
4800	855.64	3429.3	1.301	0.4557	1808	0.00106	-----	-----	-----
4400	595.41	3248.2	1.305	0.4507	1686	0.00098	3.43	0.183	27.6
4000	395.86	3073.9	1.309	0.4462	1562	0.00090	1.03	0.600	127.6
3600	254.53	2905.9	1.314	0.4413	1434	0.00082	1.04	0.833	177.7
3200	155.94	2743.9	1.320	0.4359	1303	0.00074	1.23	1.171	218.4
2800	90.114	2587.2	1.328	0.4294	1169	0.00066	1.43	1.469	248.8
2400	48.329	2434.8	1.337	0.4214	1031	0.00057	2.32	1.930	276.9
2000	23.129	2286.6	1.348	0.4114	886	0.00048	3.65	1.428	301.9
1600	9.938	2142.8	1.361	0.3995	737	0.00040	5.26	1.526	314.5
1200	3.455	2003.4	1.383	0.3886	579	0.00030	13.05	1.621	324.5
900	1.246	1868.4	1.407	0.3774	454	0.00233	26.09	1.688	328.4
600	0.310	1737.6	1.431	0.3656	320	0.0016	67.56	1.747	331.3

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TABLE III. - Concluded. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED EXIT TEMPERATURES FOR LIQUID

METHANE WITH SEVERAL FLUORINE-OXYGEN MIXTURES

[Frozen composition assumed during isentropic expansion or compression from combustion-chamber pressure of 600 lb/sq in. abs.]

(i) Percent fluorine in oxidant weight, 81.46

Temperature, T, °K	Static 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 _p	Specific impulse, I, lb-sec/lb
r, 1.38; percent fuel, 15.45; O/F, 5.471									
4800	791.82	3245.5	1.306	0.4394	1843	0.00105	---	---	---
4400	546.69	3070.7	1.310	0.4347	1718	0.0097	1.68	0.287	60.9
4000	366.16	2927.7	1.314	0.4304	1591	0.0089	1.01	0.646	137.0
3600	236.85	2797.4	1.318	0.4259	1461	0.0081	1.05	0.866	183.5
3200	145.43	2677.1	1.324	0.4207	1327	0.0073	1.27	1.037	230.0
2800	85.73	2570.0	1.330	0.4146	1200	0.0065	1.67	1.184	280.9
2400	45.737	2485.6	1.338	0.4070	1049	0.0056	2.40	1.312	327.9
2000	22.7391	2426.7	1.349	0.3972	903	0.0047	3.75	1.426	362.1
1600	9.588	2391.1	1.365	0.3844	749	0.0038	6.53	1.528	383.8
1200	3.345	2375.5	1.387	0.3683	589	0.0029	13.24	1.621	393.4
900	1.215	2388.9	1.406	0.3559	461	0.0022	26.28	1.685	397.0
600	0.305	2434.6	1.422	0.3468	325	0.0015	67.62	1.744	399.6
r, 1.40; percent fuel, 15.64; O/F, 5.393									
4800	794.70	3270.3	1.305	0.4416	1839	0.00105	---	---	---
4400	548.87	3094.7	1.309	0.4369	1715	0.0097	1.71	0.281	59.6
4000	367.45	2952.8	1.314	0.4326	1588	0.0089	1.01	0.644	136.7
3600	236.87	2820.7	1.318	0.4280	1458	0.0081	1.05	0.865	183.5
3200	145.80	2697.5	1.323	0.4228	1325	0.0073	1.27	1.037	230.2
2800	85.739	2590.0	1.329	0.4166	1198	0.0065	1.67	1.184	280.9
2400	45.739	2505.4	1.338	0.4090	1047	0.0056	2.39	1.311	327.8
2000	22.7391	2446.7	1.349	0.3991	900	0.0048	3.75	1.426	362.5
1600	9.588	2410.6	1.365	0.3862	748	0.0039	6.53	1.528	384.4
1200	3.345	2395.2	1.387	0.3701	587	0.0029	13.24	1.621	394.1
900	1.215	2408.0	1.406	0.3575	460	0.0022	26.31	1.685	397.6
600	0.305	2454.3	1.421	0.3484	324	0.0015	67.57	1.745	399.2
r, 1.42; percent fuel, 15.83; O/F, 5.317									
4800	808.31	3300.7	1.304	0.4440	1835	0.00105	---	---	---
4400	557.70	3124.1	1.308	0.4391	1711	0.0097	1.86	0.255	54.1
4000	378.96	2982.9	1.312	0.4348	1584	0.0089	1.01	0.635	134.7
3600	240.14	2850.3	1.317	0.4302	1458	0.0081	1.05	0.859	182.2
3200	147.63	2727.3	1.322	0.4249	1325	0.0073	1.26	1.033	229.2
2800	85.7382	2620.5	1.328	0.4187	1198	0.0065	1.66	1.181	277.8
2400	45.739	2535.8	1.337	0.4110	1044	0.0056	2.40	1.312	327.8
2000	22.7391	2476.8	1.348	0.4010	898	0.0048	3.73	1.425	362.2
1600	9.588	2440.5	1.364	0.3880	746	0.0039	6.52	1.528	384.2
1200	3.345	2425.1	1.386	0.3717	586	0.0029	13.23	1.621	394.0
900	1.217	2438.5	1.405	0.3591	459	0.0022	26.33	1.685	397.5
600	0.305	2484.3	1.420	0.3498	323	0.0015	67.78	1.745	399.2

(j) Percent fluorine in oxidant by weight, 82.61

Temperature, T, °K	Static 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 _p	Specific impulse, I, lb-sec/lb
r, 1.50; percent fuel, 14.53; O/F, 5.882									
4800	767.76	3136.1	1.309	0.4282	1865	0.00103	---	---	---
4400	532.84	2965.8	1.314	0.4236	1739	0.0096	1.51	0.386	68.6
4000	357.73	2823.2	1.318	0.4195	1610	0.0088	1.01	0.661	139.2
3600	231.59	2690.3	1.322	0.4151	1478	0.0080	1.06	0.874	184.9
3200	143.21	2575.1	1.327	0.4102	1343	0.0072	1.27	1.043	230.9
2800	85.739	2478.2	1.334	0.4044	1204	0.0064	1.68	1.188	279.9
2400	45.739	2394.9	1.342	0.3970	1061	0.0056	2.40	1.312	327.4
2000	22.7391	2338.3	1.353	0.3876	913	0.0047	3.73	1.425	360.1
1600	9.588	2302.3	1.369	0.3752	758	0.0038	6.47	1.526	381.5
1200	3.345	2286.9	1.391	0.3598	596	0.0029	13.01	1.618	390.8
900	1.241	2299.0	1.410	0.3480	466	0.0022	26.68	1.681	394.1
600	0.313	2347.0	1.424	0.3395	329	0.0015	68.47	1.740	396.5
r, 1.535; percent fuel, 14.85; O/F, 5.735									
4800	768.12	3174.3	1.308	0.4318	1860	0.00104	---	---	---
4400	532.01	3002.6	1.313	0.4272	1734	0.0096	1.51	0.326	68.9
4000	357.25	2860.5	1.317	0.4231	1606	0.0088	1.01	0.662	139.8
3600	231.04	2728.2	1.321	0.4186	1474	0.0080	1.06	0.875	184.9
3200	142.71	2613.7	1.326	0.4136	1339	0.0072	1.28	1.044	230.6
2800	85.7385	2516.0	1.333	0.4077	1201	0.0064	1.68	1.188	279.9
2400	45.739	2433.7	1.341	0.4003	1058	0.0056	2.41	1.314	327.6
2000	22.7391	2377.1	1.352	0.3907	910	0.0047	3.75	1.426	361.4
1600	9.588	2341.6	1.368	0.3783	756	0.0038	6.52	1.528	382.8
1200	3.345	2326.3	1.390	0.3627	594	0.0029	13.14	1.619	392.2
900	1.225	2339.3	1.409	0.3506	465	0.0022	26.97	1.683	395.6
600	0.309	2387.0	1.423	0.3420	328	0.0015	68.33	1.742	398.0
r, 1.40; percent fuel, 15.48; O/F, 5.462									
4800	806.40	3271.4	1.303	0.4401	1839	0.00104	---	---	---
4400	555.98	3096.3	1.308	0.4353	1714	0.0097	1.82	0.260	54.9
4000	371.52	2954.1	1.312	0.4309	1587	0.0089	1.01	0.637	134.5
3600	239.03	2821.6	1.316	0.4263	1457	0.0081	1.05	0.861	181.7
3200	146.82	2698.2	1.321	0.4211	1324	0.0073	1.26	1.035	228.6
2800	85.739	2600.9	1.328	0.4149	1187	0.0064	1.67	1.182	278.6
2400	45.739	2513.6	1.336	0.4072	1044	0.0056	2.39	1.310	327.9
2000	22.7391	2456.4	1.347	0.3974	899	0.0047	3.76	1.426	361.0
1600	9.588	2420.9	1.363	0.3845	747	0.0038	6.57	1.529	382.9
1200	3.319	2405.3	1.385	0.3683	586	0.0029	13.36	1.623	392.6
900	1.201	2418.7	1.404	0.3559	459	0.0022	26.64	1.687	395.1
600	0.300	2466.4	1.419	0.3468	323	0.0015	68.75	1.747	398.7
r, 1.50; percent fuel, 16.40; O/F, 5.082									
4400	602.71	3241.7	1.300	0.4481	1671	0.0096	---	---	---
4000	399.54	3063.4	1.304	0.4434	1547	0.0089	1.04	0.588	123.8
3600	254.86	2887.0	1.308	0.4384	1421	0.0081	1.03	0.832	175.2
3200	155.10	2712.8	1.314	0.4329	1291	0.0073	1.23	1.017	214.1
2800	89.020	2540.9	1.320	0.4263	1158	0.0064	1.63	1.172	264.6
2400	47.411	2471.9	1.328	0.4182	1021	0.0056	2.36	1.306	314.8
2000	23.833	2416.5	1.339	0.4078	878	0.0047	3.74	1.427	359.9
1600	9.588	2381.1	1.355	0.3943	730	0.0038	6.61	1.531	382.3
1200	3.287	2394.7	1.377	0.3774	573	0.0029	13.66	1.627	384.5
900	1.172	2440.4	1.396	0.3643	449	0.0022	27.62	1.693	386.3

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TABLE IV. - THEORETICAL ROCKET PERFORMANCE FOR PRESSURE RATIOS FROM 1 TO 300
FOR LIQUID METHANE WITH SEVERAL FLUORINE-OXYGEN MIXTURES

[Frozen composition assumed during isentropic expansion from
combustion-chamber pressure of 600 lb/sq in. abs.]

(a) Percent fluorine in oxidant, 0 (100 percent oxygen)

Pressure ratio, P_c/P	Static pressure, P , lb/sq in. abs.	Temperature, T_c , °K	Enthalpy, h , cal/g	Specific heat, c_p , cal/(g)(°K)	Isentropic exponent, γ	Area ratio, A	Thrust coefficient, C_F	Specific impulse, I_s , lb-sec/lb
r, 1.00; percent fuel, 20.04; O/F, 3.980								
1.000	600.00	3497	2646.8	0.513	1.201	2.398	0.181	32.1
1.040	576.92	3474	2633.9	.519	1.203	2.398	.565	100.0
1.478	405.84	3275	2530.8	.515	1.203	1.000	.679	120.2
1.774	336.20	3175	2479.7	.513	1.204	1.000	.792	140.4
2.218	270.56	3057	2419.3	.511	1.205	1.031	.792	140.4
10.000	60.00	2355	2066.8	.492	1.215	2.24	1.267	234.4
20.000	30.00	2081	1933.4	.482	1.220	3.57	1.405	249.0
20.414	29.392	2073	1929.7	.481	1.220	3.62	1.409	249.6
40.000	15.00	1834	1815.6	.471	1.226	5.82	1.517	268.8
40.827	14.696	1827	1812.3	.470	1.227	5.91	1.520	269.3
60.000	10.00	1700	1753.4	.464	1.231	7.81	1.573	278.7
100.000	6.00	1544	1681.4	.454	1.237	11.37	1.635	289.7
300.000	2.00	1245	1548.7	.433	1.251	25.79	1.744	309.0
r, 1.50; percent fuel, 24.58; O/F, 3.069								
1.000	600.00	3444	3237.1	0.565	1.207	2.402	0.182	33.7
1.040	576.92	3421	3224.1	.564	1.207	2.402	.567	105.0
1.481	405.90	3219	3110.3	.560	1.209	1.000	.682	127.1
1.778	337.50	3119	3054.6	.558	1.210	1.000	.794	147.1
2.222	270.00	3000	2988.5	.555	1.211	1.030	.794	147.1
10.000	60.00	2296	2605.1	.533	1.222	2.23	1.266	234.5
20.000	30.00	2023	2460.4	.522	1.228	3.54	1.404	260.0
20.414	29.392	2014	2456.4	.521	1.228	3.59	1.407	260.6
40.000	15.00	1775	2332.2	.509	1.235	5.76	1.514	280.5
40.827	14.696	1768	2329.7	.508	1.235	5.84	1.517	281.0
60.000	10.00	1643	2266.2	.501	1.240	7.71	1.570	290.7
100.000	6.00	1487	2188.9	.490	1.246	11.19	1.631	302.0
300.000	2.00	1190	2047.1	.465	1.263	25.21	1.738	321.8
r, 1.40; percent fuel, 25.88; O/F, 2.850								
1.000	600.00	3372	3419.6	0.578	1.210	2.405	0.182	33.9
1.040	576.92	3349	3406.4	.577	1.210	2.405	.568	105.9
1.483	404.48	3148	3290.7	.573	1.213	1.032	.682	127.1
1.780	337.07	3049	3234.0	.571	1.214	1.000	.795	148.3
2.225	269.66	2931	3167.0	.568	1.215	1.030	.795	148.3
10.000	60.00	2235	2779.5	.544	1.226	2.22	1.266	236.0
20.000	30.00	1964	2633.6	.532	1.233	3.52	1.403	261.3
20.414	29.392	1956	2629.5	.532	1.233	3.57	1.406	262.2
40.000	15.00	1720	2505.6	.518	1.240	5.71	1.513	282.0
40.827	14.696	1713	2502.0	.518	1.240	5.80	1.516	282.6
60.000	10.00	1589	2438.3	.510	1.245	7.64	1.567	292.2
100.000	6.00	1435	2360.8	.498	1.252	11.08	1.628	303.5
300.000	2.00	1144	2219.1	.472	1.270	24.86	1.734	323.2
r, 1.50; percent fuel, 27.32; O/F, 2.660								
1.000	600.00	3272	3595.5	0.590	1.215	2.407	0.182	34.0
1.040	576.92	3249	3582.2	.589	1.215	2.407	.570	106.6
1.486	403.85	3050	3465.2	.584	1.217	1.032	.683	127.6
1.783	336.54	2952	3408.2	.582	1.218	1.000	.797	148.6
2.229	269.23	2836	3341.0	.578	1.219	1.030	.797	148.6
10.000	60.00	2152	2953.1	.554	1.232	2.21	1.265	236.4
20.000	30.00	1886	2807.5	.541	1.239	3.49	1.402	261.8
20.414	29.392	1879	2803.5	.540	1.239	3.54	1.405	262.8
40.000	15.00	1647	2680.1	.526	1.247	5.66	1.511	282.2
40.827	14.696	1641	2676.6	.525	1.247	5.75	1.514	282.8
60.000	10.00	1519	2613.3	.517	1.252	7.56	1.565	292.3
100.000	6.00	1369	2536.3	.505	1.260	10.94	1.625	303.5
300.000	2.00	1084	2396.7	.478	1.279	24.43	1.729	323.0
r, 1.60; percent fuel, 28.62; O/F, 2.483								
1.000	600.00	3147	3765.0	0.600	1.220	2.411	0.182	34.0
1.040	576.92	3125	3751.7	.599	1.220	2.411	.572	106.6
1.488	403.10	2929	3634.5	.594	1.222	1.000	.685	127.7
1.786	335.91	2833	3577.7	.592	1.223	1.000	.798	148.7
2.233	268.73	2719	3510.8	.588	1.225	1.030	.798	148.7
10.000	60.00	2052	3126.3	.562	1.238	2.20	1.265	235.8
20.000	30.00	1782	2982.4	.548	1.246	3.47	1.400	261.6
20.414	29.392	1775	2978.5	.547	1.246	3.52	1.403	262.6
40.000	15.00	1560	2857.0	.532	1.255	5.60	1.509	281.1
40.827	14.696	1554	2853.5	.531	1.255	5.68	1.511	281.6
60.000	10.00	1436	2791.4	.522	1.261	7.47	1.562	291.1
100.000	6.00	1290	2716.2	.509	1.268	10.77	1.621	302.1
300.000	2.00	1015	2572.8	.482	1.289	23.93	1.723	321.1
r, 1.80; percent fuel, 31.09; O/F, 2.216								
1.000	600.00	2855	4086.6	0.618	1.231	2.419	0.183	33.6
1.040	576.92	2834	4073.6	.618	1.231	2.419	.576	105.7
1.493	401.85	2646	3958.1	.611	1.235	1.000	.689	128.4
1.794	331.48	2556	3903.0	.608	1.236	1.000	.802	147.0
2.242	267.57	2449	3838.1	.604	1.238	1.029	.802	147.0
10.000	60.00	1824	3469.2	.574	1.254	2.17	1.264	231.8
20.000	30.00	1582	3332.2	.557	1.264	3.40	1.397	255.2
20.414	29.392	1575	3328.7	.557	1.264	3.45	1.400	256.8
40.000	15.00	1366	3210.4	.540	1.275	5.54	1.505	274.1
40.827	14.696	1360	3210.4	.539	1.275	5.54	1.505	274.1
60.000	10.00	1250	3152.1	.529	1.281	7.25	1.565	285.2
100.000	6.00	1116	3081.9	.516	1.291	10.40	1.612	295.7
300.000	2.00	865	2956.0	.489	1.312	22.82	1.710	313.6

TABLE IV. - Continued. THEORETICAL ROCKET PERFORMANCE FOR PRESSURE RATIOS FROM 1 TO 300

FOR LIQUID METHANE WITH SEVERAL FLUORINE-OXYGEN MIXTURES

[Frozen composition assumed during isentropic expansion from combustion-chamber pressure of 600 lb/sq in. abs.]

(b) Percent fluorine in oxidant by weight, 19.19

Pressure ratio, P _c /P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Specific heat, c _p , cal/(g)(°K)	Isentropic exponent, γ	Area ratio, s	Thrust coefficient, C _F	Specific impulse, I, lb-sec/lb
r, 1.20; percent fuel, 21.10; O/F, 3.740								
1.000	600.00	3522	3017.6	0.521	1.224	-----	0.183	34.3
1.040	576.92	3596	3000.4	.521	1.224	2.414	.573	107.6
1.490	402.55	3366	2884.6	.517	1.226	1.032	.688	128.6
1.798	335.46	3254	2827.1	.515	1.228	1.000	.801	149.9
2.236	268.37	3122	2759.2	.512	1.229	1.030	.801	149.9
10.000	60.00	2349	2370.5	.492	1.241	2.19	1.265	237.3
20.000	30.00	2050	2225.3	.481	1.247	3.46	1.400	262.6
20.414	29.392	2042	2221.3	.481	1.248	3.50	1.403	263.2
40.000	15.00	1784	2093.7	.469	1.255	5.58	1.507	282.8
40.827	14.696	1777	2093.2	.469	1.256	5.66	1.507	283.3
60.000	10.00	1642	2032.4	.462	1.261	7.44	1.555	292.8
100.000	6.00	1476	1956.5	.452	1.268	10.74	1.620	303.9
300.000	2.00	1163	1818.8	.429	1.286	23.90	1.722	323.0
r, 1.40; percent fuel, 23.78; O/F, 3.206								
1.000	600.00	3536	3359.2	0.548	1.227	-----	0.183	34.9
1.040	576.92	3511	3325.2	.548	1.227	2.416	.575	109.7
1.492	402.09	3283	3220.8	.543	1.230	1.031	.687	131.3
1.791	335.07	3173	3159.1	.541	1.231	1.000	.800	152.5
2.238	268.06	3042	3090.7	.538	1.232	1.030	.800	152.5
10.000	60.00	2281	2688.9	.516	1.245	2.18	1.264	241.5
20.000	30.00	1987	2539.0	.504	1.252	3.44	1.399	267.1
20.414	29.392	1979	2534.9	.504	1.252	3.49	1.402	267.8
40.000	15.00	1725	2408.7	.491	1.261	5.55	1.506	287.6
40.827	14.696	1718	2405.1	.490	1.261	5.63	1.509	288.1
60.000	10.00	1586	2340.6	.483	1.266	7.38	1.559	297.7
100.000	6.00	1432	2262.7	.472	1.274	10.64	1.617	308.9
300.000	2.00	1116	2121.8	.447	1.293	23.58	1.718	328.1
r, 1.50; percent fuel, 25.05; O/F, 2.992								
1.000	600.00	3460	3521.4	0.560	1.230	-----	0.183	35.1
1.040	576.92	3435	3507.2	.560	1.230	2.418	.576	110.4
1.494	401.70	3209	3381.4	.555	1.232	1.031	.688	132.0
1.792	334.75	3100	3321.2	.553	1.234	1.000	.801	153.6
2.240	267.80	2971	3250.3	.549	1.235	1.030	.801	153.6
10.000	60.00	2221	2846.2	.526	1.248	2.18	1.264	242.4
20.000	30.00	1932	2695.7	.514	1.256	3.42	1.398	268.0
20.414	29.392	1924	2691.6	.513	1.256	3.47	1.401	268.7
40.000	15.00	1674	2565.1	.500	1.265	5.51	1.505	288.5
40.827	14.696	1667	2561.5	.499	1.265	5.59	1.507	289.0
60.000	10.00	1537	2496.9	.491	1.271	7.34	1.557	298.6
100.000	6.00	1377	2419.1	.480	1.279	10.56	1.615	309.7
300.000	2.00	1076	2278.6	.455	1.299	23.32	1.715	328.8
r, 1.60; percent fuel, 26.28; O/F, 2.805								
1.000	600.00	3362	3678.2	0.571	1.233	-----	0.183	35.1
1.040	576.92	3337	3664.1	.571	1.233	2.420	.577	110.7
1.495	401.21	3115	3537.5	.566	1.236	1.031	.689	132.3
1.795	334.34	3008	3477.2	.563	1.237	1.000	.802	153.8
2.243	267.47	2882	3406.3	.560	1.239	1.029	.802	153.8
10.000	60.00	2146	3002.8	.536	1.253	2.17	1.264	242.4
20.000	30.00	1863	2852.9	.522	1.261	3.41	1.397	268.0
20.414	29.392	1855	2848.8	.522	1.261	3.45	1.401	268.6
40.000	15.00	1611	2723.1	.507	1.270	5.48	1.503	288.3
40.827	14.696	1604	2719.5	.507	1.271	5.55	1.506	288.8
60.000	10.00	1477	2655.5	.498	1.277	7.28	1.555	298.3
100.000	6.00	1320	2578.4	.487	1.285	10.45	1.613	309.4
300.000	2.00	1028	2439.7	.461	1.306	23.00	1.711	328.3
r, 1.80; percent fuel, 28.62; O/F, 2.483								
1.000	600.00	3119	3977.0	0.591	1.242	-----	0.184	34.9
1.040	576.92	3096	3963.0	.590	1.242	2.426	.580	110.3
1.500	399.98	2882	3837.2	.585	1.245	1.031	.692	131.7
1.808	333.31	2780	3777.8	.582	1.246	1.000	.805	153.0
2.250	266.65	2659	3708.1	.578	1.248	1.029	.805	153.0
10.000	60.00	1963	3314.2	.550	1.264	2.15	1.263	240.2
20.000	30.00	1695	3168.6	.535	1.274	3.36	1.395	265.2
20.414	29.392	1687	3164.6	.535	1.274	3.41	1.398	265.9
40.000	15.00	1457	3043.2	.519	1.285	5.38	1.499	285.1
40.827	14.696	1450	3039.8	.519	1.285	5.46	1.502	285.6
60.000	10.00	1331	2978.2	.509	1.292	7.13	1.550	294.8
100.000	6.00	1184	2904.4	.497	1.301	10.20	1.607	305.5
300.000	2.00	912	2772.7	.472	1.322	22.24	1.702	323.7

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TABLE IV. - Continued. THEORETICAL ROCKET PERFORMANCE FOR PRESSURE RATIOS FROM 1 TO 300
FOR LIQUID METHANE WITH SEVERAL FLUORINE-OXYGEN MIXTURES

[Frozen composition assumed during isentropic expansion from
combustion-chamber pressure of 800 lb/sq in. abs.]

(c) Percent fluorine in oxidant by weight, 37.25

Pressure ratio, P_0/P	Static pressure, P , lb/sq in. abs	Temperature, T , °K	Enthalpy, h , cal/g	Specific heat, c_p , cal/(g)(°K)	Isentropic exponent, γ	Area ratio, a	Thrust coefficient, C_F	Specific impulse, I , lb-sec/lb
r, 1.30; percent fuel, 20.36; O/F, 3.913								
1.000	600.00	3753	3145.8	0.503	1.247	---	---	---
1.040	576.92	3724	3131.2	.505	1.247	2.429	0.184	35.7
1.502	399.38	3461	2999.1	.501	1.249	1.031	.582	113.0
1.803	332.81	3337	2937.2	.498	1.251	1.000	.694	134.7
2.254	266.25	3191	2864.4	.496	1.253	1.029	.806	156.5
10.000	60.00	2349	2454.6	.476	1.266	2.14	1.263	245.3
20.000	30.00	2087	2303.2	.465	1.274	3.35	1.394	270.8
20.414	29.392	2018	2299.1	.464	1.274	3.40	1.398	271.4
40.000	15.00	1743	2172.8	.453	1.283	5.37	1.498	291.0
40.827	14.696	1735	2169.2	.452	1.284	5.44	1.501	291.5
60.000	10.00	1592	2105.2	.445	1.290	7.11	1.549	300.9
100.000	6.00	1418	2028.5	.435	1.298	10.18	1.606	311.8
300.000	2.00	1095	1891.1	.414	1.319	22.26	1.701	330.4
r, 1.50; percent fuel, 22.77; O/F, 3.391								
1.000	600.00	3650	3447.2	0.530	1.248	---	---	---
1.040	576.92	3621	3432.2	.530	1.248	2.430	0.184	36.2
1.503	399.14	3364	3296.7	.525	1.251	1.031	.582	114.5
1.804	332.61	3243	3233.2	.523	1.253	1.000	.694	136.5
2.255	266.09	3100	3158.6	.520	1.254	1.029	.806	158.5
10.000	60.00	2277	2739.4	.498	1.269	2.14	1.263	248.2
20.000	30.00	1963	2584.8	.486	1.277	3.34	1.394	273.9
20.414	29.392	1955	2580.5	.486	1.277	3.39	1.397	274.6
40.000	15.00	1686	2451.7	.473	1.287	5.34	1.498	294.3
40.827	14.696	1678	2448.1	.472	1.287	5.42	1.500	294.9
60.000	10.00	1539	2382.8	.465	1.293	7.08	1.548	304.3
100.000	6.00	1369	2304.7	.454	1.302	10.13	1.604	315.3
300.000	2.00	1053	2165.1	.431	1.323	22.07	1.699	334.0
r, 1.80; percent fuel, 23.95; O/F, 3.179								
1.000	600.00	3572	3591.2	0.541	1.250	---	---	---
1.040	576.92	3544	3576.1	.541	1.250	2.431	0.184	36.3
1.504	398.88	3290	3439.6	.536	1.253	1.031	.583	114.8
1.805	332.40	3171	3375.9	.534	1.254	1.000	.695	137.9
2.256	265.92	3030	3301.0	.531	1.256	1.029	.807	158.9
10.000	60.00	2222	2880.7	.508	1.271	2.14	1.263	248.6
20.000	30.00	1913	2725.8	.495	1.280	3.33	1.393	274.4
20.414	29.392	1905	2721.5	.495	1.280	3.38	1.397	275.1
40.000	15.00	1641	2592.7	.481	1.290	5.32	1.497	294.8
40.827	14.696	1633	2589.0	.481	1.290	5.40	1.499	295.3
60.000	10.00	1496	2523.0	.473	1.297	7.04	1.547	304.7
100.000	6.00	1329	2445.8	.462	1.306	10.07	1.603	315.7
300.000	2.00	1021	2306.7	.439	1.328	21.90	1.698	334.3
r, 1.70; percent fuel, 25.05; O/F, 2.992								
1.000	600.00	3479	3730.9	0.552	1.252	---	---	---
1.040	576.92	3451	3715.8	.551	1.253	2.433	0.184	36.3
1.506	398.53	3202	3579.0	.546	1.255	1.030	.584	115.0
1.807	332.11	3085	3515.3	.544	1.257	1.000	.696	137.0
2.258	265.69	2947	3440.5	.541	1.259	1.029	.808	159.0
10.000	60.00	2155	3021.3	.516	1.274	2.13	1.262	248.5
20.000	30.00	1853	2867.1	.503	1.284	3.32	1.393	274.2
20.414	29.392	1845	2862.9	.503	1.284	3.37	1.396	274.8
40.000	15.00	1586	2734.8	.489	1.294	5.30	1.496	294.4
40.827	14.696	1579	2731.2	.488	1.295	5.37	1.498	294.9
60.000	10.00	1446	2666.5	.480	1.301	7.00	1.546	304.3
100.000	6.00	1282	2589.1	.469	1.311	10.00	1.601	315.2
300.000	2.00	982	2451.5	.448	1.332	21.69	1.695	333.6
r, 1.90; percent fuel, 27.19; O/F, 2.677								
1.000	600.00	3258	3998.3	0.571	1.258	---	---	---
1.040	576.92	3231	3983.4	.570	1.259	2.437	0.185	36.0
1.509	397.64	2992	3847.7	.565	1.262	1.030	.585	114.5
1.811	331.37	2881	3784.9	.562	1.264	1.000	.698	136.3
2.263	265.09	2750	3711.3	.558	1.266	1.029	.809	158.0
10.000	60.00	1998	3300.8	.532	1.283	2.12	1.262	248.4
20.000	30.00	1711	3150.3	.517	1.293	3.29	1.392	272.3
20.414	29.392	1703	3146.2	.517	1.294	3.34	1.395	272.9
40.000	15.00	1459	3021.8	.501	1.305	5.23	1.493	291.5
40.827	14.696	1452	3018.3	.501	1.306	5.30	1.495	292.0
60.000	10.00	1325	2955.6	.492	1.313	6.90	1.543	301.2
100.000	6.00	1172	2880.9	.481	1.323	9.82	1.597	311.8
300.000	2.00	890	2748.8	.458	1.344	21.16	1.689	329.7

TABLE IV. - Continued. THEORETICAL ROCKET PERFORMANCE FOR PRESSURE RATIOS FROM 1 TO 300 FOR LIQUID METHANE WITH SEVERAL FLUORINE-OXYGEN MIXTURES

[Frozen composition assumed during isentropic expansion from combustion-chamber pressure of 800 lb/sq in. abs.]

(d) Percent fluorine in oxidant by weight, 54.29

Pressure ratio, P ₀ /P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Specific heat, c _p , cal/(g)(°K)	Isentropic exponent, γ	Area ratio, *	Thrust coefficient, C _F	Specific impulse, I, lb-sec/lb
r, 1.30; percent fuel, 18.26; O/F, 4.475								
1.0000	600.00	3957	3100.6	0.474	1.271	2.444	0.185	36.9
1.0400	576.6	3924	3084.9	0.475	1.271	2.444	0.185	36.9
1.515	339.6	3620	2941.1	0.471	1.274	1.030	0.591	117.8
1.818	330.0	3481	2875.5	0.469	1.276	1.000	0.702	139.9
2.272	264.0	3316	2798.7	0.467	1.278	1.028	0.813	162.1
10.0000	60.00	2388	2373.6	0.448	1.293	2.10	1.261	251.5
20.0000	30.00	2037	2218.4	0.437	1.302	3.25	1.389	277.1
20.414	29.9	2028	2214.2	0.437	1.302	3.30	1.393	277.7
40.0000	15.00	1731	2086.2	0.426	1.313	5.15	1.490	297.1
40.827	14.0	1723	2082.6	0.425	1.313	5.23	1.492	297.6
60.0000	10.00	1571	2018.4	0.419	1.320	6.79	1.539	306.9
100.0000	6.00	1386	1942.0	0.409	1.329	9.65	1.592	317.5
300.0000	2.00	1049	1807.1	0.390	1.351	20.74	1.682	335.5
r, 1.40; percent fuel, 19.40; O/F, 4.156								
1.0000	600.00	3917	3238.7	0.488	1.270	2.444	0.185	37.2
1.0400	576.6	3885	3222.9	0.487	1.270	2.444	0.185	37.2
1.515	339.6	3585	3077.3	0.483	1.273	1.030	0.590	118.5
1.818	330.0	3447	3010.9	0.481	1.275	1.000	0.701	140.8
2.272	264.0	3285	2933.0	0.478	1.277	1.028	0.813	163.1
10.0000	60.00	2366	2502.1	0.459	1.292	2.10	1.261	253.2
20.0000	30.00	2019	2344.7	0.448	1.301	3.25	1.389	278.9
20.414	29.9	2010	2340.5	0.448	1.302	3.30	1.393	279.6
40.0000	15.00	1716	2210.7	0.436	1.312	5.16	1.490	297.1
40.827	14.0	1708	2207.1	0.436	1.313	5.23	1.492	297.6
60.0000	10.00	1557	2141.9	0.429	1.319	6.80	1.539	308.9
100.0000	6.00	1374	2064.4	0.419	1.329	9.66	1.592	319.7
300.0000	2.00	1040	1927.6	0.400	1.351	20.76	1.683	337.8
r, 1.50; percent fuel, 20.50; O/F, 3.879								
1.0000	600.00	3864	3373.1	0.499	1.270	2.444	0.185	37.3
1.0400	576.6	3832	3357.1	0.499	1.270	2.444	0.185	37.3
1.515	339.6	3536	3210.2	0.495	1.273	1.030	0.590	119.1
1.818	330.0	3400	3143.1	0.492	1.275	1.000	0.701	141.5
2.272	264.0	3240	3064.5	0.490	1.277	1.028	0.813	163.9
10.0000	60.00	2334	2629.6	0.469	1.292	2.10	1.261	254.4
20.0000	30.00	1992	2470.8	0.458	1.302	3.25	1.389	280.2
20.414	29.9	1982	2466.4	0.458	1.302	3.30	1.393	280.9
40.0000	15.00	1693	2335.5	0.446	1.313	5.16	1.490	300.5
40.827	14.0	1684	2331.8	0.445	1.313	5.23	1.492	301.0
60.0000	10.00	1536	2266.1	0.438	1.320	6.80	1.539	310.4
100.0000	6.00	1355	2187.8	0.428	1.330	9.66	1.592	321.1
300.0000	2.00	1025	2049.9	0.408	1.351	20.74	1.682	339.3
r, 1.60; percent fuel, 21.57; O/F, 3.636								
1.0000	600.00	3798	3503.9	0.511	1.270	2.444	0.185	37.4
1.0400	576.6	3766	3487.8	0.510	1.270	2.444	0.185	37.4
1.515	339.6	3475	3340.0	0.505	1.274	1.030	0.590	119.4
1.818	330.0	3341	3272.6	0.503	1.275	1.000	0.702	141.9
2.272	264.0	3184	3193.5	0.500	1.277	1.028	0.813	164.3
10.0000	60.00	2293	2756.4	0.479	1.293	2.10	1.261	255.0
20.0000	30.00	1955	2596.8	0.467	1.303	3.25	1.389	280.9
20.414	29.9	1946	2592.5	0.467	1.303	3.30	1.393	281.6
40.0000	15.00	1661	2461.0	0.454	1.314	5.15	1.490	301.2
40.827	14.0	1653	2457.3	0.454	1.314	5.22	1.492	301.8
60.0000	10.00	1506	2391.3	0.447	1.321	6.78	1.539	311.1
100.0000	6.00	1328	2312.8	0.436	1.331	9.64	1.592	321.9
300.0000	2.00	1004	2174.5	0.416	1.353	20.68	1.682	340.1
r, 1.80; percent fuel, 25.63; O/F, 3.232								
1.0000	600.00	3628	3755.1	0.531	1.272	2.446	0.185	37.4
1.0400	576.6	3598	3739.0	0.531	1.273	2.446	0.185	37.4
1.515	339.6	3317	3590.9	0.525	1.276	1.030	0.591	119.5
1.818	330.0	3189	3523.5	0.523	1.278	1.000	0.702	142.0
2.272	264.0	3037	3444.6	0.520	1.280	1.028	0.813	164.4
10.0000	60.00	2181	3008.7	0.496	1.297	2.09	1.261	254.8
20.0000	30.00	1857	2849.9	0.484	1.307	3.24	1.389	280.6
20.414	29.9	1848	2845.6	0.483	1.308	3.28	1.393	281.3
40.0000	15.00	1574	2715.0	0.470	1.319	5.12	1.489	300.8
40.827	14.0	1567	2711.3	0.470	1.319	5.19	1.491	301.4
60.0000	10.00	1426	2645.9	0.462	1.327	6.74	1.537	310.7
100.0000	6.00	1256	2568.1	0.451	1.337	9.56	1.590	321.4
300.0000	2.00	946	2431.4	0.431	1.359	20.46	1.679	339.4

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TABLE IV. - Continued. THEORETICAL ROCKET PERFORMANCE FOR PRESSURE RATIOS FROM 1 TO 300
FOR LIQUID METHANE WITH SEVERAL FLUORINE-OXYGEN MIXTURES

[Frozen composition assumed during isentropic expansion from
combustion-chamber pressure of 600 lb/sq in. abs.]

(e) Percent fluorine in oxidant by weight, 70.37

Pressure ratio, P_0/P	Static pressure, P , lb/sq in. abs	Temperature, T , °K	Enthalpy, h , cal/g	Specific heat, c_p , cal/(g)(°K)	Isentropic exponent, γ	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I , lb-sec/lb
r, 1.40; percent fuel, 17.22; O/F, 4.809								
1.000	600.00	4209	3178.8	0.458	1.294	---	---	---
1.040	576.92	4171	3161.7	.458	1.294	2.459	0.186	38.6
1.527	392.88	3821	3001.9	.454	1.298	1.029	.599	124.1
1.833	327.40	3664	2930.8	.452	1.300	1.000	.709	146.9
2.291	261.92	3480	2847.8	.449	1.302	1.028	.819	169.7
10.000	60.00	2456	2396.3	.431	1.319	2.06	1.260	260.9
20.000	30.00	2073	2233.2	.421	1.329	3.16	1.385	286.8
20.414	29.392	2062	2228.8	.421	1.329	3.20	1.388	287.5
40.000	15.00	1742	2095.8	.410	1.340	4.97	1.482	307.0
40.827	14.696	1733	2092.1	.410	1.341	5.04	1.485	307.5
60.000	10.00	1571	2025.9	.403	1.348	6.51	1.529	316.7
100.000	6.00	1375	1947.6	.395	1.358	9.19	1.580	327.3
300.000	2.00	1022	1811.4	.378	1.381	19.45	1.665	344.9
r, 1.50; percent fuel, 18.22; O/F, 4.488								
1.000	600.00	4157	3299.0	0.469	1.293	---	---	---
1.040	576.92	4120	3281.7	.469	1.293	2.459	0.186	38.8
1.527	393.02	3775	3120.7	.464	1.297	1.029	.599	124.6
1.832	327.52	3620	3049.0	.462	1.299	1.000	.709	147.5
2.290	262.01	3438	2965.3	.460	1.301	1.028	.819	170.4
10.000	60.00	2428	2509.5	.441	1.318	2.06	1.260	262.1
20.000	30.00	2051	2344.8	.431	1.328	3.17	1.385	288.2
20.414	29.392	2040	2340.3	.430	1.328	3.21	1.388	288.8
40.000	15.00	1724	2205.9	.419	1.340	4.97	1.482	308.4
40.827	14.696	1715	2202.2	.419	1.340	5.04	1.485	308.9
60.000	10.00	1554	2135.3	.412	1.347	6.52	1.530	318.2
100.000	6.00	1361	2056.2	.404	1.358	9.20	1.581	328.8
300.000	2.00	1012	1918.5	.386	1.380	19.48	1.666	346.6
r, 1.60; percent fuel, 19.20; O/F, 4.208								
1.000	600.00	4091	3416.3	0.480	1.292	---	---	---
1.040	576.92	4055	3398.9	.479	1.293	2.458	0.186	38.8
1.526	393.08	3716	3237.2	.475	1.296	1.029	.599	124.8
1.832	327.57	3564	3165.1	.473	1.298	1.000	.709	147.8
2.290	262.05	3386	3080.9	.470	1.300	1.028	.819	170.8
10.000	60.00	2392	2622.7	.451	1.317	2.06	1.260	262.8
20.000	30.00	2020	2457.0	.440	1.328	3.17	1.385	288.9
20.414	29.392	2010	2452.5	.439	1.328	3.21	1.388	289.6
40.000	15.00	1698	2317.4	.428	1.340	4.97	1.482	309.2
40.827	14.696	1689	2313.6	.428	1.340	5.04	1.485	309.8
60.000	10.00	1531	2246.4	.421	1.348	6.52	1.530	319.1
100.000	6.00	1340	2166.9	.412	1.358	9.20	1.581	329.7
300.000	2.00	996	2028.4	.394	1.380	19.48	1.666	347.5
r, 1.70; percent fuel, 20.16; O/F, 3.960								
1.000	600.00	4014	3530.8	0.490	1.292	---	---	---
1.040	576.92	3979	3513.4	.489	1.293	2.458	0.186	38.9
1.526	393.07	3646	3351.4	.485	1.296	1.029	.599	124.9
1.832	327.56	3497	3279.2	.482	1.298	1.000	.709	148.0
2.290	262.05	3322	3194.9	.480	1.300	1.028	.819	171.0
10.000	60.00	2346	2735.9	.459	1.318	2.06	1.260	263.0
20.000	30.00	1981	2570.1	.448	1.328	3.16	1.385	289.1
20.414	29.392	1971	2565.6	.448	1.329	3.21	1.388	289.8
40.000	15.00	1665	2430.3	.436	1.341	4.97	1.482	309.4
40.827	14.696	1656	2426.6	.436	1.341	5.04	1.485	310.0
60.000	10.00	1501	2359.2	.429	1.349	6.51	1.529	319.3
100.000	6.00	1313	2279.7	.419	1.359	9.19	1.581	329.7
300.000	2.00	976	2141.2	.402	1.381	19.45	1.666	347.7

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TABLE IV. - Continued. THEORETICAL ROCKET PERFORMANCE FOR PRESSURE RATIOS FROM 1 TO 300

FOR LIQUID METHANE WITH SEVERAL FLUORINE-OXYGEN MIXTURES

[Frozen composition assumed during isentropic expansion from combustion-chamber pressure of 600 lb/sq in. abs.]

(f) Percent fluorine in oxidant by weight, 78.08

Pressure ratio, P ₀ /P	Static pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Specific heat, Cp, cal/(g)(°K)	Isentropic exponent, γ	Area ratio, ε	Thrust coefficient, C _p	Specific impulse, I, lb-sec/lb
r, 1.55; percent fuel, 17.55; O/F, 4.897								
1.000	600.00	4333	3317.5	0.460	1.303	2.465	0.187	39.7
1.040	576.92	4293	3299.4	.459	1.303	1.029	.602	127.9
1.538	391.68	3922	3129.4	.455	1.307	1.000	.712	151.2
1.838	326.40	3757	3034.6	.453	1.309	1.000	.712	151.2
2.298	261.12	3564	2907.3	.450	1.311	1.027	.822	174.4
10.000	60.00	2496	2495.3	.433	1.328	2.04	1.259	267.5
20.000	30.00	2099	2325.4	.423	1.339	3.13	1.383	293.8
20.414	29.392	2088	2320.8	.422	1.339	3.17	1.387	294.5
40.000	15.00	1784	2175.0	.412	1.351	4.90	1.479	314.2
40.827	14.696	1748	2179.0	.411	1.351	4.97	1.482	314.7
60.000	10.00	1581	2110.6	.405	1.359	6.41	1.526	324.1
100.000	6.00	1379	2029.8	.396	1.369	9.02	1.576	334.7
300.000	2.00	1019	1869.9	.380	1.392	18.99	1.659	352.4
r, 1.60; percent fuel, 18.02; O/F, 4.551								
1.000	600.00	4298	3372.4	0.465	1.303	2.465	0.187	39.7
1.040	576.92	4259	3354.3	.464	1.303	1.029	.602	128.0
1.538	391.72	3891	3184.0	.460	1.307	1.000	.712	151.4
1.838	326.43	3728	3109.0	.458	1.309	1.000	.712	151.4
2.298	261.15	3536	3021.5	.455	1.311	1.027	.822	174.7
10.000	60.00	2477	2548.3	.437	1.328	2.04	1.259	267.8
20.000	30.00	2083	2378.0	.427	1.339	3.13	1.383	294.2
20.414	29.392	2073	2373.4	.427	1.339	3.17	1.387	294.8
40.000	15.00	1744	2235.1	.417	1.351	4.90	1.479	314.6
40.827	14.696	1735	2231.2	.415	1.351	4.97	1.482	315.1
60.000	10.00	1569	2162.6	.409	1.359	6.41	1.526	324.5
100.000	6.00	1369	2081.7	.400	1.369	9.02	1.576	335.1
300.000	2.00	1011	1941.4	.384	1.392	18.99	1.659	352.9
r, 1.65; percent fuel, 18.48; O/F, 4.413								
1.000	600.00	4228	3426.7	0.470	1.300	2.463	0.187	39.5
1.040	576.92	4190	3408.8	.470	1.301	1.029	.601	127.2
1.538	392.03	3831	3240.7	.465	1.304	1.000	.711	150.5
1.837	326.43	3671	3166.5	.463	1.306	1.000	.711	150.5
2.296	261.36	3483	3079.9	.460	1.308	1.027	.821	173.7
10.000	60.00	2445	2610.7	.442	1.326	2.05	1.259	266.5
20.000	30.00	2058	2441.7	.431	1.336	3.14	1.384	292.6
20.414	29.392	2047	2437.2	.431	1.337	3.18	1.387	293.4
40.000	15.00	1724	2299.8	.420	1.349	4.92	1.480	313.1
40.827	14.696	1715	2295.9	.420	1.349	4.98	1.483	313.7
60.000	10.00	1551	2227.7	.413	1.357	6.43	1.527	323.0
100.000	6.00	1354	2147.3	.404	1.367	9.06	1.577	333.7
300.000	2.00	1002	2007.7	.387	1.389	19.09	1.661	351.4
(g) Percent fluorine in oxidant by weight, 79.87								
r, 1.48; percent fuel, 16.66; O/F, 5.003								
1.000	600.00	4418	3232.1	0.450	1.305	2.467	0.187	39.7
1.040	576.92	4377	3213.9	.449	1.306	1.029	.602	128.2
1.533	391.33	3955	3043.3	.445	1.310	1.000	.713	151.5
1.840	326.13	3826	2968.2	.443	1.311	1.000	.713	151.5
2.300	260.91	3628	2880.7	.441	1.314	1.027	.823	174.9
10.000	60.00	2537	2408.6	.423	1.331	2.04	1.259	267.7
20.000	30.00	2151	2238.7	.414	1.341	3.12	1.382	294.0
20.414	29.392	2120	2234.2	.413	1.341	3.16	1.385	294.7
40.000	15.00	1783	2096.4	.403	1.353	4.88	1.479	314.4
40.827	14.696	1774	2092.5	.403	1.353	4.95	1.481	314.9
60.000	10.00	1603	2024.2	.397	1.361	6.39	1.525	324.2
100.000	6.00	1398	1943.7	.388	1.371	8.99	1.575	334.8
300.000	2.00	1031	1804.3	.372	1.394	18.89	1.658	352.5
r, 1.51; percent fuel, 16.94; O/F, 4.904								
1.000	600.00	4402	3265.2	0.453	1.305	2.466	0.187	39.8
1.040	576.92	4362	3247.0	.452	1.305	1.029	.601	128.3
1.533	391.41	3938	3075.0	.448	1.309	1.000	.713	151.7
1.840	326.17	3813	3000.7	.446	1.311	1.000	.713	151.7
2.300	260.94	3616	2913.0	.444	1.313	1.027	.822	175.1
10.000	60.00	2529	2439.6	.426	1.330	2.04	1.259	268.0
20.000	30.00	2138	2269.3	.417	1.341	3.12	1.382	294.4
20.414	29.392	2114	2264.7	.416	1.341	3.16	1.385	295.0
40.000	15.00	1778	2126.5	.406	1.353	4.89	1.479	314.8
40.827	14.696	1768	2122.7	.405	1.353	4.95	1.481	315.3
60.000	10.00	1598	2054.2	.399	1.361	6.39	1.525	324.6
100.000	6.00	1394	1973.4	.391	1.371	8.99	1.575	335.3
300.000	2.00	1028	1833.6	.375	1.394	18.90	1.658	352.9
r, 1.56; percent fuel, 17.31; O/F, 4.777								
1.000	600.00	4351	3309.0	0.457	1.303	2.465	0.187	39.6
1.040	576.92	4312	3290.9	.457	1.303	1.029	.602	127.8
1.538	391.67	3939	3121.3	.452	1.307	1.000	.712	151.1
1.838	326.39	3773	3046.6	.450	1.309	1.000	.712	151.1
2.298	261.11	3579	2959.4	.448	1.311	1.027	.822	174.4
10.000	60.00	2507	2488.3	.430	1.328	2.04	1.259	267.2
20.000	30.00	2108	2318.7	.420	1.339	3.13	1.383	293.5
20.414	29.392	2097	2314.2	.420	1.339	3.17	1.387	294.2
40.000	15.00	1765	2176.4	.409	1.351	4.90	1.479	313.9
40.827	14.696	1755	2172.6	.409	1.351	4.97	1.482	314.4
60.000	10.00	1587	2104.3	.402	1.359	6.41	1.526	323.8
100.000	6.00	1385	2023.7	.394	1.369	9.02	1.576	334.4
300.000	2.00	1023	1884.1	.378	1.392	18.99	1.659	352.1

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TABLE IV. - Continued. THEORETICAL ROCKET PERFORMANCE FOR PRESSURE RATIOS FROM 1 TO 300 FOR LIQUID METHANE WITH SEVERAL FLUORINE-OXYGEN MIXTURES

[Frozen composition assumed during isentropic expansion from combustion-chamber pressure of 600 lb/sq in. abs.]

(h) Percent fluorine in oxidant by weight, 80.15

Pressure ratio, P_0/P	Static pressure, P_s , lb/sq in. abs.	Temperature, T , °K	Enthalpy, h , cal/g	Specific heat, c_p , cal/(g)(°K)	Isentropic exponent, γ	Area ratio, a	Thrust coefficient, C_F	Specific impulse, I_s , lb-sec/lb
r, 1.46; percent fuel, 16.40; O/F , 5.088								
1.000	600.00	4440	3207.7	0.447	1.306	2.467	0.187	39.7
1.040	576.92	4399	3189.5	.446	1.307	1.028	.603	128.3
1.533	391.25	4015	3018.6	.442	1.310	1.000	.713	151.6
1.840	326.08	3844	2943.6	.440	1.312	1.000	.823	174.9
2.300	260.94	3645	2856.2	.438	1.314	1.027	.823	174.9
10.000	60.00	2547	2384.3	.421	1.331	2.04	1.259	267.7
20.000	30.00	2139	2214.6	.411	1.342	3.12	1.383	294.0
20.414	29.398	2128	2210.1	.411	1.342	3.16	1.386	294.6
40.000	15.00	1789	2072.4	.402	1.354	4.95	1.479	314.3
40.827	14.696	1777	2068.6	.402	1.354	4.95	1.481	314.8
60.000	10.00	1608	2000.4	.394	1.362	6.38	1.525	324.1
100.000	6.00	1402	1920.0	.386	1.372	8.97	1.575	334.7
300.000	2.00	1034	1780.9	.370	1.395	18.86	1.658	352.4
r, 1.46; percent fuel, 16.59; O/F , 5.028								
1.000	600.00	4431	3229.8	0.449	1.306	2.467	0.187	39.8
1.040	576.92	4390	3211.6	.448	1.306	1.028	.603	128.4
1.533	391.29	4007	3040.4	.444	1.310	1.000	.713	151.7
1.840	326.08	3837	2953.3	.442	1.312	1.000	.823	175.1
2.300	260.86	3638	2877.6	.440	1.314	1.027	.823	175.1
10.000	60.00	2543	2404.7	.422	1.331	2.04	1.259	267.9
20.000	30.00	2136	2234.7	.413	1.341	3.12	1.383	294.3
20.414	29.398	2125	2230.1	.413	1.342	3.16	1.386	294.9
40.000	15.00	1786	2092.1	.402	1.354	4.95	1.479	314.6
40.827	14.696	1777	2088.3	.402	1.354	4.95	1.481	315.2
60.000	10.00	1606	2019.9	.396	1.361	6.38	1.525	324.6
100.000	6.00	1400	1939.3	.388	1.372	8.98	1.575	335.1
300.000	2.00	1033	1799.8	.372	1.394	18.87	1.658	352.7
r, 1.50; percent fuel, 16.77; O/F , 4.982								
1.000	600.00	4408	3251.8	0.451	1.305	2.466	0.187	39.7
1.040	576.92	4368	3233.7	.450	1.305	1.028	.603	128.2
1.533	391.40	3987	3063.0	.446	1.309	1.000	.713	151.5
1.840	326.17	3819	2980.1	.444	1.311	1.000	.823	174.8
2.299	260.94	3621	2900.7	.442	1.313	1.027	.823	174.8
10.000	60.00	2533	2428.6	.424	1.330	2.04	1.259	267.9
20.000	30.00	2128	2258.8	.415	1.341	3.12	1.383	293.9
20.414	29.398	2117	2254.2	.414	1.341	3.16	1.386	294.6
40.000	15.00	1780	2116.4	.404	1.353	4.95	1.479	314.3
40.827	14.696	1771	2112.6	.404	1.353	4.95	1.481	314.8
60.000	10.00	1600	2044.3	.398	1.361	6.39	1.525	324.1
100.000	6.00	1396	1963.8	.389	1.371	8.99	1.575	334.8
300.000	2.00	1030	1824.3	.373	1.394	18.91	1.658	352.4
(i) Percent fluorine in oxidant by weight, 81.46								
r, 1.38; percent fuel, 19.45; O/F , 5.471								
1.000	600.00	4498	3113.3	0.436	1.309	2.469	0.187	39.6
1.040	576.92	4456	3095.2	.435	1.309	1.028	.604	128.1
1.533	390.88	4063	2924.4	.431	1.313	1.000	.714	151.3
1.842	325.74	3890	2850.3	.429	1.315	1.000	.824	174.5
2.302	260.59	3687	2763.3	.427	1.317	1.027	.824	174.5
10.000	60.00	2570	2295.3	.410	1.334	2.03	1.259	266.8
20.000	30.00	2157	2127.2	.401	1.345	3.11	1.382	292.9
20.414	29.398	2145	2122.7	.401	1.345	3.15	1.386	293.6
40.000	15.00	1809	1990.1	.392	1.355	4.89	1.475	312.6
40.827	14.696	1800	1986.3	.391	1.356	4.95	1.478	313.2
60.000	10.00	1622	1917.8	.385	1.364	6.37	1.522	322.5
100.000	6.00	1413	1836.5	.377	1.375	8.95	1.573	333.3
300.000	2.00	1041	1698.8	.362	1.397	18.99	1.656	350.8
r, 1.40; percent fuel, 18.64; O/F , 5.593								
1.000	600.00	4493	3135.6	0.437	1.308	2.469	0.187	39.7
1.040	576.92	4452	3117.4	.437	1.308	1.028	.604	128.2
1.533	390.93	4060	2946.6	.433	1.313	1.000	.714	151.5
1.842	325.78	3887	2871.8	.431	1.315	1.000	.824	174.8
2.308	260.62	3684	2784.6	.429	1.317	1.027	.824	174.8
10.000	60.00	2569	2315.0	.412	1.334	2.04	1.259	267.2
20.000	30.00	2156	2146.3	.403	1.344	3.11	1.382	293.4
20.414	29.398	2145	2141.7	.403	1.344	3.15	1.386	294.1
40.000	15.00	1801	2005.0	.393	1.356	4.86	1.478	313.6
40.827	14.696	1792	2001.2	.393	1.357	4.93	1.480	314.2
60.000	10.00	1618	1933.3	.387	1.364	6.35	1.524	323.4
100.000	6.00	1410	1853.7	.379	1.375	8.93	1.574	334.0
300.000	2.00	1038	1715.8	.363	1.397	18.76	1.656	351.5
r, 1.42; percent fuel, 18.83; O/F , 5.317								
1.000	600.00	4476	3187.7	0.440	1.308	2.468	0.187	39.7
1.040	576.92	4435	3169.6	.440	1.308	1.028	.604	128.1
1.534	391.06	4045	2969.1	.435	1.312	1.000	.714	151.4
1.841	325.88	3873	2894.4	.433	1.314	1.000	.823	174.6
2.301	260.71	3672	2807.3	.431	1.316	1.027	.823	174.6
10.000	60.00	2563	2337.8	.414	1.333	2.04	1.259	267.1
20.000	30.00	2151	2169.0	.405	1.343	3.11	1.383	293.3
20.414	29.398	2140	2164.5	.405	1.344	3.15	1.386	294.0
40.000	15.00	1798	2027.7	.395	1.355	4.87	1.478	313.6
40.827	14.696	1788	2023.9	.395	1.356	4.93	1.481	314.1
60.000	10.00	1618	1956.1	.389	1.363	6.36	1.524	323.3
100.000	6.00	1408	1876.3	.380	1.374	8.95	1.574	333.9
300.000	2.00	1037	1738.2	.365	1.396	18.80	1.657	351.4

TABLE IV. - Concluded. THEORETICAL ROCKET PERFORMANCE FOR PRESSURE RATIOS FROM 1 TO 300
FOR LIQUID METHANE WITH SEVERAL FLUORINE-OXYGEN MIXTURES

[Frozen composition assumed during isentropic expansion from combustion-chamber pressure of 600 lb/sq in. abs.]

(j) Percent fluorine in oxidant by weight, 82.61

Pressure ratio, P_c/P	Static pressure, P , lb/sq in. abs	Temperature, T , °K	Enthalpy, h , cal/g	Specific heat, c_p , cal/(g)(°K)	Isentropic exponent, γ	Area ratio, ϵ	Thrust coefficient, C_F	Specific impulse, I , lb-sec/lb
r, 1.30; percent fuel, 14.53; O/F, 5.882								
1.000	600.00	4527	3019.9	0.425	1.312	2.471	0.187	39.4
1.040	576.92	4485	3002.0	.425	1.313	1.028	.606	127.5
1.537	390.44	4085	2832.9	.420	1.317	1.000	.715	150.6
1.844	325.37	3910	2759.2	.419	1.319	1.027	.824	173.6
2.305	260.29	3704	2673.4	.416	1.321			
10.000	60.00	2576	2212.0	.400	1.338	2.03	1.259	265.1
20.000	30.00	2158	2046.5	.392	1.348	3.10	1.382	291.0
20.414	29.392	2147	2042.0	.391	1.348	3.14	1.385	291.7
40.000	15.00	1800	1908.1	.382	1.360	4.84	1.477	311.0
40.827	14.696	1791	1904.4	.381	1.361	4.90	1.479	311.5
60.000	10.00	1616	1838.1	.376	1.368	6.31	1.523	320.7
100.000	6.00	1406	1760.2	.368	1.379	8.87	1.572	331.1
300.000	2.00	1033	1625.6	.353	1.401	18.58	1.654	348.3
r, 1.333; percent fuel, 14.85; O/F, 5.735								
1.000	600.00	4528	3057.2	0.429	1.311	2.470	0.187	39.6
1.040	576.92	4486	3039.2	.428	1.312	1.028	.605	127.9
1.536	390.57	4087	2869.2	.424	1.316	1.000	.715	151.0
1.843	325.47	3911	2795.0	.422	1.318	1.027	.824	174.2
2.304	260.38	3706	2708.6	.420	1.320			
10.000	60.00	2579	2243.8	.404	1.337	2.03	1.259	266.0
20.000	30.00	2162	2077.0	.395	1.347	3.10	1.382	292.0
20.414	29.392	2150	2072.5	.395	1.347	3.14	1.385	292.7
40.000	15.00	1804	1937.5	.385	1.359	4.84	1.477	312.1
40.827	14.696	1794	1933.8	.385	1.360	4.91	1.480	312.7
60.000	10.00	1620	1867.0	.379	1.367	6.32	1.523	321.8
100.000	6.00	1410	1788.3	.371	1.378	8.89	1.572	332.3
300.000	2.00	1036	1652.6	.356	1.400	18.63	1.654	349.6
r, 1.40; percent fuel, 15.48; O/F, 5.462								
1.000	600.00	4480	3131.0	0.436	1.307	2.467	0.187	39.5
1.040	576.92	4438	3113.1	.436	1.307	1.028	.604	127.4
1.534	391.16	4049	2944.3	.431	1.311	1.000	.713	150.6
1.841	325.97	3877	2870.3	.430	1.313	1.027	.823	173.7
2.301	260.77	3676	2784.1	.427	1.315			
10.000	60.00	2567	2318.9	.411	1.332	2.04	1.259	265.8
20.000	30.00	2156	2151.6	.402	1.342	3.12	1.383	291.9
20.414	29.392	2144	2147.1	.401	1.343	3.16	1.386	292.6
40.000	15.00	1802	2011.5	.391	1.354	4.87	1.478	312.1
40.827	14.696	1793	2007.7	.391	1.355	4.94	1.481	312.6
60.000	10.00	1620	1940.5	.385	1.362	6.37	1.525	321.9
100.000	6.00	1412	1861.3	.377	1.373	8.96	1.574	332.4
300.000	2.00	1041	1724.3	.362	1.395	18.83	1.657	349.9
r, 1.50; percent fuel, 16.40; O/F, 5.098								
1.000	600.00	4395	3239.7	0.448	1.300	2.463	0.187	39.3
1.040	576.92	4356	3221.9	.448	1.300	1.029	.601	126.5
1.530	392.08	3982	3055.7	.443	1.304	1.000	.711	149.7
1.836	326.74	3816	2982.2	.441	1.306	1.027	.821	172.8
2.295	261.39	3622	2896.5	.439	1.308			
10.000	60.00	2543	2432.0	.421	1.325	2.05	1.259	265.1
20.000	30.00	2142	2264.6	.412	1.335	3.14	1.384	291.3
20.414	29.392	2131	2260.1	.412	1.335	3.18	1.387	291.9
40.000	15.00	1796	2124.0	.401	1.347	4.92	1.480	311.6
40.827	14.696	1786	2120.2	.401	1.347	4.99	1.483	312.1
60.000	10.00	1616	2052.5	.395	1.354	6.44	1.527	321.4
100.000	6.00	1412	1972.7	.387	1.365	9.08	1.577	332.0
300.000	2.00	1046	1834.1	.371	1.387	19.16	1.662	349.7

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TABLE V. - EQUILIBRIUM COMPOSITION IN COMBUSTION CHAMBER FOR LIQUID METHANE WITH SEVERAL MIXTURES OF FLUORINE AND OXYGEN

Equiva- lence ratio, $\frac{x(C) + (H)}{2(O) + (F)}$	Fuel, percent by weight	Oxidant to-fuel ratio, O/F	Equilibrium composition (mole fraction ²)																
			C	CF	CF ₂	CF ₃	C ₂ F ₂	CO	CO ₂	F	F ₂	H	H ₂	HF	H ₂ O	O	O ₂	OH	
Percent fluorine in oxidant, 0 (100 percent oxygen)																			
1.00	20.04	3.990						0.15840	0.14751				0.02123	0.05368		0.46668	0.02156	0.07074	0.08027
1.50	24.58	3.069						.21085	.10577				.02790	.11814		.47275	.00747	.01133	.04680
1.40	25.98	2.850						.25185	.08879				.02648	.15088		.46075	.00385	.00482	.03270
1.50	27.52	2.660						.24986	.07314				.02292	.18712		.44122	.00174	.00158	.02041
1.60	28.82	2.495						.26481	.06385				.01799	.22588		.41557	.00065	.00048	.01141
1.80	31.09	2.218						.28452	.04892				.00849	.30181		.35558	.00006	.00003	.00269
Percent fluorine in oxidant by weight, 19.19																			
1.20	21.10	5.740						0.18552	0.08641	0.00154			0.05490	0.08425	0.18465	0.35151	0.01786	0.02688	0.06484
1.40	25.78	3.208						.22241	.08782	.00072			.05680	.13366	.15009	.35333	.00749	.00714	.04074
1.50	25.05	2.992						.25827	.05618	.00048			.05410	.16475	.14526	.32607	.00405	.00308	.02878
1.60	26.28	2.805						.25190	.04948	.00029			.02970	.19900	.15670	.31122	.00192	.00115	.01865
1.80	28.82	2.495						.27257	.03598	.00008			.01821	.27038	.12450	.27190	.00030	.00012	.00518
Percent fluorine in oxidant by weight, 37.25																			
1.50	20.35	3.915						0.19828	0.06387	0.00354			0.04755	0.09144	0.30680	0.20844	0.01874	0.01634	0.06482
1.50	22.77	3.591						.22885	.04105	.00195			.04784	.14104	.28358	.21148	.00775	.00445	.03427
1.60	25.93	3.179						.25877	.05508	.00132			.04464	.17091	.27252	.20588	.00431	.00199	.02480
1.70	25.05	2.992						.24834	.02974	.00084			.05951	.20304	.26183	.19821	.00216	.00081	.01851
1.80	27.19	2.677						.26603	.02130	.00029			.02849	.26902	.24168	.18846	.00045	.00010	.00620
Percent fluorine in oxidant by weight, 54.29																			
1.50	18.28	4.475						0.19147	0.03170	0.01100			0.08088	0.08984	0.44878	0.09860	0.02700	0.01459	0.04615
1.40	19.40	4.156						.20375	.02785	.00841			.06490	.08988	.43288	.10456	.01902	.00849	.04112
1.50	20.50	3.879						.21512	.02418	.00624			.06529	.11264	.41915	.10709	.01282	.00456	.03525
1.60	21.57	3.658						.22566	.02053	.00447			.06586	.13862	.40567	.10613	.00782	.00223	.02651
1.80	25.65	3.252						.24537	.01411	.00205			.05410	.19781	.37940	.09458	.00223	.00041	.01225
Percent fluorine in oxidant by weight, 70.57																			
1.40	17.22	4.809						0.19468	0.01018	0.02982			0.08184	0.05638	0.55515	0.02475	0.02197	0.00582	0.02525
1.50	18.22	4.488						.20398	.00828	.02211			.08758	.07558	.54388	.02577	.01414	.00160	.01878
1.60	19.20	4.208						.21271	.00638	.01603			.08982	.09579	.53159	.02475	.00825	.00091	.01581
1.70	20.16	3.960						.22076	.00498	.01134			.08858	.12104	.51982	.02143	.00422	.00029	.00601
Percent fluorine in oxidant by weight, 78.08																			
1.88	17.55	4.887						0.20269	0.00668	0.04108			0.10280	0.05844	0.58875	0.00171	0.00216	0.00002	0.00197
1.80	18.02	4.551	0.00011	0.00008				.20645	.00002	.05480			.10818	.08815	.58486	.00006	.00008		.00006
1.65	18.48	4.415	.00188	.00134	0.00003		0.00157	.20444		.02712			.10215	.07975	.58170				.00006
Percent fluorine in oxidant by weight, 78.87																			
1.48	18.88	5.005	0.00001	0.00001				0.19577	0.00058	0.06005			0.09880	0.04187	0.80818	0.00071	0.00188	0.00001	0.00114
1.61	18.84	4.804	.00015	.00012			0.00001	.19799	.00002	.08482			.10108	.04844	.80907	.00004	.00009		.00006
1.65	17.31	4.777	.00178	.00141	0.00004		.00103	.19648		.04668			.10087	.06351	.80818	.00001			.00001
Percent fluorine in oxidant by weight, 80.15																			
1.48	18.40	5.068	0.00001	0.00001				0.19373	0.00028	0.06874			0.08683	0.03774	0.80268	0.00047	0.00130	0.00001	0.00082
1.48	18.59	5.029	.00009	.00008			0.00029	.19386	.00004	.08305			.09845	.04054	.80215	.00007	.00017		.00011
1.50	16.77	4.562	.00101	.00088	0.00005			.18473		.05785			.09878	.04557	.80286	.00001	.00001		.00001
Percent fluorine in oxidant by weight, 81.46																			
1.38	15.45	5.471	0.00001	0.00001				0.18590	0.00023	0.09328			0.08535	0.02826	0.80710	0.00035	0.00172	0.00001	0.00082
1.40	15.84	5.393	.00007	.00007				.18747	.00006	.08877			.08835	.02758	.80727	.00007	.00032		.00018
1.42	15.85	5.317	.00089	.00066	0.00003		0.00023	.18721		.08262			.08870	.02959	.80691	.00001	.00002		.00001
Percent fluorine in oxidant by weight, 82.61																			
1.50	14.53	5.882	0.00001	0.00001				0.17758	0.00041	0.12375	0.00001	0.07130	0.01626	0.80684	0.00053	0.00277	0.00002	0.00103	
1.335	14.88	5.735	.00014	.00016	0.00001		0.00001	.18045	.00003	.11486	.00001	.07703	.01888	.80803	.00003	.00019		.00008	
1.40	15.48	5.482	.00258	.00233	.00010	0.00001	0.00001	.17829	.00186	.08102		.08504	.02518	.81530		.00001			
1.50	16.40	5.098	.00484	.00397	.00013	0.00001	0.00001	.17478	.00873	.08181		.09075	.03811	.81848					

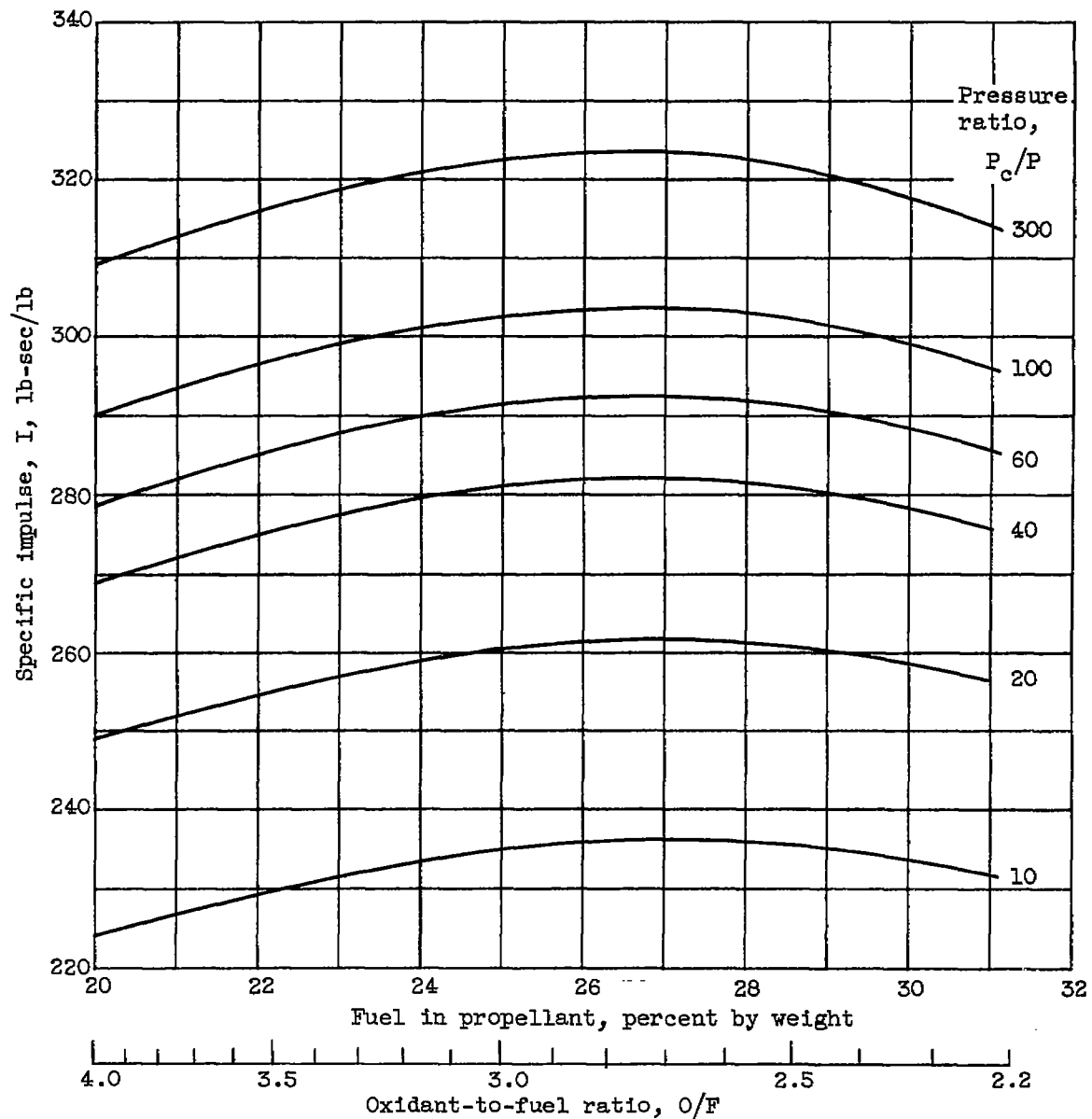
²Mole fractions were computed for all 19 substances considered in this report but were omitted if less than 5x10⁻⁶.

TABLE VI. - THEORETICAL ROCKET PERFORMANCE FOR EXPANSION TO EXIT
 PRESSURE OF 1 ATMOSPHERE FOR LIQUID METHANE WITH SEVERAL
 MIXTURES OF FLUORINE AND OXYGEN

Equivalence ratio, $\frac{4(C) + (H)}{2(O) + (F)}$	Fuel, percent 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 , lb-sec/lb
Percent fluorine in oxidant, 0 (100 percent oxygen)								
1.00	20.04	3.990	3497	1827	5700	5.91	1.520	269.3
1.30	24.58	3.069	3444	1768	5959	5.84	1.517	281.0
1.40	25.98	2.850	3372	1713	5998	5.80	1.516	282.6
1.50	27.32	2.660	3272	1641	6011	5.75	1.514	282.8
1.60	28.62	2.493	3147	1554	5996	5.68	1.511	281.6
1.80	31.09	2.216	2855	1360	5901	5.54	1.505	276.1
Percent fluorine in oxidant by weight, 19.19								
1.20	21.10	3.740	3622	1777	6036	5.66	1.510	283.3
1.40	23.78	3.206	3536	1718	6145	5.63	1.509	288.1
1.50	25.05	2.992	3460	1667	6169	5.59	1.507	289.0
1.60	26.28	2.805	3362	1604	6172	5.55	1.506	288.8
1.80	28.62	2.493	3119	1450	6118	5.46	1.502	285.6
Percent fluorine in oxidant by weight, 37.25								
1.30	20.35	3.913	3753	1735	6248	5.44	1.501	291.5
1.50	22.77	3.391	3650	1678	6324	5.42	1.500	294.9
1.60	23.93	3.179	3572	1633	6336	5.40	1.499	295.3
1.70	25.05	2.992	3479	1579	6333	5.37	1.498	294.9
1.90	27.19	2.677	3258	1452	6282	5.30	1.496	292.0
Percent fluorine in oxidant by weight, 54.29								
1.30	18.26	4.475	3957	1723	6416	5.23	1.492	297.6
1.40	19.40	4.156	3917	1708	6459	5.23	1.493	299.6
1.50	20.50	3.879	3864	1684	6489	5.23	1.493	301.0
1.60	21.57	3.636	3798	1653	6506	5.22	1.492	301.8
1.80	23.63	3.232	3628	1567	6503	5.19	1.491	301.4
Percent fluorine in oxidant by weight, 70.37								
1.40	17.22	4.809	4209	1733	6664	5.04	1.485	307.5
1.50	18.22	4.488	4157	1715	6694	5.04	1.485	308.9
1.60	19.20	4.208	4091	1689	6711	5.04	1.485	309.8
1.70	20.16	3.960	4014	1656	6717	5.04	1.485	310.0
Percent fluorine in oxidant by weight, 78.08								
1.55	17.55	4.697	4333	1748	6833	4.97	1.482	314.7
1.60	18.02	4.551	4298	1735	6841	4.97	1.482	315.1
1.65	18.48	4.413	4228	1715	6807	4.98	1.483	313.7
Percent fluorine in oxidant by weight, 79.67								
1.48	16.66	5.003	4418	1774	6840	4.95	1.481	314.9
1.51	16.94	4.904	4402	1768	6848	4.95	1.481	315.3
1.55	17.31	4.777	4351	1755	6827	4.97	1.482	314.4
Percent fluorine in oxidant by weight, 80.15								
1.46	16.40	5.098	4440	1780	6859	4.94	1.481	314.8
1.48	16.59	5.029	4431	1777	6846	4.95	1.481	315.2
1.50	16.77	4.962	4408	1771	6838	4.95	1.481	314.8
Percent fluorine in oxidant by weight, 81.46								
1.38	15.45	5.471	4498	1803	6817	4.96	1.479	313.5
1.40	15.64	5.393	4493	1792	6828	4.93	1.480	314.2
1.42	15.83	5.317	4476	1788	6825	4.93	1.481	314.1
Percent fluorine in oxidant by weight, 82.61								
1.30	14.53	5.882	4527	1791	6776	4.90	1.479	311.5
1.333	14.85	5.735	4528	1794	6799	4.91	1.480	312.7
1.40	15.48	5.462	4480	1793	6793	4.94	1.481	312.6
1.50	16.40	5.098	4395	1786	6772	4.99	1.483	312.1

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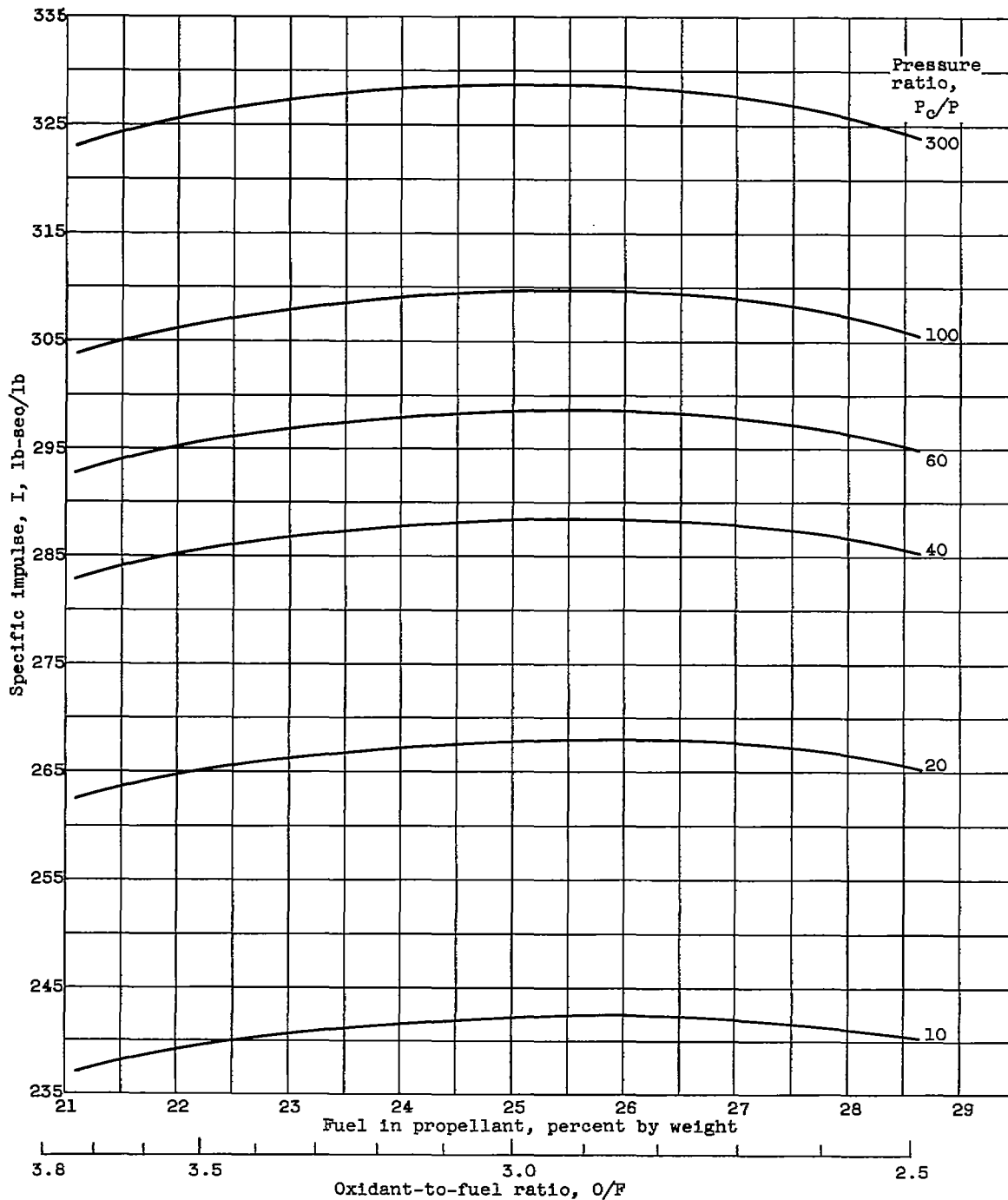
CJ-4 back



(a) Percent fluorine in oxidant by weight, 0 (100 percent oxygen).

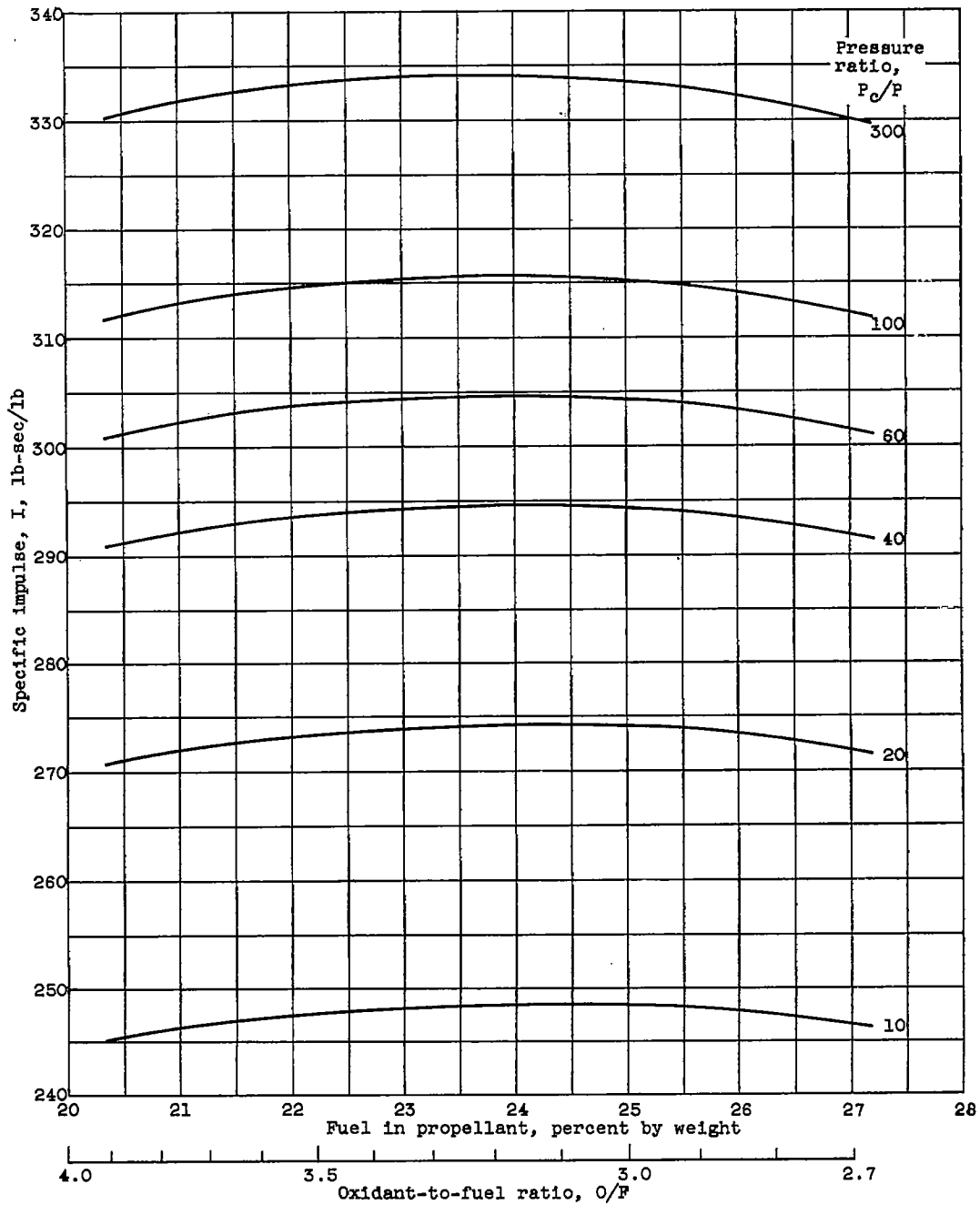
Figure 1. - Theoretical specific impulse of liquid methane with several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from combustion-chamber pressure of 600 pounds per square inch absolute to pressure ratio indicated.

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(b) Percent fluorine in oxidant by weight, 19.19.

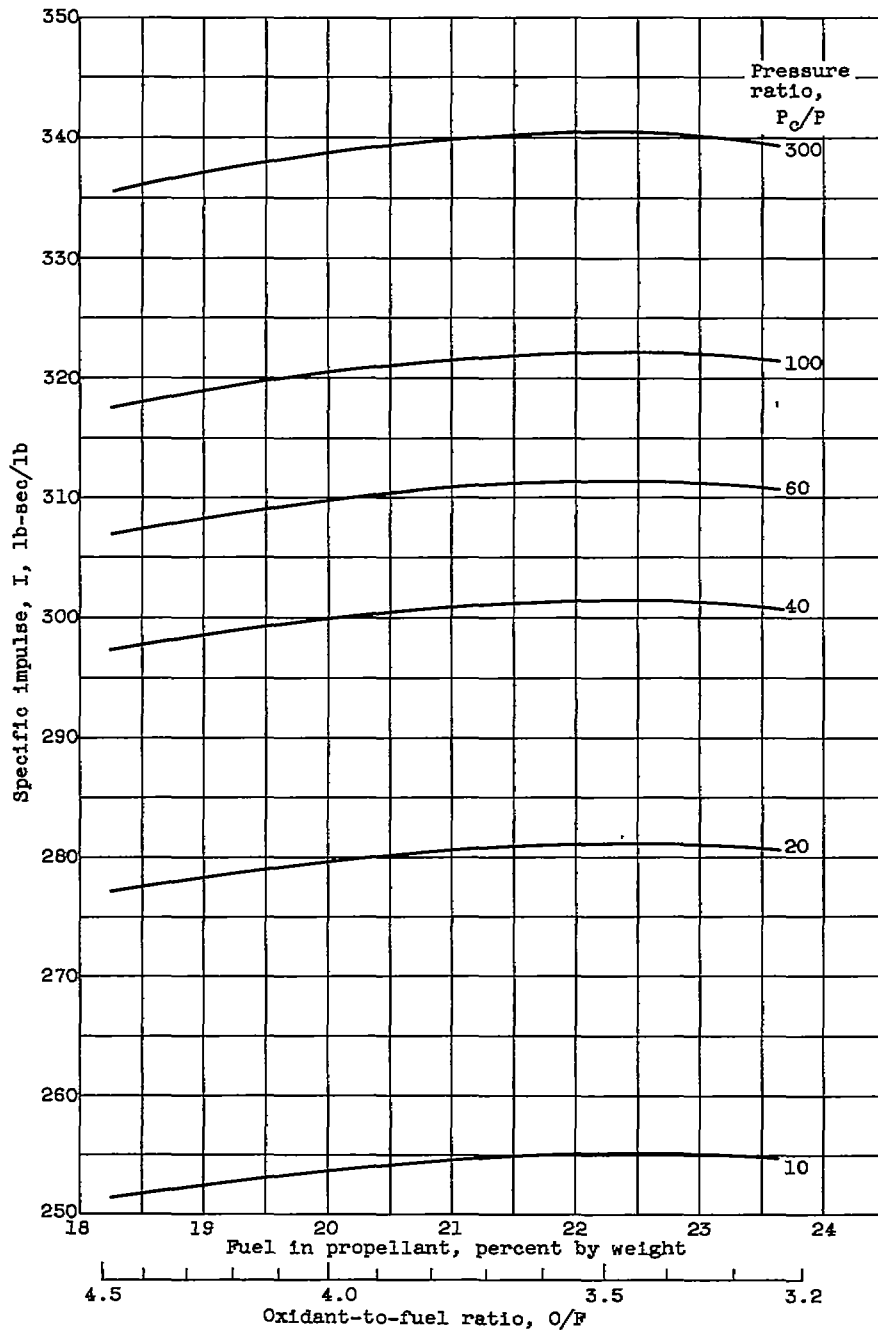
Figure 1. - Continued. Theoretical specific impulse of liquid methane with several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from combustion-chamber pressure of 600 pounds per square inch absolute to pressure ratio indicated.



(c) Percent fluorine in oxidant by weight, 37.25.

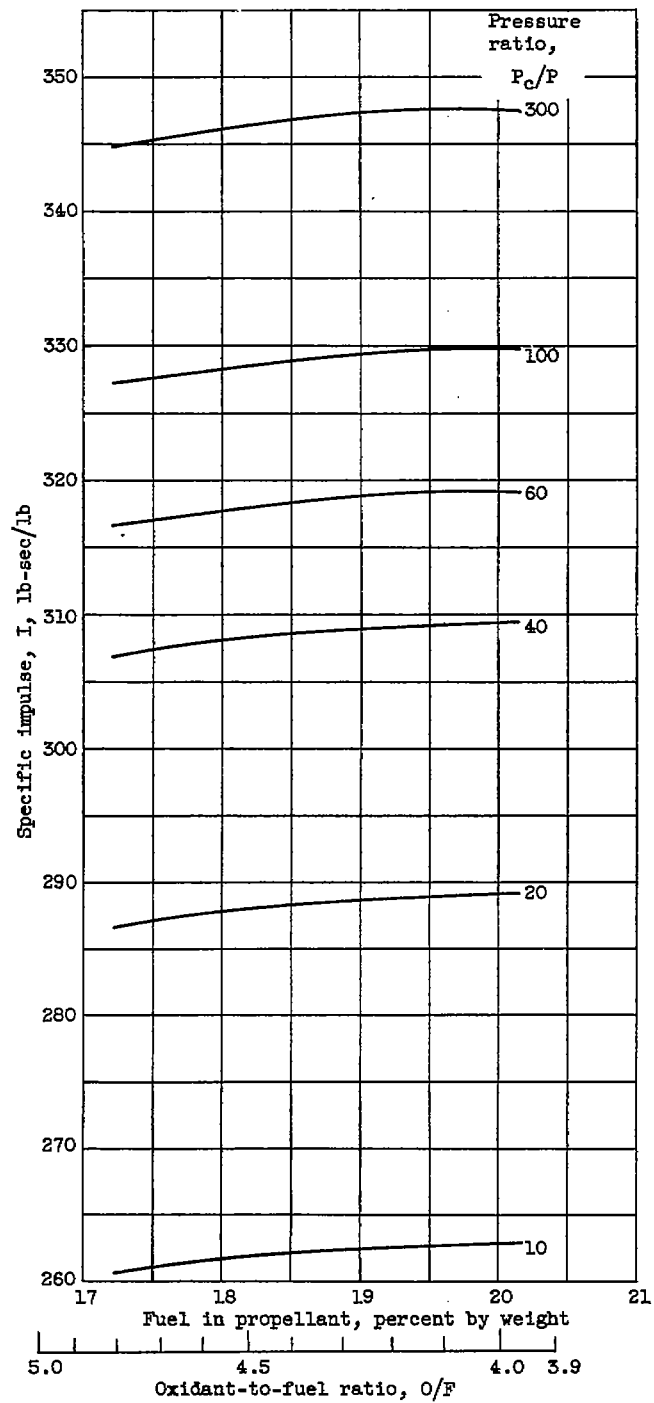
Figure 1. - Continued. Theoretical specific impulse of liquid methane with several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from combustion-chamber pressure of 600 pounds per square inch absolute to pressure ratio indicated.

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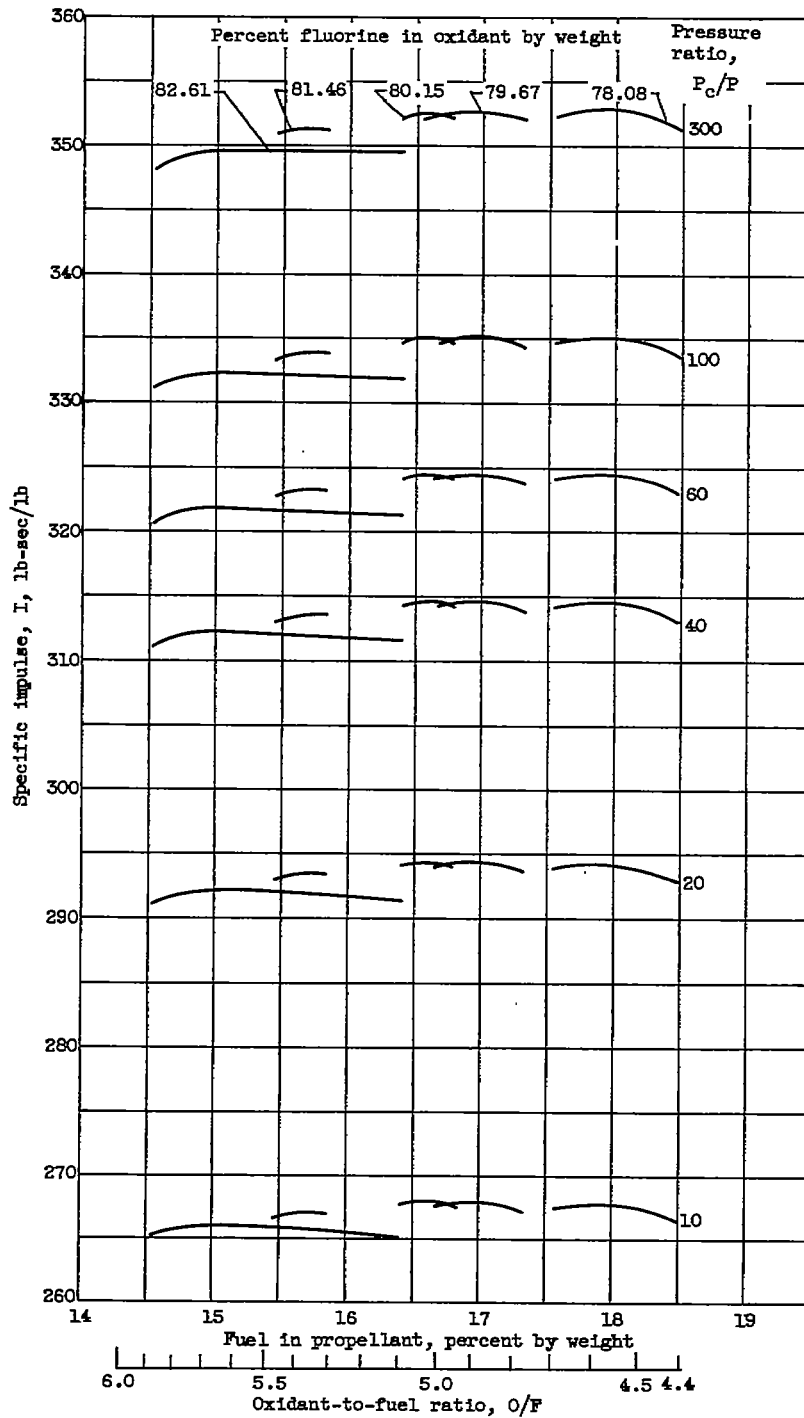
(d) Percent fluorine in oxidant by weight, 54.29.

Figure 1. - Continued. Theoretical specific impulse of liquid methane with several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from combustion-chamber pressure of 600 pounds per square inch absolute to pressure ratio indicated.



(e) Percent fluorine in oxidant by weight, 70.37.

Figure 1. - Continued. Theoretical specific impulse of liquid methane with several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from combustion-chamber pressure of 600 pounds per square inch absolute to pressure ratio indicated.

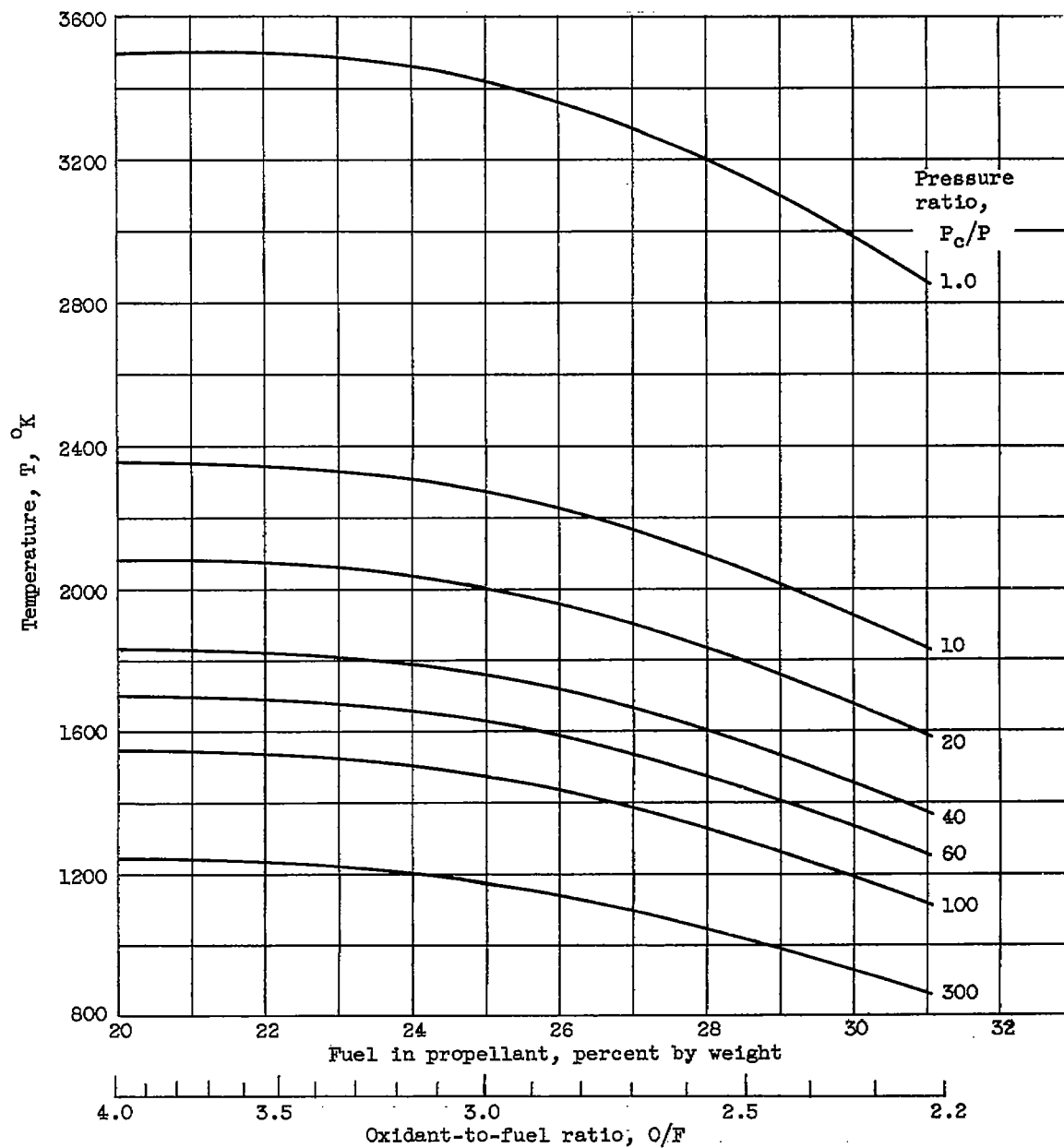


(f) Percent fluorine in oxidant by weight, 78.08 to 82.61.

Figure 1. - Concluded. Theoretical specific impulse of liquid methane with several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from combustion-chamber pressure of 600 pounds per square inch absolute to pressure ratios indicated.

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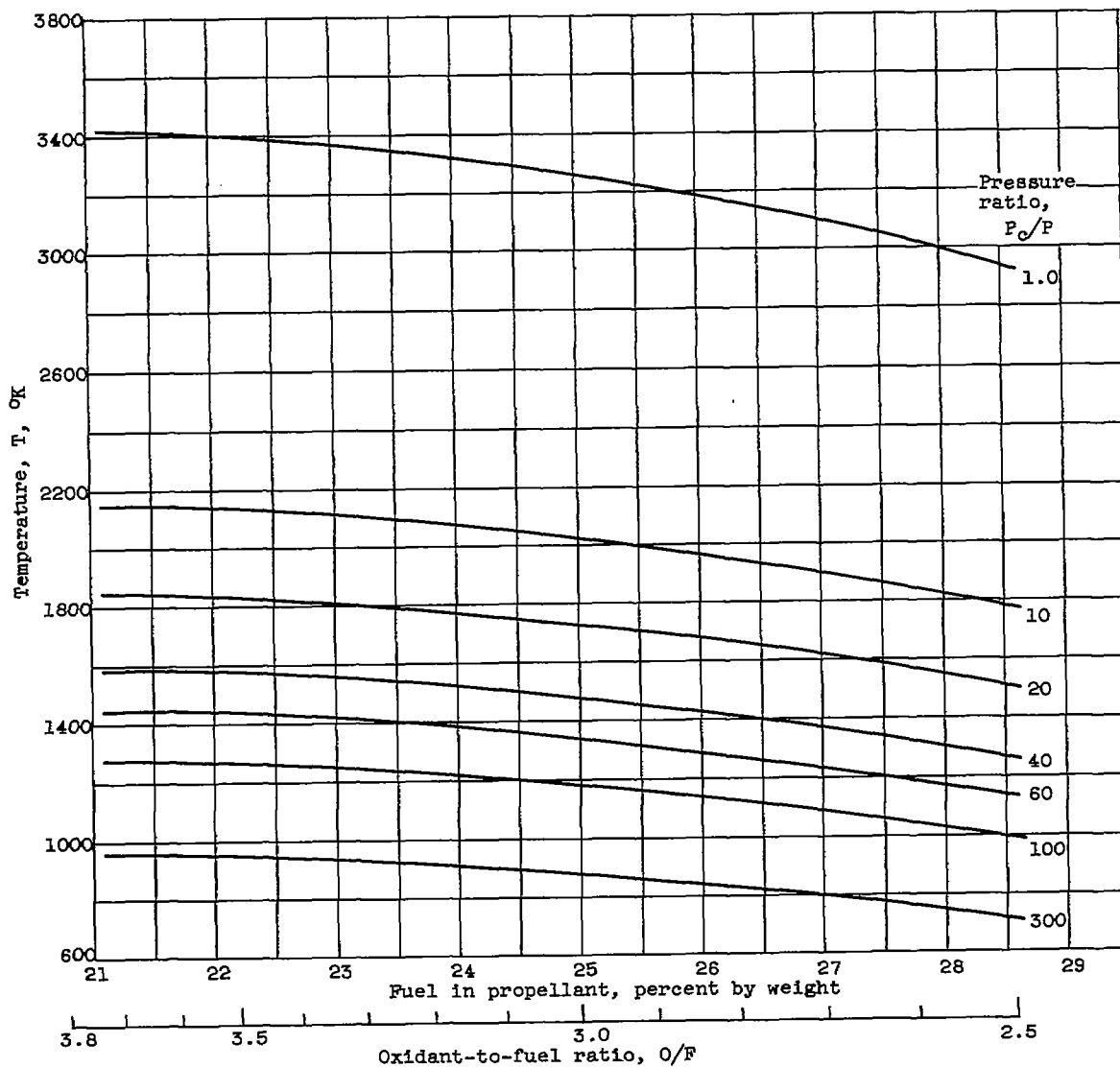
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(a) Percent fluorine in oxidant by weight, 0 (100 percent oxygen).

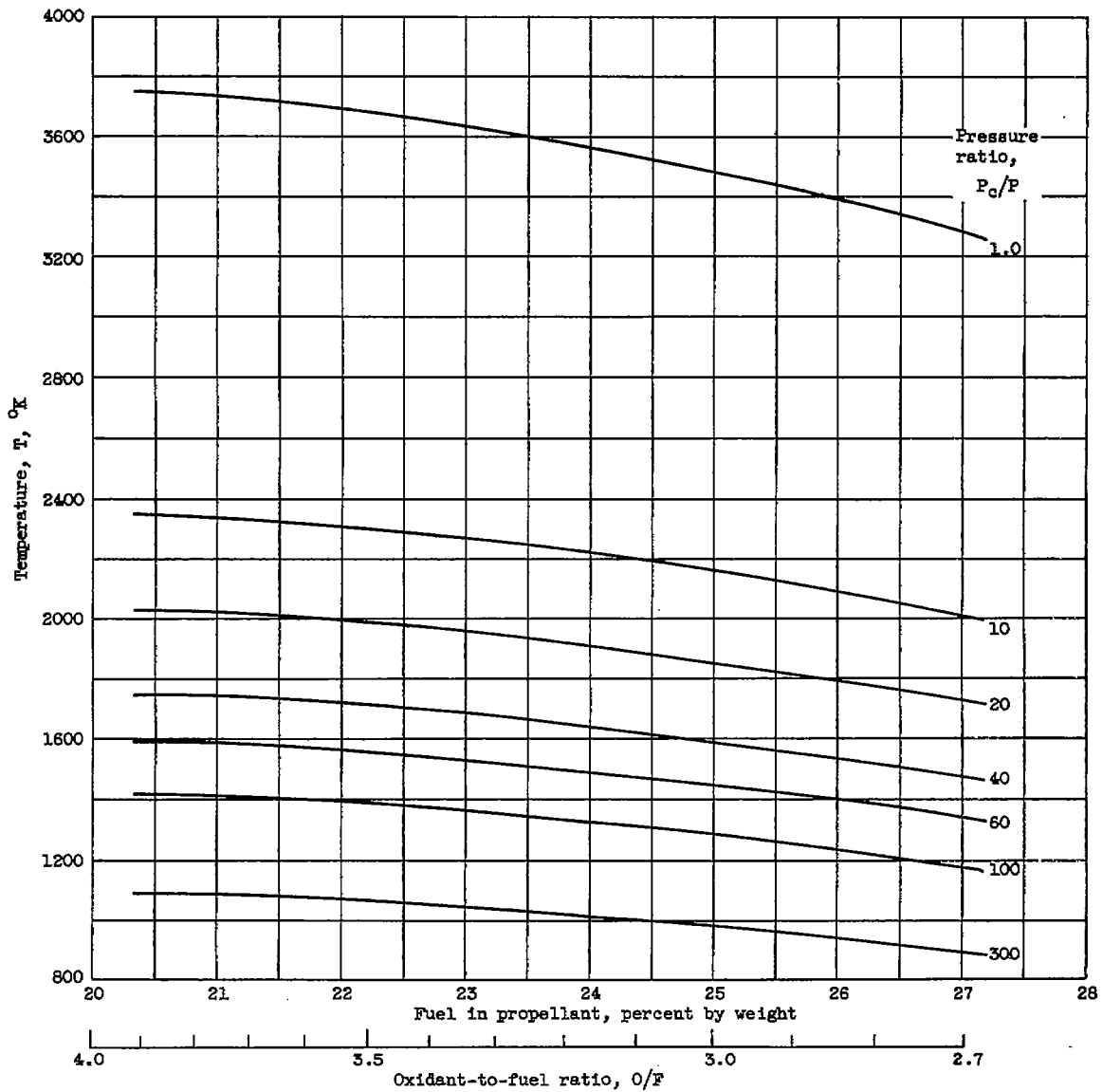
Figure 2. - Theoretical combustion-chamber temperature and nozzle-exit temperature for liquid methane and several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from combustion-chamber pressure of 600 pounds per square inch absolute to pressure ratio indicated.

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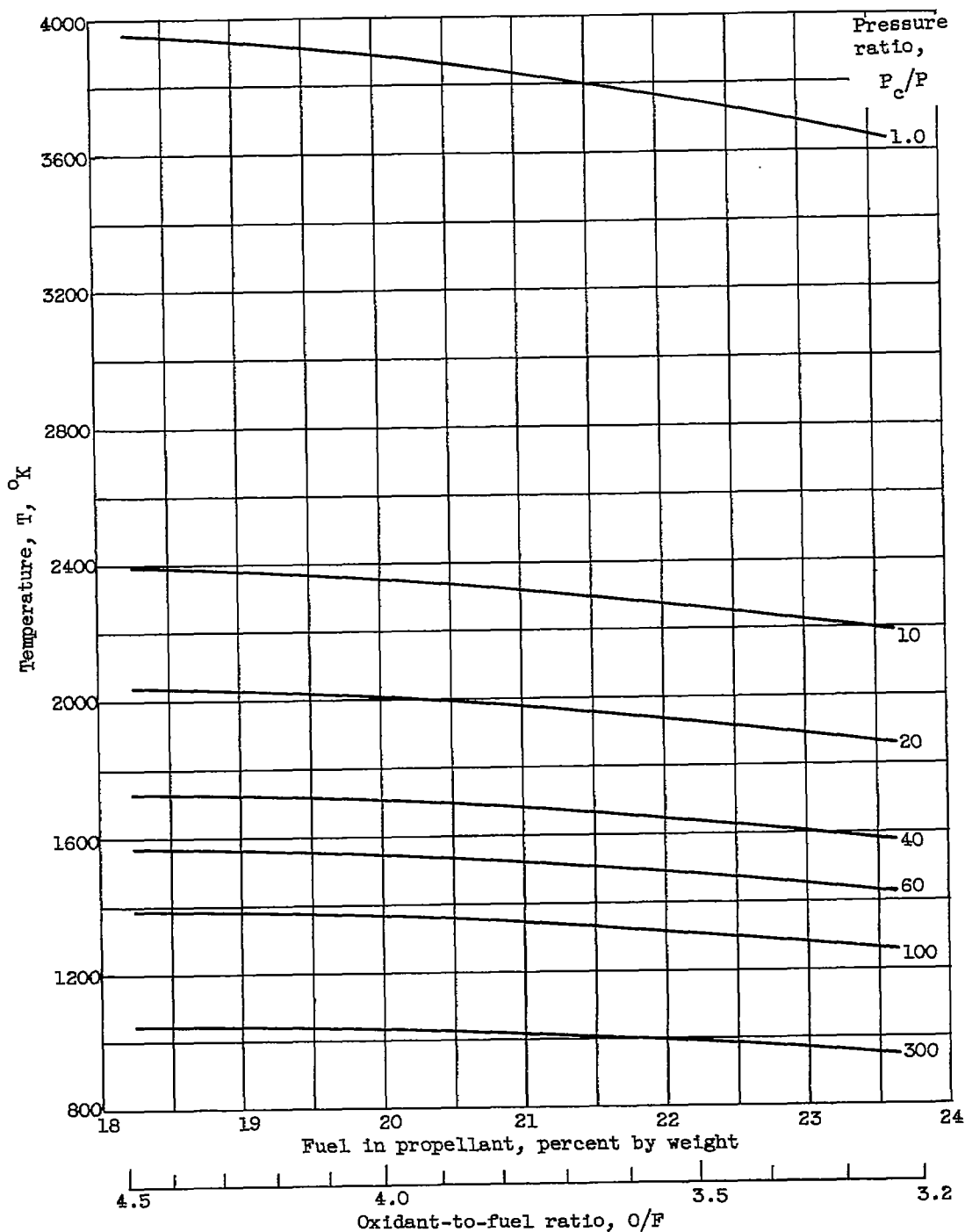
(b) Percent fluorine in oxidant by weight, 19.19.

Figure 2. - Continued. Theoretical combustion-chamber temperature and nozzle-exit temperature for liquid methane and several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from combustion-chamber pressure of 600 pounds per square inch absolute to pressure ratio indicated.



(c) Percent fluorine in oxidant by weight, 37.25.

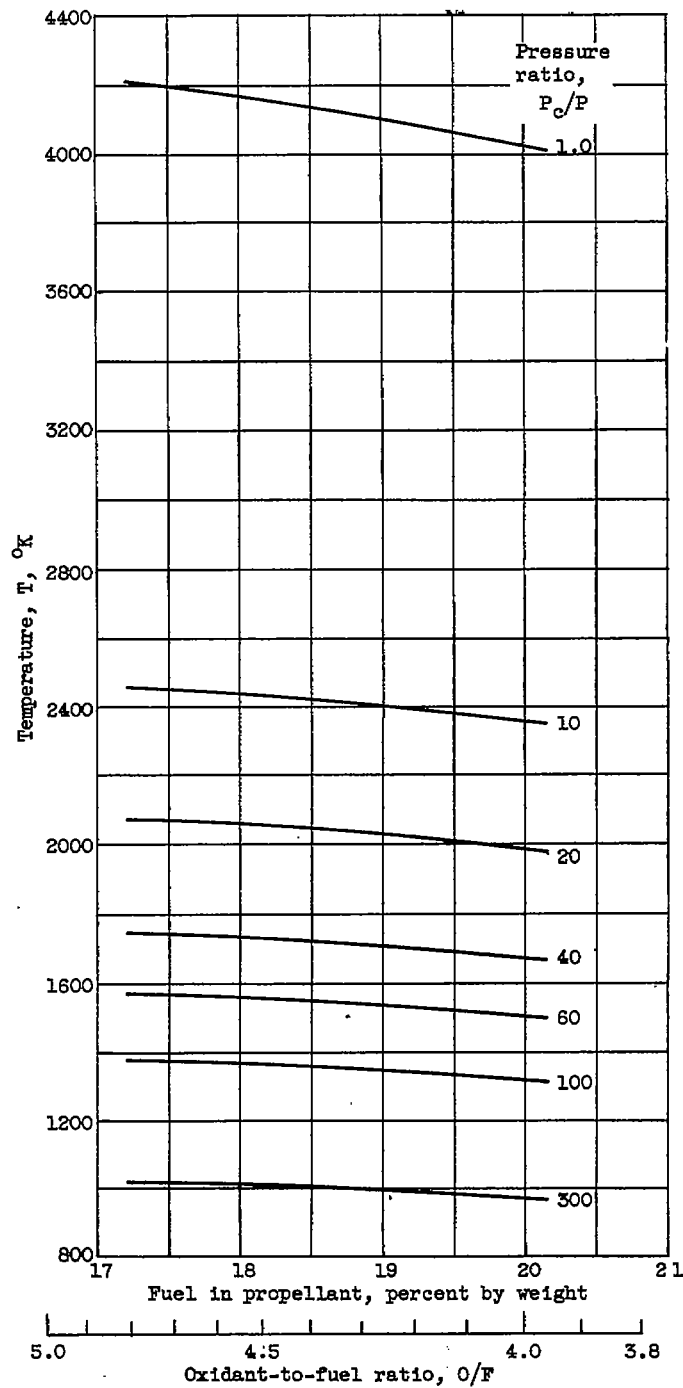
Figure 2. - Continued. Theoretical combustion-chamber temperature and nozzle-exit temperature for liquid methane and several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from combustion-chamber pressure of 600 pounds per square inch absolute to pressure ratio indicated.



(d) Percent fluorine in oxidant by weight, 54.29.

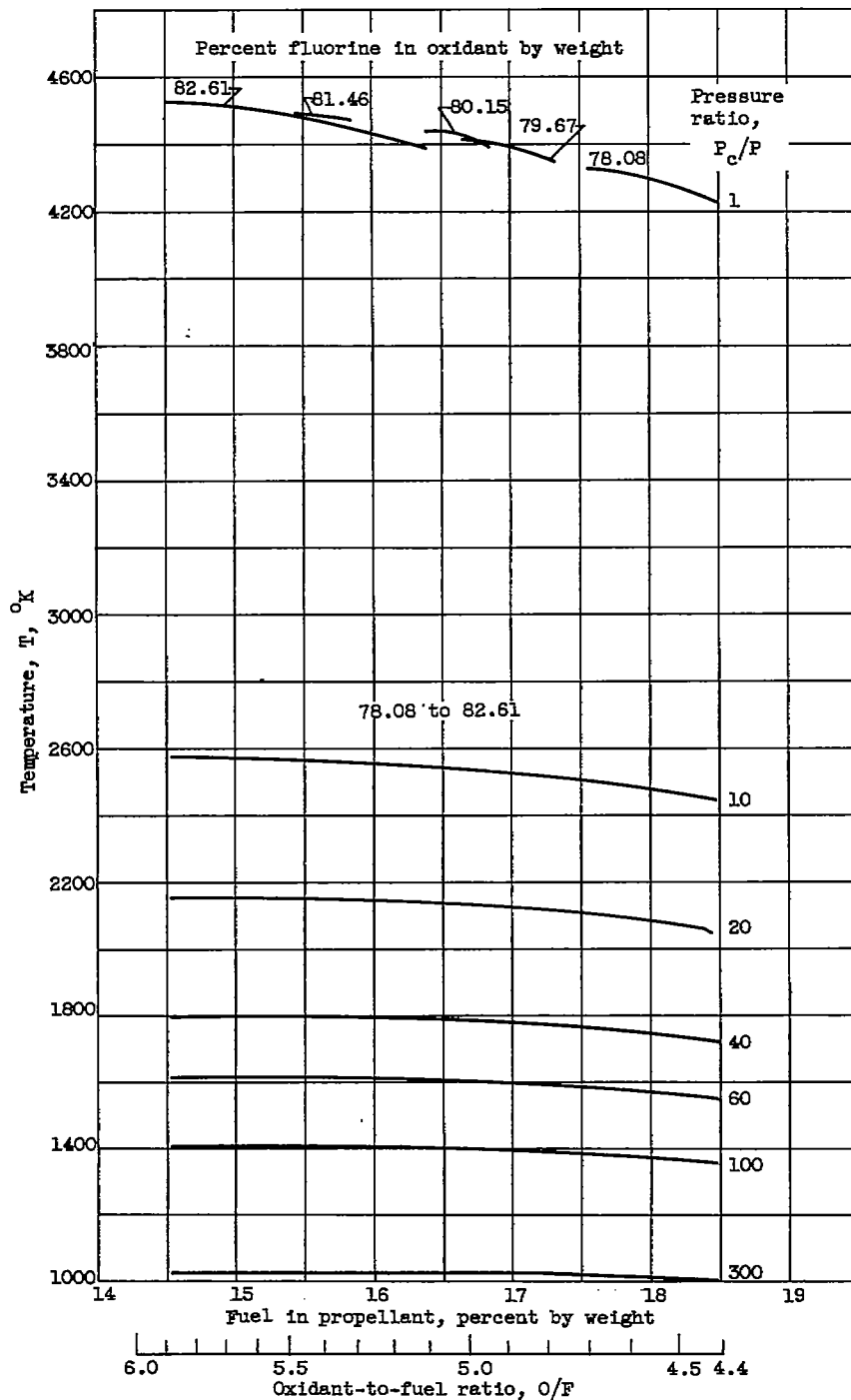
Figure 2. - Continued. Theoretical combustion-chamber temperature and nozzle-exit temperature for liquid methane and several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from combustion-chamber pressure of 600 pounds per square inch absolute to pressure ratio indicated.

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(e) Percent fluorine in oxidant by weight, 70.37.

Figure 2. - Continued. Theoretical combustion-chamber temperature and nozzle-exit temperature for liquid methane and several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from combustion-chamber pressure of 600 pounds per square inch absolute to pressure ratio indicated.



(f) Percent fluorine in oxidant by weight, 78.08 to 82.61.

Figure 2. - Concluded. Theoretical combustion-chamber temperature and nozzle-exit temperature for liquid methane and several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from combustion-chamber pressure of 600 pounds per square inch absolute to pressure ratio indicated.

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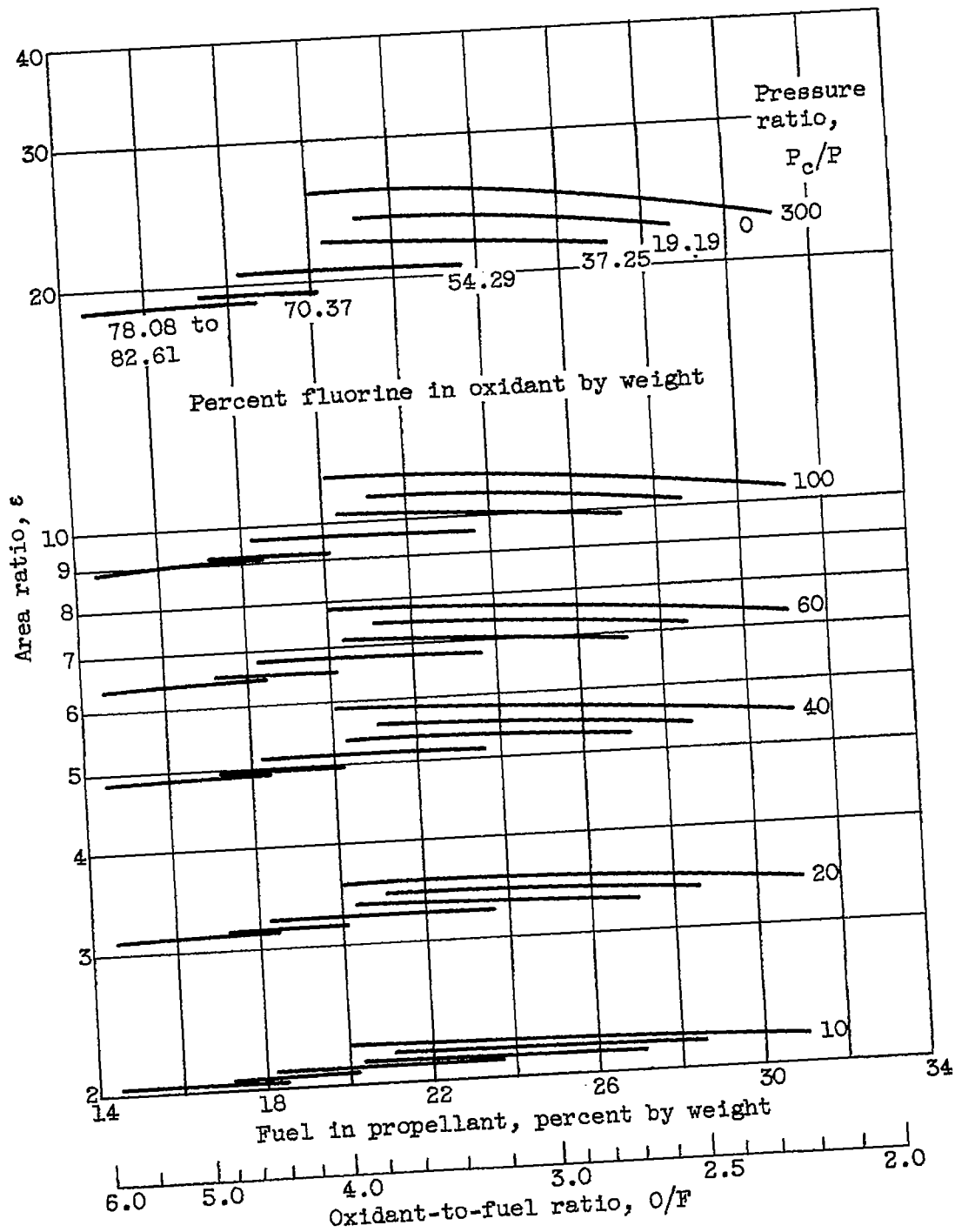


Figure 3. - Theoretical ratio of nozzle area to throat area for liquid methane with several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from combustion-chamber pressure of 600 pounds per square inch absolute to pressure ratio indicated.

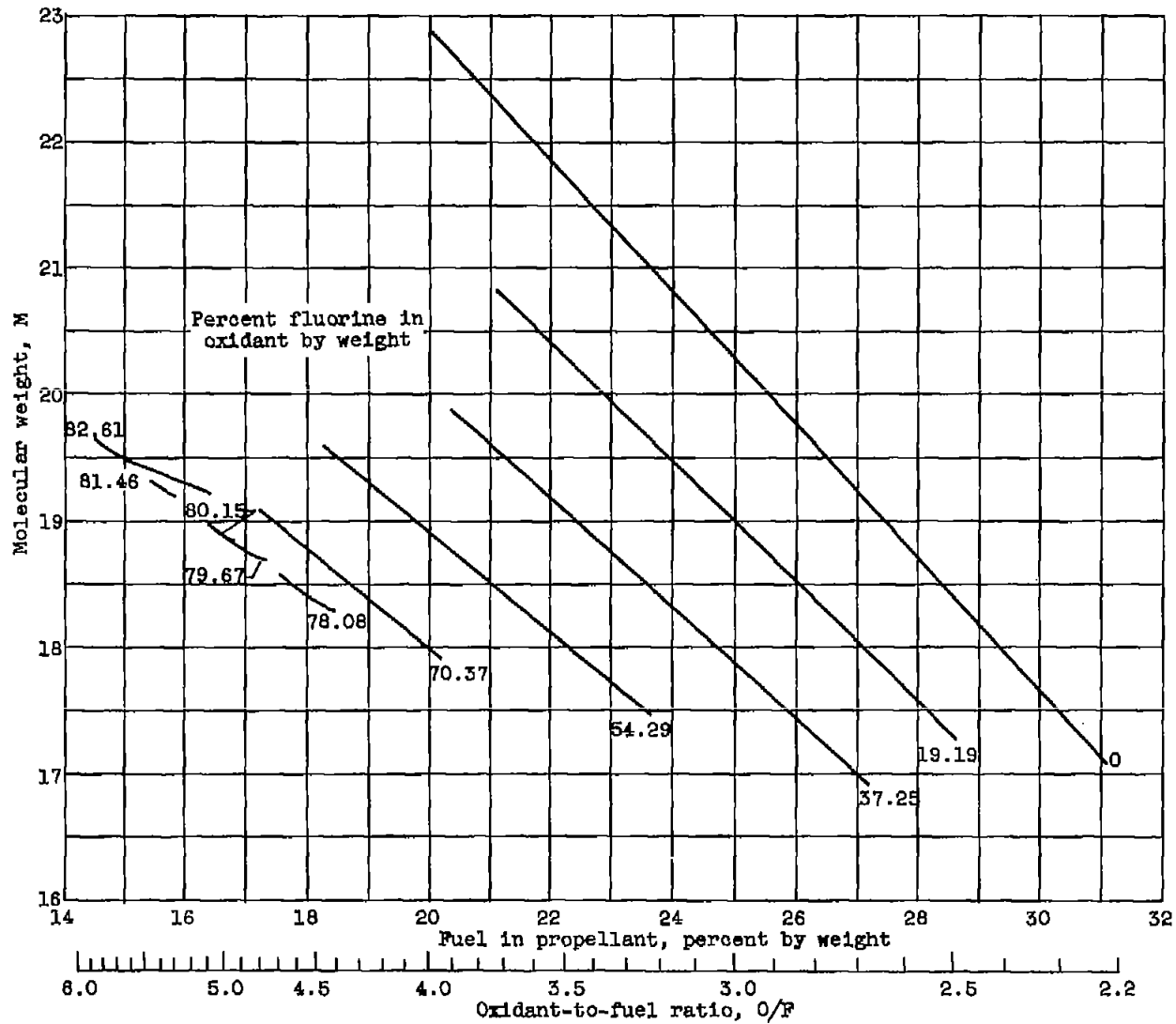


Figure 4. - Theoretical combustion-chamber molecular weight for liquid methane with several fluorine-oxygen mixtures. Combustion-chamber pressure, 600 pounds per square inch absolute.

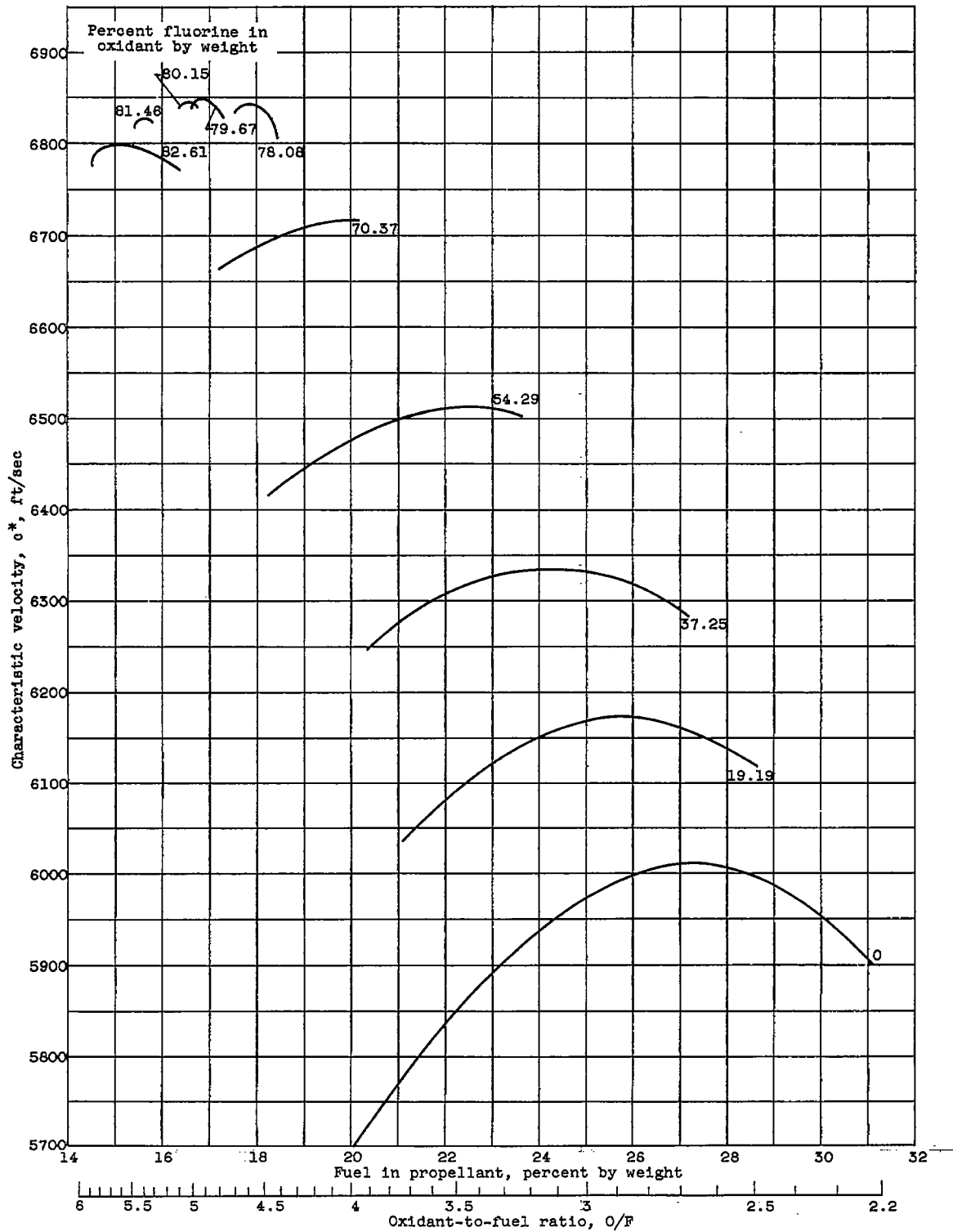


Figure 5. - Theoretical characteristic velocity for liquid methane with several fluorine-oxygen mixtures. Isentropic expansion assuming frozen composition from combustion-chamber pressure of 600 pounds per square inch absolute.

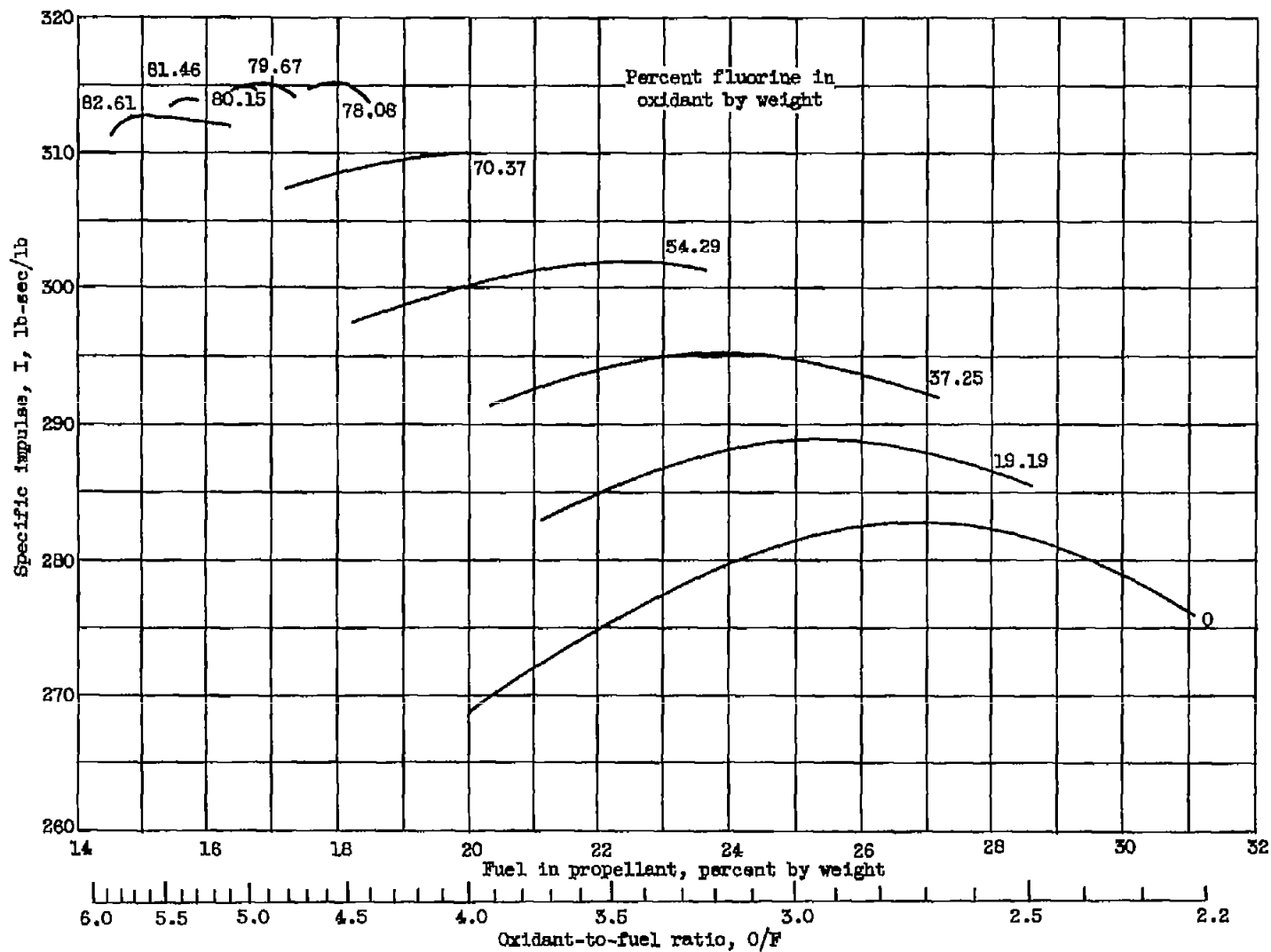


Figure 6. - Theoretical specific impulse for liquid methane with several fluorine-oxygen mixtures. Isentropic expansion assuming frozen composition from combustion-chamber pressure of 600 pounds per square inch absolute to exit pressure of 1 atmosphere.

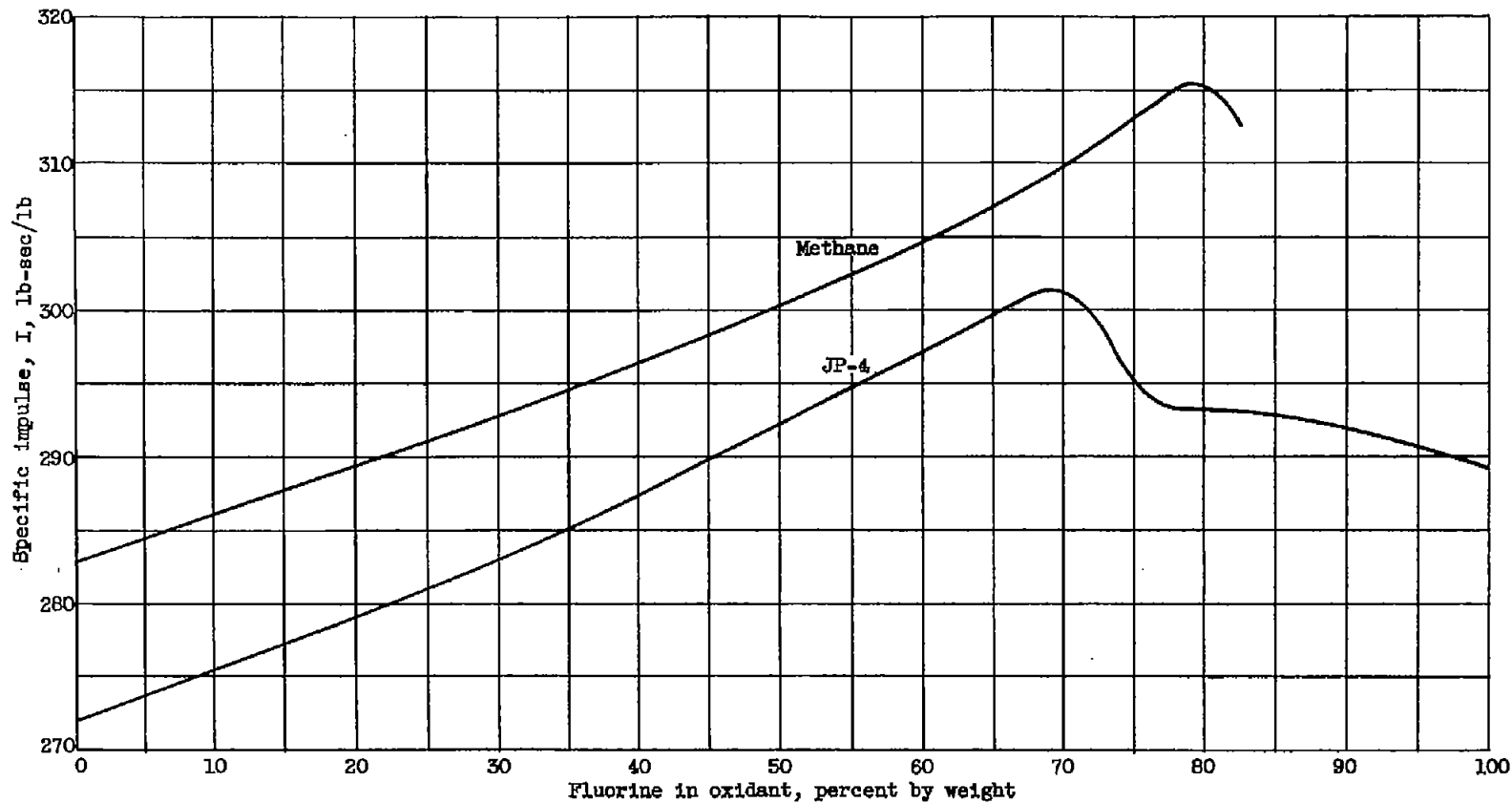


Figure 7. - Comparison of theoretical specific impulse of liquid methane with that of JP-4 fuel both with fluorine-oxygen mixtures at equivalence ratios for which specific impulse is maximum. Frozen composition assumed during isentropic expansion from combustion-chamber pressure of 600 pounds per square inch absolute to 1 atmosphere.