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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

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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. Kestner

## 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, $C_F = g_c I/c^* = F/P_c A_t$

$C_p^\circ$ molar specific heat at constant pressure, cal/(mole)(°K)

$c_p$ specific heat at constant pressure, $\dfrac{\sum_i x_i (C_p^\circ)_i}{M(1 - x_k)}$, 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)

$H_T^\circ$ sum of sensible enthalpy and chemical energy at temperature T, cal/mole

$h$ sum of sensible enthalpy and chemical energy per unit mass, $\dfrac{\sum_i x_i (H_T^\circ)_i}{M(1 - x_k)}$, cal/g

$I$ specific impulse, (lb force)(sec)/lb mass

$k$ coefficient of thermal conductivity, cal/(sec)(cm)(°K)

$M$ molecular weight, $\dfrac{\sum_i x_i M_i}{1 - x_k}$, 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, $\dfrac{4(C) + (H)}{2(O) + (F)}$

$S_T^\circ$ entropy at a pressure of 1 atmosphere, cal/(mole)(°K)

$s$ entropy per unit mass, $\dfrac{\sum_i x_i (S_T^\circ)_i}{M(1 - x_k)} - \dfrac{R \sum_j p_j \ln(p_j/14.696)}{PM}$, cal/(g)(°K)

$T$ temperature, °K

$w$ mass-flow rate, lb/sec

$x$ mole fraction

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

$\epsilon$ ratio of nozzle area to throat area

$\mu$ absolute viscosity, g/(cm)(sec) or poises

$\rho$ 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 refere 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 $CF_2$, carbon trifluoride $CF_3$, carbon tetrafluoride $CF_4$, difluoroacetylene $C_2F_2$, methane $CH_4$, carbon monoxide CO, carbon dioxide $CO_2$, atomic fluorine F, fluorine $F_2$, atomic hydrogen H, hydrogen $H_2$, hydrogen fluoride HF, water $H_2O$, atomic oxygen O, oxygen $O_2$, 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 1.

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.

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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, $H_2$, and HF are given in reference 13. The viscosities of the remaining substances except $H_2O$ were calculated using similar techniques. The viscosity of $H_2O$ 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

$$I = 294.98 \sqrt{\frac{h_c - h_e}{1000}} \tag{1}$$

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

$$\frac{A_t}{w} = \frac{2781.6\ T_t}{P_t M_t a} \tag{2}$$

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

$$c^* = g_c P_c \frac{A_t}{w} = 32.174\ P_c \frac{A_t}{w} \tag{3}$$

Coefficient of thrust

$$\overline{C_F} = \frac{g_c I}{c^*} = \frac{32.174\ I}{c^*} \tag{4}$$

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

$$\frac{A}{w} = \frac{86.455\ T}{PMI} \tag{5}$$

Ratio of nozzle area to throat area

$$\epsilon = \frac{A/w}{A_t/w} \tag{6}$$

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

$$c_p = \frac{\sum_i x_i (C_p^\circ)_i}{M(1 - x_r)} \tag{7}$$

Isentropic exponent

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

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

$$\mu = \frac{PM}{\sum_j \frac{p_j}{\mu_j/M_j}} \tag{9}$$

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

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



## 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.

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 $\epsilon$ 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 $5 \times 10^{-7}$ for all the conditions considered in this report and therefore these substances were also omitted from table V. Performance data for expansion from a 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



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

## REFERENCES

1. Gordon, Sanford, and Wilkins, Roger L.: Theoretical Maximum Performance of Liquid Fluorine - Liquid Oxygen Mixtures with JP-4 as Rocket Propellants. NACA RM E54H09, 1954.

2. Gordon, Sanford, and Drellishak, Kenneth S.: Theoretical Rocket Performance of JP-4 Fuel with Several Fluorine-Oxygen Mixtures Assuming Frozen Composition. NACA RM E57G16a, 1957.

3. Gordon, Sanford: Theoretical Rocket Performance of JP-4 Fuel with Several Fluorine-Oxygen Mixtures Assuming Equilibrium Composition. NACA RM E57K22, 1958.

4. Huff, Vearl N., Gordon, Sanford, and Morrell, Virginia E.: General Method and Thermodynamic Tables for Computation of Equilibrium Composition and Temperature of Chemical Reactions. NACA Rep. 1037, 1951. (Supersedes NACA TN's 2113 and 2161.)

5. Anon: Tables of Selected Values of Chemical Thermodynamic Properties. Table 23, Substance C, Ser. III (C, graphite), NBS, Mar. 31, 1947 and June 30, 1948.

6. Haar, Lester, and Beckett, Charles W.: Thermal Properties of Fluorine Compounds: Heat Capacity, Entropy, Heat Content and Free Energy Functions of Carbon Monofluoride in the Ideal Gaseous State. Rep. 1164, NBS, Oct. 1, 1951. (Office Naval Res. Contract NAonr 112-51.)

7. Potocki, Rita M., and Mann, David Emerson: Thermal Properties of Fluorine Compounds: Heat Capacity, Entropy, Heat Content and Free Energy Functions of Carbon Difluoride, Carbon Trifluoride, Carbon Tetrafluoride and Difluoroacetylene in the Ideal Gaseous State. Rep. 1439, NBS, Feb. 15, 1952. (Office Naval Res. Contract NAonr 112-51.)

8. Glatt, Leonard, Adams, Joan H., and Johnston, Herrick L.: Thermodynamic Properties of the $H_2O$ Molecule from Spectroscopic Data. Tech. Rep. 316-8, Cryogenic Lab., Dept. Chem., Ohio State Univ., June 1, 1953. (Navy Contract N6onr-225, Task order XII, ONR Proj. NR 085-005.)

9. Herzberg, Gerhard: Infrared and Raman Spectra of Polyatomic Molecules. D. Van Nostrand Co., Inc., 1945, p. 308.

10. Rossini, Frederick, D., et al.: Selected Values of Chemical Thermodynamic Properties. Circ. 500, NBS, Feb. 1952.

11. Washburn, Edward W., ed.: International Critical Tables. Vol. 1-7. McGraw-Hill Book Co., Inc., 1928.

12. Kilner, Scott B., Randolph, Carl L., Jr., and Gillespie, Rollin W.: The Density of Liquid Fluorine. Jour. Am. Chem. Soc., vol. 74, no. 4, 1952, pp. 1086-1087.

13. Gordon, Sanford, and Huff, Vearl N.: Theoretical Performance of Liquid Hydrogen and Liquid Fluorine as a Rocket Propellant. NACA RM E52L11, 1953.

14. Keyes, Frederick G.: Thermal Conductivities for Several Gases with a Description of New Means for Obtaining Data at Low Temperatures and Above 500° C. Tech. Memo. No. 1, Proj. Squid, M.I.T., Oct. 1, 1952. (Contract N5-ori-07855.)

15. Huff, Vearl N., Fortini, Anthony, and Gordon, Sanford: Theoretical Performance of JP-4 Fuel and Liquid Oxygen as a Rocket Propellant. II - Equilibrium Composition. NACA RM E56D23, 1956.



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 |

[a]At -182.0° C; ref. 11.
[b]At -196° C; ref. 12.
[c]At -161.5° C; ref. 11.
[d]Ref. 10.
[e]At 1.1 mm Hg.
[f]At 87.7 mm Hg.
[g]Ref. 4.
[h]Unpublished NACA calculations based on data of ref. 9.
[i]At -182.97° C.
[j]At -187.92° C.
[k]At -161.49° C.
[l]At -218.76° C.
[m]At -217.96° C.
[n]At -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, $\Phi$ $\frac{4(C)+(H)}{2(O)+(F)}$ | Fuel, percent by weight | Oxidant-to-fuel weight ratio, O/F | Temperature, T, °K | Molecular weight, M | Enthalpy, h, cal/g (a) | Entropy, s, $\frac{cal}{(g)(°K)}$ | Specific heat, $c_p$, $\frac{cal}{(g)(°K)}$ (b) | Isentropic exponent, $\gamma$ (b) | Density-weight-average vel. of sound, a, m/sec (b) |
|---|---|---|---|---|---|---|---|---|---|
| Percent fluorine in oxidant, 0 (100 percent oxygen) | | | | | | | | | |
| 1.00 | 20.04 | 3.990 | 4437 | 22.37 | 2046.7 | 2.4259 | 0.514 | 1.201 | 5[illegible] |
| 1.30 | 24.58 | 3.069 | 4444 | 20.54 | 3247.1 | 2.6420 | .565 | 1.207 | 5[illegible] |
| 1.40 | 25.99 | 2.850 | 4472 | 19.90 | 3413.6 | [illegible] | .574 | 1.210 | 5[illegible] |
| 1.50 | 27.32 | 2.660 | 4272 | 19.05 | 3595.5 | [illegible] | .590 | 1.215 | [illegible] |
| 1.60 | 28.62 | 2.495 | 4147 | 18.39 | 3765.0 | [illegible] | .600 | 1.220 | 5[illegible] |
| 1.80 | 31.09 | 2.210 | 3955 | 17.10 | 4046.6 | [illegible] | [illegible] | [illegible] | [illegible] |
| Percent fluorine in oxidant by weight, 13.19 | | | | | | | | | |
| 1.20 | 21.10 | 3.740 | 4622 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.40 | 23.78 | 3.206 | 4556 | 19.69 | 3469.2 | [illegible] | .545 | [illegible] | [illegible] |
| 1.50 | 25.05 | 2.972 | [illegible] | [illegible] | 3621.4 | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.60 | 26.28 | 2.765 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.80 | 28.62 | 2.405 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Percent fluorine in oxidant by weight, [illegible] | | | | | | | | | |
| 1.30 | 22.75 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.50 | 22.77 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.60 | 25.38 | 3.174 | 4572 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.70 | 26.05 | 2.992 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.90 | 27.19 | 2.677 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Percent fluorine in oxidant by weight, 61.09 | | | | | | | | | |
| 1.30 | 18.26 | 4.475 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.40 | 19.40 | 4.150 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.50 | 20.50 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.60 | 21.57 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.80 | 23.73 | 3.232 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Percent fluorine in oxidant by weight, 70.47 | | | | | | | | | |
| 1.40 | 17.22 | 4.639 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.50 | 18.02 | 4.488 | 4157 | [illegible] | [illegible] | 2.9830 | [illegible] | [illegible] | [illegible] |
| 1.60 | 19.20 | 4.245 | 4091 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.70 | 20.12 | 3.960 | 4014 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Percent fluorine in oxidant by weight, 74.08 | | | | | | | | | |
| 1.55 | 17.55 | 4.697 | 4355 | [illegible] | [illegible] | 2.6700 | [illegible] | [illegible] | [illegible] |
| 1.60 | 18.02 | 4.551 | 4296 | [illegible] | [illegible] | 2.9990 | [illegible] | [illegible] | [illegible] |
| 1.65 | 18.48 | 4.413 | 4229 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Percent fluorine in oxidant by weight, 78.07 | | | | | | | | | |
| 1.45 | 16.86 | 5.005 | 4410 | [illegible] | [illegible] | 2.9272 | [illegible] | [illegible] | [illegible] |
| 1.51 | 16.94 | 4.904 | 4402 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.55 | 17.31 | 4.777 | 4351 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Percent fluorine in oxidant by weight, [illegible] | | | | | | | | | |
| 1.46 | [illegible] | 5.098 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.48 | 16.59 | 5.029 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.50 | 16.77 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Percent fluorine in oxidant by weight, [illegible] | | | | | | | | | |
| 1.39 | 15.45 | 5.471 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.40 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.42 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Percent fluorine in oxidant by weight, [illegible] | | | | | | | | | |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1.40 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

[a]The base used for enthalpy is given in ref. 4.
[b]Parameters 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 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, $\gamma$ | Specific heat, $c_p$, $\frac{cal}{(g)(°K)}$ | Absolute viscosity, $\mu$, micropoises | Thermal conductivity, k, $\frac{cal}{(cm)(sec)(°K)}$ | Area ratio, $\epsilon$ | Thrust coefficient, $C_F$ | Specific impulse, $I_s$, $\frac{lb-sec}{lb}$ |
|---|---|---|---|---|---|---|---|---|---|
| F, 1.00 (100 percent fuel); O/F, 2.990 | | | | | | | | | |
| 3600 | 714.07 | 2469.4 | 1.200 | 0.5212 | 865 | 0.00056 | | | |
| 3200 | 354.07 | 2492.4 | 1.204 | .5138 | 829 | .00052 | 1.00 | 0.652 | 115.5 |
| 2800 | 161.89 | 2288.8 | 1.208 | .5047 | 761 | .00047 | 1.26 | .995 | 176.3 |
| 2400 | 66.796 | 2089.0 | 1.214 | .4933 | 688 | .00041 | 2.09 | 1.242 | 220.1 |
| 2000 | 24.097 | 1894.5 | 1.222 | .4783 | 609 | .00036 | 4.14 | 1.443 | 255.7 |
| 1600 | 7.240 | 1707.1 | 1.234 | .4578 | 523 | .00030 | 9.9 | 1.613 | 285.6 |
| 1200 | 1.664 | 1529.4 | 1.254 | .4280 | 427 | .00023 | 29.56 | 1.759 | 311.7 |
| 900 | .423 | 1404.0 | 1.277 | .4008 | 346 | .00018 | 86.95 | 1.855 | 328.6 |
| 600 | .071 | 1289.4 | 1.309 | .3684 | 252 | .00012 | 317.07 | 1.939 | 343.5 |
| F, 1.30 (77.42 percent fuel); O/F, 4.000 | | | | | | | | | |
| 3600 | 777.80 | 3925.6 | 1.205 | 0.5679 | 870 | 0.00065 | | | |
| 3200 | 391.56 | 3130.0 | 1.209 | .5597 | 807 | .00045 | 1.02 | 0.590 | 104.2 |
| 2800 | 182.10 | 2818.0 | 1.214 | .5497 | 740 | .00041 | 1.19 | .954 | 170.8 |
| 2400 | 76.507 | 2507.6 | 1.220 | .5372 | 669 | .00036 | 1.91 | 1.209 | 224.1 |
| 2000 | 28.272 | 2248.8 | 1.228 | .5208 | 593 | .00031 | 3.65 | 1.414 | 261.9 |
| 1600 | 8.733 | 2244.9 | 1.241 | .4978 | 510 | .00025 | 8.57 | 1.567 | 293.8 |
| 1200 | 2.045 | 2051.9 | 1.259 | .4657 | 417 | .00019 | 24.44 | 1.734 | 321.1 |
| 900 | .547 | 1918.7 | 1.284 | .4350 | 337 | .00015 | 66.20 | 1.830 | 336.0 |
| 600 | .095 | 1791.2 | 1.318 | .4019 | 245 | .00010 | 242.19 | 1.915 | 354.7 |
| F, 1.40 (71.43 percent fuel); O/F, 3.850 | | | | | | | | | |
| 3600 | 875.72 | 3551.9 | 1.208 | 0.5825 | 864 | 0.00061 | | | |
| 3200 | 444.25 | 3320.5 | 1.212 | .5740 | 802 | .00055 | 1.07 | 0.496 | 97.6 |
| 2800 | 208.99 | 3092.0 | 1.217 | .5637 | 732 | .00051 | 1.12 | .904 | 168.6 |
| 2400 | 88.535 | 2865.9 | 1.224 | .5504 | 665 | .00045 | 1.74 | 1.173 | 218.7 |
| 2000 | 33.048 | 2652.8 | 1.232 | .5338 | 590 | .00039 | 3.69 | 1.386 | 258.3 |
| 1600 | 10.348 | 2443.7 | 1.245 | .5103 | 507 | .00032 | 7.46 | 1.563 | 291.4 |
| 1200 | 2.512 | 2245.9 | 1.266 | .4775 | 415 | .00025 | 21.01 | 1.714 | 319.6 |
| 900 | .669 | 2117.2 | 1.291 | .4463 | 334 | .00019 | 55.96 | 1.813 | 337.9 |
| 600 | .114 | 1978.3 | 1.322 | .4124 | 244 | .00013 | 200.88 | 1.900 | 354.1 |
| F, 1.50 (66.67 percent fuel); O/F, 3.333 | | | | | | | | | |
| 3600 | 1034.4 | 3760.2 | 1.211 | 0.5707 | 860 | 0.00062 | | | |
| 3200 | 529.34 | 3553.2 | 1.215 | .5680 | 796 | .00057 | 1.45 | 0.524 | 91.6 |
| 2800 | 250.76 | 3320.1 | 1.220 | .5774 | 732 | .00052 | 1.05 | .829 | 154.5 |
| 2400 | 107.73 | 3091.7 | 1.226 | .5641 | 663 | .00046 | 1.51 | 1.121 | 209.4 |
| 2000 | 40.735 | 2869.4 | 1.235 | .5468 | 587 | .00040 | 2.84 | 1.345 | 251.3 |
| 1600 | 12.952 | 2653.3 | 1.249 | .5228 | 505 | .00033 | 6.51 | 1.531 | 284.4 |
| 1200 | 3.202 | 2452.8 | 1.270 | .4892 | 413 | .00026 | 17.30 | 1.688 | 315.3 |
| 900 | .868 | 2310.5 | 1.295 | .4575 | 335 | .00020 | 45.61 | 1.795 | 334.4 |
| 600 | .158 | 2178.2 | 1.326 | .4239 | 244 | .00014 | 158.99 | 1.880 | 351.2 |
| F, 1.60 (62.50 percent fuel); O/F, 2.500 | | | | | | | | | |
| 3200 | 658.21 | 3796.8 | 1.210 | 0.6018 | 795 | 0.00059 | | | |
| 2800 | 315.14 | 3558.3 | 1.224 | .5907 | 730 | .00053 | 1.00 | 0.720 | 134.1 |
| 2400 | 137.03 | 3324.8 | 1.230 | .5771 | 660 | .00047 | 1.35 | 1.050 | 195.5 |
| 2000 | 52.541 | 3097.2 | 1.240 | .5592 | 584 | .00041 | 2.14 | 1.293 | 241.1 |
| 1600 | 16.978 | 2878.2 | 1.253 | .5348 | 504 | .00034 | 5.14 | 1.491 | 277.6 |
| 1200 | 4.274 | 2670.7 | 1.275 | .5000 | 413 | .00026 | 13.55 | 1.655 | 308.5 |
| 900 | 1.117 | 2525.0 | 1.299 | .4693 | 335 | .00020 | 35.46 | 1.762 | 326.5 |
| 600 | .214 | 2399.3 | 1.330 | .4357 | 244 | .00014 | 121.46 | 1.856 | 342.0 |
| F, 1.70 (58.82 percent fuel); O/F, 2.353 | | | | | | | | | |
| 3200 | 1103.9 | 4001.3 | 1.207 | 0.6273 | 795 | 0.00061 | | | |
| 2800 | 540.88 | 4054.3 | 1.212 | .6164 | 727 | .00055 | 1.57 | 0.597 | 114.5 |
| 2400 | 240.90 | 3808.5 | 1.219 | .6022 | 659 | .00049 | 1.16 | .848 | 165.5 |
| 2000 | 94.990 | 3571.2 | 1.229 | .5837 | 584 | .00043 | 1.84 | 1.155 | 211.8 |
| 1600 | 31.710 | 3342.4 | 1.243 | .5585 | 503 | .00035 | 3.67 | 1.367 | 254.3 |
| 1200 | 8.319 | 3125.8 | 1.265 | .5242 | 412 | .00028 | 8.47 | 1.537 | 291.5 |
| 900 | 2.359 | 2973.0 | 1.290 | .4926 | 335 | .00021 | 20.57 | 1.677 | 315.3 |
| 600 | .450 | 2830.1 | 1.320 | .4598 | 244 | .00015 | 67.74 | 1.7[illegible] | 331.6 |

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, 19.15

| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|
| P, [illegible], percent fuel, [illegible] | | | | | | | | | | |
| 4000 | 1036.0 | 3215.7 | 1.471 | 0.5270 | 1044 | 0.00168 | | | | |
| 3600 | [illegible] | 3004.1 | 1.428 | .5209 | 975 | .00162 | 1.07 | | 0.188 | 31 |
| 3200 | 914.55 | 2790.1 | 1.428 | .5136 | 901 | .00157 | 1.21 | | .755 | 137 |
| 2800 | 851.21 | 2553.6 | 1.439 | .5047 | 823 | .00151 | 1.49 | | 1.322 | 191 |
| 2400 | 767.44 | 2315.6 | 1.460 | .4934 | 740 | .00145 | 1.78 | | 1.267 | 232 |
| 2000 | 654.64 | 2061.3 | 1.469 | .4790 | 652 | .00139 | 2.18 | | 1.421 | 264 |
| 1600 | 5.457 | 1813.9 | 1.452 | .4602 | 557 | .00132 | 2.68 | | 1.578 | 285 |
| 1200 | 2.314 | 1534.7 | 1.419 | .4319 | 452 | .00123 | 3.31 | | 1.716 | 292 |
| 800 | .631 | 1228.0 | 1.307 | .4043 | 343 | .00119 | 5.34 | | 1.796 | 259 |
| P, [illegible], percent fuel, [illegible] | | | | | | | | | | |
| 3600 | 660.36 | 3194.7 | 1.437 | 0.5492 | 954 | 0.00162 | | | | |
| 3200 | 595.70 | 3013.5 | 1.431 | .5414 | 887 | .00156 | 1.08 | | 0.601 | 126 |
| 2800 | 525.53 | 2821.1 | 1.424 | .5320 | 817 | .00151 | 1.18 | | .574 | 150 |
| 2400 | 457.47 | 2611.5 | 1.442 | .5202 | 747 | .00147 | 1.44 | | 1.171 | 237 |
| 2000 | 36.665 | 2383.4 | 1.432 | .5047 | 661 | .00140 | 1.91 | | 1.321 | 277 |
| 1600 | 1.441 | 2147.4 | 1.426 | .4835 | 564 | .00131 | 2.47 | | 1.551 | 290 |
| 1200 | 2.761 | 1836.7 | 1.407 | .4585 | 463 | .00121 | 3.17 | | 1.682 | 291 |
| 800 | .761 | 1507.7 | 1.311 | .4277 | 354 | .00112 | 4.73 | | 1.772 | 261 |
| P, [illegible], percent fuel, [illegible] | | | | | | | | | | |
| 3600 | 742.44 | 3400.4 | 1.423 | .5629 | 968 | .00168 | | | | |
| 3200 | 685.06 | 3224.5 | 1.419 | .5549 | 911 | .00161 | 1.06 | | 0.596 | 131 |
| 2800 | 624.27 | 3034.5 | 1.414 | .5451 | 844 | .00154 | 1.14 | | 1.175 | 175 |
| 2400 | 557.54 | 2824.8 | 1.414 | .5329 | 765 | .00147 | 1.37 | | 1.372 | 216 |
| 2000 | 483.554 | 2593.7 | 1.414 | .5170 | 677 | .00141 | 1.70 | | 1.505 | 251 |
| 1600 | 12.784 | 2343.0 | 1.414 | .4955 | 578 | .00132 | 2.12 | | 1.573 | 274 |
| 1200 | 3.224 | 2035.8 | 1.397 | .4654 | 472 | .00121 | 2.67 | | 1.675 | 287 |
| 800 | .892 | 2139.9 | 1.314 | .4394 | 354 | .00120 | 3.55 | | 1.749 | 287 |
| P, [illegible], percent fuel, [illegible] | | | | | | | | | | |
| 3600 | 862.51 | 3618.7 | 1.451 | 0.5747 | 1047 | 0.00167 | | | | |
| 3200 | 862.85 | 3485.8 | 1.435 | .5679 | 971 | .00161 | 1.05 | | 0.601 | 140 |
| 2800 | 795.51 | 3342.8 | 1.440 | .5574 | 891 | .00155 | 1.13 | | .867 | 168 |
| 2400 | .91 | 3139.0 | 1.447 | .5453 | 798 | .00149 | 1.31 | | 1.147 | 218 |
| 2000 | .763 | 2924.9 | 1.457 | .5290 | 694 | .00142 | 1.54 | | 1.355 | 255 |
| 1600 | 1.328 | 2717.5 | 1.471 | .5088 | 582 | .00135 | 1.86 | | 1.507 | 277 |
| 1200 | .922 | 2520.8 | 1.443 | .4776 | 461 | .00127 | 2.31 | | 1.631 | 287 |
| 800 | 1.144 | 2383.8 | 1.317 | .4491 | 335 | .00121 | 3.42 | | 1.751 | 293 |
| P, [illegible], percent fuel, [illegible] | | | | | | | | | | |
| 3200 | 944.23 | 4026.8 | 1.241 | 0.5931 | 1064 | [illegible] | | | | |
| 2800 | 945.76 | 3986.8 | 1.244 | .5922 | 1000 | [illegible] | 1.06 | | 0.633 | 167 |
| 2400 | 939.76 | 3939.1 | 1.253 | .5903 | 919 | [illegible] | 1.14 | | 1.073 | 196 |
| 2000 | 45.850 | 3884.7 | 1.263 | .5923 | 829 | [illegible] | 1.27 | | 1.247 | 231 |
| 1600 | 22.080 | 3818.1 | 1.278 | .5903 | 730 | [illegible] | 1.52 | | 1.432 | 271 |
| 1200 | 6.324 | 3912.3 | 1.325 | .5883 | 627 | [illegible] | 1.96 | | 1.631 | 314 |
| 800 | 1.889 | 3746.8 | 1.329 | .4706 | 354 | [illegible] | 2.93 | | 1.731 | 314 |
| (b) Percent fluorine in oxidant by weight, 37.25 | | | | | | | | | | |
| P, [illegible], percent fuel, 20.05, OF, 3.015 | | | | | | | | | | |
| 4000 | 878.44 | 3271.0 | 1.444 | 0.5088 | 1163 | 0.00074 | | | | |
| 3600 | 864.18 | 3148.7 | 1.448 | .5029 | 1080 | .00068 | 1.21 | | 0.622 | 81 |
| 3200 | 770.01 | 3048.9 | 1.452 | .4960 | 994 | .00062 | 1.57 | | .788 | 133 |
| 2800 | 139.97 | 2972.1 | 1.458 | .4876 | 904 | .00055 | 1.92 | | 1.065 | 203 |
| 2400 | 66.31 | 2878.7 | 1.465 | .4773 | 809 | .00049 | 2.21 | | 1.284 | 240 |
| 2000 | 28.192 | 2790.7 | 1.475 | .4638 | 704 | .00042 | 2.69 | | 1.405 | 272 |
| 1600 | 10.215 | 2708.6 | 1.480 | .4456 | 601 | .00038 | 3.13 | | 1.487 | 290 |
| 1200 | 2.935 | 2535.1 | 1.511 | .4212 | 493 | .00026 | 16.92 | | 1.671 | 326 |
| 800 | .902 | 2611.9 | 1.394 | .3944 | 384 | .00020 | 34.35 | | 1.754 | 340 |
| P, [illegible], percent fuel, 22.77, OF, 4.991 | | | | | | | | | | |
| 4000 | 953.46 | 3633.8 | 1.445 | 0.5355 | 1138 | 0.00076 | | | | |
| 3600 | 939.97 | 3427.9 | 1.449 | .5292 | 1054 | .00070 | 1.25 | | 0.244 | 47 |
| 3200 | 911.72 | 3211.7 | 1.459 | .5214 | 973 | .00064 | 1.46 | | .730 | 141 |
| 2800 | 141.38 | 3003.7 | 1.458 | .5120 | 885 | .00057 | 1.69 | | .900 | 156 |
| 2400 | 76.979 | 2800.7 | 1.464 | .5018 | 793 | .00050 | 1.94 | | 1.237 | 237 |
| 2000 | 32.488 | 2602.7 | 1.476 | .4875 | 693 | .00043 | 2.16 | | 1.379 | 271 |
| 1600 | 11.852 | 2411.4 | 1.491 | .4681 | 590 | .00035 | 6.49 | | 1.520 | 305 |
| 1200 | 3.431 | 2229.8 | 1.519 | .4427 | 478 | .00027 | 15.56 | | 1.657 | 325 |
| 800 | 1.060 | 2049.8 | 1.396 | .4103 | 360 | .00021 | 32.72 | | 1.742 | 342 |
| P, [illegible], percent fuel, 23.97, OF, 3.179 | | | | | | | | | | |
| 4000 | 424.14 | 3464.4 | 1.250 | 0.5418 | 1047 | 0.00071 | | | | |
| 3600 | 367.56 | 3341.3 | 1.254 | .5342 | 964 | .00065 | 1.10 | | 0.470 | 101 |
| 3200 | 180.43 | 3179.6 | 1.260 | .5250 | 874 | .00058 | 1.17 | | .961 | 189 |
| 2800 | 84.307 | 2971.6 | 1.267 | .5137 | 767 | .00051 | 1.72 | | 1.179 | 232 |
| 2400 | 36.781 | 2748.9 | 1.277 | .4980 | 650 | .00044 | 2.02 | | 1.358 | 267 |
| 2000 | 13.420 | 2513.3 | 1.292 | .4760 | 524 | .00036 | 5.75 | | 1.511 | 297 |
| 1600 | 3.493 | 2284.6 | 1.314 | .4525 | 473 | .00029 | 11.46 | | 1.622 | 321 |
| 1200 | 1.207 | 2254.3 | 1.197 | .4292 | 370 | .00021 | 31.38 | | 1.732 | 341 |
| P, [illegible], percent fuel, 25.05, OF, 2.992 | | | | | | | | | | |
| 4000 | 711.74 | 3798.1 | 1.251 | 0.5543 | 1039 | 0.00072 | | | | |
| 3600 | 597.12 | 3578.0 | 1.254 | .5461 | 957 | .00066 | 1.09 | | 0.596 | 115 |
| 3200 | 207.12 | 3361.3 | 1.261 | .5369 | 872 | .00059 | 1.11 | | .911 | 179 |
| 2800 | 99.479 | 3148.8 | 1.268 | .5252 | 782 | .00052 | 1.55 | | 1.163 | 223 |
| 2400 | 42.477 | 2949.4 | 1.279 | .5101 | 686 | .00045 | 2.45 | | 1.331 | 264 |
| 2000 | 13.574 | 2741.4 | 1.294 | .4897 | 583 | .00037 | 3.14 | | 1.491 | 293 |
| 1600 | 4.349 | 2550.7 | 1.318 | .4627 | 470 | .00028 | 14.15 | | 1.626 | 326 |
| 1200 | 1.418 | 2413.4 | 1.338 | .4191 | 337 | .00022 | 27.71 | | 1.716 | 330 |
| P, [illegible], percent fuel, 27.15, OF, 2.677 | | | | | | | | | | |
| 4000 | 979.20 | 4193.1 | 1.254 | 0.5782 | 1047 | 0.00074 | | | | |
| 3600 | 550.13 | 3965.5 | 1.259 | .5698 | 945 | .00068 | 1.12 | | 0.274 | 53 |
| 3200 | 259.12 | 3717.5 | 1.265 | .5598 | 862 | .00061 | 1.01 | | .769 | 130 |
| 2800 | 119.41 | 3478.0 | 1.272 | .5475 | 774 | .00055 | 1.32 | | 1.047 | 204 |
| 2400 | 75.117 | 3302.0 | 1.281 | .5317 | 673 | .00045 | 2.11 | | 1.201 | 244 |
| 2000 | 24.327 | 3193.4 | 1.298 | .5105 | 578 | .00038 | 2.11 | | 1.417 | 284 |
| 1600 | 5.614 | 3054.5 | 1.321 | .4828 | 467 | .00029 | 3.1 | | 1.567 | 315 |
| 1200 | 2.125 | 2753.2 | 1.363 | .4584 | 372 | .00023 | 20.55 | | 1.684 | 325 |
| 800 | .441 | 2414.0 | 1.345 | .4341 | 277 | .00016 | 85.9 | | 1.776 | 346 |





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.)

(c) Percent fluorine in oxidant by weight, 54.23

| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|
| [illegible] | | | | | | | | | | |

TABLE II . - 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, °R | Density, ρ, lb/cu ft | Enthalpy, h, Btu/lb | Isentropic exp. coeff., γ | Specific heat, $c_p$, Btu/(lb)(°R) | Sonic velocity, a, ft/sec | Mach number, M | Thrust coefficient, $C_F$ | Specific impulse, I, lb-sec/lb |
|---|---|---|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |



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 by weight, 81.46

| Temperature, T, °R | Density, ρ, lb/cu ft | Enthalpy, h, Btu/lb | Isentropic exp. coeff., γ | Specific heat, $c_p$, Btu/(lb)(°R) | Sonic velocity, a, ft/sec | Mach number, M | Thrust coefficient, $C_F$ | Specific impulse, I, lb-sec/lb |
|---|---|---|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

TABLE IV. - THEORETICAL ROCKET PERFORMANCE FOR PRESSURE RATIOS FROM 1 TO 500

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 | Pressure, p, lb/sq in. abs | Temperature, T, K | Enthalpy, H, Btu/lb | Specific heat ratio, γ | Density ratio, ρ/ρ₀ | Area ratio, A/A* | Thrust coefficient, $C_F$ | Specific impulse, I, lb-sec/lb |
|---|---|---|---|---|---|---|---|---|
| | | Propellant composition, O/F, 2.414 | | | | | | |
| 1.000 | 600.00 | 3497 | 3645.8 | 0.519 | 1.201 | -------- | -------- | -------- |
| 1.040 | 576.92 | 3474 | 3613.8 | .519 | 1.201 | 2.398 | 0.183 | 32.1 |
| 1.496 | 401.34 | 3275 | 3130.8 | .515 | 1.203 | 1.033 | .945 | 100.0 |
| 1.774 | 338.20 | 3175 | 2879.7 | .513 | 1.204 | 1.000 | .879 | 120.8 |
| 2.414 | 248.56 | 3057 | 2619.3 | .511 | 1.205 | 1.031 | .792 | 140.4 |
| 10.000 | 60.00 | 2351 | 2054.8 | .492 | 1.215 | 2.26 | 1.467 | 226.6 |
| 20.000 | 30.00 | 2081 | 1835.4 | .482 | 1.220 | 3.57 | 1.405 | 248.0 |
| 20.414 | 29.392 | 2073 | 1829.7 | .481 | 1.220 | 3.62 | 1.409 | 249.6 |
| 40.000 | 15.00 | 1836 | 1615.8 | .471 | 1.226 | 5.82 | 1.317 | 268.8 |
| 40.827 | 14.696 | 1827 | 1612.3 | .470 | 1.227 | 5.91 | 1.323 | 269.3 |
| 60.000 | 10.00 | 1700 | 1513.4 | .464 | 1.231 | 7.81 | 1.273 | 278.7 |
| 100.000 | 6.00 | 1544 | 1371.4 | .456 | 1.237 | 11.37 | 1.215 | 289.7 |
| 300.000 | 2.00 | 1245 | 1148.9 | .443 | 1.251 | 25.78 | 1.124 | 309.0 |
| | | Propellant composition, O/F, 2.414 | | | | | | |
| 1.000 | 600.00 | 3444 | 3237.1 | .541 | 1.207 | -------- | -------- | -------- |
| 1.040 | 576.92 | 3421 | 3206.1 | .544 | 1.207 | 2.405 | 0.182 | 33.7 |
| 1.493 | 402.09 | 3219 | 3112.0 | .544 | 1.209 | 1.033 | .947 | 105.0 |
| 1.779 | 337.07 | 3119 | 2854.6 | .545 | 1.211 | 1.000 | .881 | 126.0 |
| 2.414 | 248.56 | 3000 | 2584.5 | .555 | 1.211 | 1.031 | .794 | 147.1 |
| 10.000 | 60.00 | 2295 | 2051.1 | .573 | 1.222 | 2.43 | 1.266 | 274.0 |
| 20.000 | 30.00 | 2024 | 1828.4 | .561 | 1.224 | 3.59 | 1.199 | 296.0 |
| 20.414 | 29.392 | 2016 | 1822.4 | .561 | 1.224 | 3.64 | 1.203 | 297.6 |
| 40.000 | 15.00 | 1775 | 1613.2 | .550 | 1.231 | 5.78 | 1.114 | 317.5 |
| 40.827 | 14.696 | 1766 | 1609.7 | .550 | 1.235 | 5.86 | 1.117 | 318.0 |
| 60.000 | 10.00 | 1649 | 1512.8 | .561 | 1.237 | 7.71 | 1.073 | 327.7 |
| 100.000 | 6.00 | 1487 | 1380.3 | .490 | 1.245 | 11.19 | 1.031 | 338.0 |
| 300.000 | 2.00 | 1190 | 1147.1 | .485 | 1.263 | 25.21 | 1.974 | 371.0 |
| | | Propellant composition, O/F, 2.414 | | | | | | |
| 1.000 | 600.00 | 3372 | 3161.6 | .578 | 1.210 | -------- | -------- | -------- |
| 1.040 | 576.92 | 3346 | 3124.4 | .577 | 1.211 | 2.403 | 0.182 | 33.9 |
| 1.493 | 401.48 | 3144 | 3029.7 | .573 | 1.213 | 1.034 | .947 | 105.7 |
| 1.780 | 337.07 | 3044 | 2734.0 | .571 | 1.214 | 1.000 | .882 | 127.1 |
| 2.225 | 269.46 | 2931 | 2467.0 | .583 | 1.215 | 1.030 | .795 | 148.3 |
| 10.000 | 60.00 | 2235 | 2776.3 | .544 | 1.228 | 2.27 | 1.466 | 276.0 |
| 20.000 | 30.00 | 1964 | 2571.6 | .531 | 1.233 | 3.52 | 1.455 | 261.5 |
| 20.414 | 29.392 | 1956 | 2565.5 | .532 | 1.233 | 3.57 | 1.458 | 262.2 |
| 40.000 | 15.00 | 1720 | 2360.0 | .518 | 1.240 | 5.71 | 1.317 | 282.6 |
| 40.827 | 14.696 | 1713 | 2352.0 | .518 | 1.240 | 5.80 | 1.321 | 283.6 |
| 60.000 | 10.00 | 1593 | 2254.3 | .510 | 1.245 | 7.64 | 1.267 | 292.2 |
| 100.000 | 6.00 | 1435 | 2120.8 | .498 | 1.252 | 11.04 | 1.205 | 303.5 |
| 300.000 | 2.00 | 1144 | 1814.1 | .469 | 1.277 | 24.84 | 1.114 | 329.2 |
| | | Propellant composition, O/F, 2.414 | | | | | | |
| 1.000 | 600.00 | 3272 | 3065.3 | .597 | 1.215 | -------- | -------- | -------- |
| 1.040 | 576.92 | 3242 | 3022.2 | .596 | 1.215 | 2.407 | 0.182 | 34.0 |
| 1.494 | 401.55 | 3050 | 2845.2 | .594 | 1.217 | 1.034 | .946 | 106.3 |
| 1.783 | 336.34 | 2952 | 2648.2 | .592 | 1.218 | 1.000 | .883 | 127.5 |
| 2.224 | 269.25 | 2836 | 2441.0 | .578 | 1.219 | 1.031 | .797 | 148.6 |
| 10.000 | 60.00 | 2132 | 2353.1 | .554 | 1.232 | 2.21 | 1.465 | 286.4 |
| 20.000 | 30.00 | 1864 | 2157.5 | .541 | 1.236 | 3.49 | 1.452 | 271.8 |
| 20.414 | 29.392 | 1857 | 2153.5 | .540 | 1.238 | 3.54 | 1.455 | 272.5 |
| 40.000 | 15.00 | 1647 | 1960.1 | .525 | 1.247 | 5.68 | 1.311 | 292.2 |
| 40.827 | 14.696 | 1641 | 1957.8 | .525 | 1.247 | 5.75 | 1.314 | 292.8 |
| 60.000 | 10.00 | 1519 | 1863.5 | .537 | 1.252 | 7.54 | 1.265 | 298.9 |
| 100.000 | 6.00 | 1359 | 1734.3 | .565 | 1.260 | 10.88 | 1.625 | 307.2 |
| 300.000 | 2.00 | 1084 | 1494.7 | .478 | 1.274 | 24.41 | 1.723 | 329.0 |
| | | Propellant composition, O/F, 2.414 | | | | | | |
| 1.000 | 600.00 | 3147 | 3763.3 | .603 | 1.223 | -------- | -------- | -------- |
| 1.040 | 576.92 | 3125 | 3731.7 | .600 | 1.223 | 2.411 | 0.182 | 34.0 |
| 1.494 | 401.10 | 2929 | 3534.3 | .594 | 1.224 | 1.034 | .946 | 106.8 |
| 1.784 | 335.91 | 2837 | 3377.2 | .592 | 1.225 | 1.000 | .881 | 127.7 |
| 2.233 | 268.75 | 2719 | 3210.8 | .588 | 1.225 | 1.030 | .794 | 148.7 |
| 10.000 | 60.00 | 2052 | 3124.3 | .562 | 1.238 | 2.20 | 1.465 | 291.8 |
| 20.000 | 30.00 | 1793 | 2926.4 | .548 | 1.244 | 3.47 | 1.457 | 281.0 |
| 20.414 | 29.392 | 1785 | 2918.5 | .547 | 1.246 | 3.52 | 1.454 | 281.8 |
| 40.000 | 15.00 | 1560 | 2657.0 | .537 | 1.255 | 5.61 | 1.318 | 301.3 |
| 40.827 | 14.696 | 1554 | 2653.3 | .537 | 1.255 | 5.68 | 1.321 | 301.8 |
| 60.000 | 10.00 | 1438 | 2741.8 | .526 | 1.261 | 7.47 | 1.267 | 311.1 |
| 100.000 | 6.00 | 1290 | 2716.2 | .509 | 1.269 | 10.77 | 1.641 | 322.1 |
| 300.000 | 2.00 | 1013 | 2579.8 | .492 | 1.289 | 23.93 | 1.723 | 323.3 |
| | | Propellant composition, O/F, 2.414 | | | | | | |
| 1.000 | 600.00 | 2955 | 4375.4 | .618 | 1.231 | -------- | -------- | -------- |
| 1.040 | 576.92 | 2934 | 4333.4 | .618 | 1.232 | 2.419 | 0.181 | 33.6 |
| 1.495 | 401.55 | 2744 | 4054.3 | .611 | 1.235 | 1.031 | .936 | 107.4 |
| 1.794 | 334.44 | 2656 | 3903.0 | .608 | 1.236 | 1.000 | .869 | 127.4 |
| 2.242 | 267.57 | 2569 | 3758.1 | .604 | 1.238 | 1.029 | .802 | 147.0 |
| 10.000 | 60.00 | 1924 | 3692.2 | .574 | 1.254 | 2.17 | 1.464 | 271.9 |
| 20.000 | 30.00 | 1682 | 3397.2 | .557 | 1.264 | 3.40 | 1.397 | 256.2 |
| 20.414 | 29.392 | 1675 | 3384.4 | .557 | 1.264 | 3.45 | 1.400 | 256.8 |
| 40.000 | 15.00 | 1466 | 3113.7 | .540 | 1.275 | 5.44 | 1.309 | 275.6 |
| 40.827 | 14.696 | 1460 | 3105.4 | .539 | 1.275 | 5.54 | 1.312 | 276.1 |
| 60.000 | 10.00 | 1350 | 3154.1 | .527 | 1.281 | 7.25 | 1.275 | 285.2 |
| 100.000 | 6.00 | 1215 | 3081.2 | .515 | 1.291 | 10.45 | 1.531 | 292.7 |
| 300.000 | 2.00 | 945 | 2954.0 | .479 | 1.314 | 22.82 | 1.711 | 317.6 |



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(b) Percent fluorine in oxidant, 10 (90 percent oxygen)

| Pressure ratio | Pressure, p, lb/sq in. abs | Temperature, T, K | Enthalpy, H, Btu/lb | Specific heat ratio, γ | Density ratio, ρ/ρ₀ | Area ratio, A/A* | Thrust coefficient, $C_F$ | Specific impulse, I, lb-sec/lb |
|---|---|---|---|---|---|---|---|---|
| | | Propellant composition, O/F, 2.414 | | | | | | |
| 1.000 | 600.00 | 3622 | 3017.6 | 0.521 | 1.224 | -------- | -------- | -------- |
| 1.040 | 576.92 | 3596 | 3004.1 | .521 | 1.224 | 2.414 | 0.183 | 34.3 |
| 1.490 | 402.55 | 3346 | 2884.6 | .517 | 1.226 | 1.032 | .973 | 107.6 |
| 1.789 | 335.46 | 3254 | 2827.1 | .515 | 1.228 | 1.000 | .885 | 128.9 |
| 2.234 | 268.37 | 3142 | 2759.2 | .512 | 1.229 | 1.030 | .799 | 149.9 |
| 10.000 | 60.00 | 2349 | 2370.3 | .492 | 1.241 | 2.19 | 1.265 | 237.3 |
| 20.000 | 30.00 | 2050 | 2225.3 | .481 | 1.247 | 3.46 | 1.430 | 262.6 |
| 20.414 | 29.392 | 2042 | 2221.3 | .481 | 1.248 | 3.50 | 1.433 | 263.2 |
| 40.000 | 15.00 | 1784 | 2094.7 | .469 | 1.255 | 5.58 | 1.307 | 282.8 |
| 40.827 | 14.696 | 1777 | 2095.2 | .469 | 1.256 | 5.66 | 1.310 | 283.3 |
| 60.000 | 10.00 | 1642 | 2032.4 | .462 | 1.261 | 7.44 | 1.261 | 292.8 |
| 100.000 | 6.00 | 1476 | 1956.5 | .452 | 1.268 | 10.74 | 1.640 | 303.9 |
| 300.000 | 2.00 | 1143 | 1818.8 | .429 | 1.286 | 23.93 | 1.722 | 325.0 |
| | | Propellant composition, O/F, 2.414 | | | | | | |
| 1.000 | 600.00 | 3535 | 3359.2 | 0.543 | 1.227 | -------- | -------- | -------- |
| 1.040 | 576.92 | 3511 | 3345.1 | .543 | 1.227 | 2.415 | 0.183 | 34.9 |
| 1.492 | 402.09 | 3243 | 3220.8 | .543 | 1.230 | 1.032 | .975 | 109.7 |
| 1.791 | 335.07 | 3173 | 3161.1 | .541 | 1.231 | 1.000 | .887 | 131.3 |
| 2.234 | 268.06 | 3042 | 3090.7 | .538 | 1.232 | 1.030 | .800 | 152.6 |
| 10.000 | 60.00 | 2281 | 2648.9 | .514 | 1.245 | 2.19 | 1.464 | 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 | .490 | 1.261 | 5.55 | 1.306 | 287.6 |
| 40.827 | 14.696 | 1718 | 2405.1 | .490 | 1.261 | 5.63 | 1.309 | 288.1 |
| 60.000 | 10.00 | 1586 | 2340.8 | .483 | 1.266 | 7.38 | 1.259 | 297.7 |
| 100.000 | 6.00 | 1422 | 2262.7 | .472 | 1.274 | 10.64 | 1.617 | 308.9 |
| 300.000 | 2.00 | 1116 | 2121.8 | .447 | 1.293 | 23.58 | 1.714 | 328.1 |
| | | Propellant composition, O/F, 2.414 | | | | | | |
| 1.000 | 600.00 | 3441 | 3521.4 | 0.566 | 1.230 | -------- | -------- | -------- |
| 1.040 | 576.92 | 3435 | 3507.2 | .566 | 1.230 | 2.416 | 0.183 | 35.1 |
| 1.493 | 401.70 | 3205 | 3381.4 | .555 | 1.232 | 1.031 | .976 | 110.4 |
| 1.792 | 334.75 | 3103 | 3321.2 | .553 | 1.234 | 1.000 | .885 | 132.0 |
| 2.240 | 267.80 | 2971 | 3250.3 | .549 | 1.235 | 1.030 | .801 | 153.4 |
| 10.000 | 60.00 | 2231 | 2846.2 | .524 | 1.248 | 2.18 | 1.464 | 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 | 2555.1 | .500 | 1.265 | 5.51 | 1.305 | 288.5 |
| 40.827 | 14.696 | 1667 | 2551.5 | .499 | 1.265 | 5.59 | 1.307 | 289.0 |
| 60.000 | 10.00 | 1537 | 2492.9 | .491 | 1.271 | 7.34 | 1.257 | 298.6 |
| 100.000 | 6.00 | 1377 | 2419.1 | .480 | 1.279 | 10.55 | 1.615 | 309.7 |
| 300.000 | 2.00 | 1076 | 2278.6 | .455 | 1.299 | 23.32 | 1.715 | 329.6 |
| | | Propellant composition, O/F, 2.414 | | | | | | |
| 1.000 | 600.00 | 3342 | 3678.2 | 0.571 | 1.233 | -------- | -------- | -------- |
| 1.040 | 576.92 | 3337 | 3664.1 | .571 | 1.233 | 2.420 | 0.183 | 35.1 |
| 1.495 | 401.21 | 3115 | 3537.5 | .564 | 1.236 | 1.031 | .977 | 110.7 |
| 1.795 | 334.34 | 3008 | 3477.2 | .563 | 1.237 | 1.000 | .889 | 132.3 |
| 2.243 | 267.47 | 2882 | 3404.3 | .560 | 1.239 | 1.029 | .802 | 153.8 |
| 10.000 | 60.00 | 2146 | 3002.8 | .534 | 1.253 | 2.17 | 1.464 | 242.4 |
| 20.000 | 30.00 | 1843 | 2852.9 | .522 | 1.261 | 3.41 | 1.397 | 268.0 |
| 20.414 | 29.392 | 1835 | 2848.8 | .522 | 1.261 | 3.45 | 1.401 | 268.6 |
| 40.000 | 15.00 | 1611 | 2721.1 | .507 | 1.270 | 5.48 | 1.303 | 288.3 |
| 40.827 | 14.696 | 1604 | 2719.5 | .507 | 1.271 | 5.55 | 1.306 | 288.8 |
| 60.000 | 10.00 | 1477 | 2655.5 | .499 | 1.277 | 7.28 | 1.254 | 298.3 |
| 100.000 | 6.00 | 1320 | 2574.4 | .487 | 1.285 | 10.45 | 1.613 | 309.4 |
| 300.000 | 2.00 | 1029 | 2419.7 | .461 | 1.306 | 23.10 | 1.711 | 328.3 |
| | | Propellant composition, O/F, 2.414 | | | | | | |
| 1.000 | 600.00 | 3119 | 3977.0 | 0.591 | 1.242 | -------- | -------- | -------- |
| 1.040 | 576.92 | 3096 | 3963.0 | .590 | 1.242 | 2.420 | 0.184 | 34.7 |
| 1.500 | 399.98 | 2900 | 3837.2 | .585 | 1.245 | 1.031 | .985 | 111.3 |
| 1.800 | 333.33 | 2808 | 3777.8 | .582 | 1.246 | 1.000 | .891 | 133.7 |
| 2.250 | 266.65 | 2694 | 3704.1 | .578 | 1.248 | 1.029 | .805 | 154.0 |
| 10.000 | 60.00 | 1967 | 3314.2 | .550 | 1.264 | 2.15 | 1.463 | 240.2 |
| 20.000 | 30.00 | 1693 | 3184.2 | .535 | 1.274 | 3.38 | 1.395 | 265.2 |
| 20.414 | 29.392 | 1687 | 3184.6 | .535 | 1.274 | 3.41 | 1.398 | 265.9 |
| 40.000 | 15.00 | 14[illegible] | 3063.2 | .519 | 1.285 | 5.39 | 1.299 | 285.1 |
| 40.827 | 14.696 | 14[illegible] | 3062.8 | .519 | 1.285 | 5.45 | 1.302 | 285.7 |
| 60.000 | 11.00 | 1331 | 2979.2 | .509 | 1.292 | 7.13 | 1.252 | 294.2 |
| 100.000 | 6.00 | 1184 | 2914.4 | .497 | 1.301 | 10.20 | 1.607 | 305.5 |
| 300.000 | 2.00 | 912 | 2772.7 | .472 | 1.322 | 22.64 | 1.707 | 324.5 |

TABLE IV. - CONCLUDED. THEORETICAL ROCKET PERFORMANCE FOR PRESSURE RATIOS FROM 1 TO 100

FOR LIQUID METHANE WITH VARIOUS FLUORINE-OXYGEN MIXTURES

[Performance results assuming isentropic expansion from combustion-chamber pressure of 100 lb/sq in. abs.]

(d) Percent fluorine in oxidant by weight, 47.25

| Pressure ratio, $p_c/p$ | Static pressure, p, lb/sq in. abs | Temperature, T, °R | Enthalpy, h, Btu/lb | Specific heat, $c_p$, Btu/(lb)(°R) | Isentropic exponent, $\gamma$ | Area ratio, $\epsilon$ | Thrust coefficient, $C_F$ | Specific impulse, I, lb-sec/lb |
|---|---|---|---|---|---|---|---|---|
| $p_c$ = 600 psia; percent fuel, 25.95; O/F, [illegible] | | | | | | | | |
| 1.000 | 600.00 | 3753 | 3145.8 | 0.505 | 1.247 | -------- | -------- | -------- |
| 1.040 | 576.92 | 3744 | 3131.2 | .505 | 1.247 | 2.429 | 0.184 | 95.7 |
| 1.504 | 399.38 | 3461 | 2999.1 | .501 | 1.249 | 1.031 | .582 | 117.[illegible] |
| 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 | .808 | 150.[illegible] |
| 10.000 | 60.00 | 2349 | 2454.6 | .476 | 1.266 | 2.14 | 1.263 | 245.3 |
| 20.000 | 30.00 | 2027 | 2303.2 | .465 | 1.274 | 3.35 | 1.394 | 270.0 |
| 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.[illegible] |
| 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 | 10.13 | 1.606 | 311.9 |
| 300.000 | 2.00 | 1095 | 1891.1 | .414 | 1.319 | 22.24 | 1.701 | 330.4 |
| $p_c$ = 600 psia; percent fuel, 25.95; O/F, [illegible] | | | | | | | | |
| 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 | 95.2 |
| 1.503 | 399.14 | 3364 | 3294.7 | .525 | 1.251 | 1.031 | .582 | 114.5 |
| 1.804 | 332.41 | 3243 | 3233.2 | .523 | 1.253 | 1.000 | .694 | 130.5 |
| 2.255 | 266.09 | 3100 | 3159.6 | .520 | 1.254 | 1.029 | .808 | 154.5 |
| 10.000 | 60.00 | 2277 | 2735.4 | .498 | 1.269 | 2.14 | 1.263 | 248.6 |
| 20.000 | 30.00 | 1963 | 2584.8 | .484 | 1.277 | 3.34 | 1.394 | 273.6 |
| 20.414 | 29.392 | 1955 | 2581.5 | .484 | 1.277 | 3.39 | 1.397 | 274.6 |
| 40.000 | 15.00 | 1686 | 2441.7 | .473 | 1.287 | 5.34 | 1.494 | 294.3 |
| 40.827 | 14.696 | 1678 | 2438.1 | .472 | 1.287 | 5.42 | 1.500 | 294.9 |
| 60.000 | 10.00 | 1539 | 2382.8 | .465 | 1.293 | 7.09 | 1.548 | 304.3 |
| 100.000 | 6.00 | 1363 | 2304.7 | .454 | 1.302 | 10.13 | 1.604 | 315.3 |
| 300.000 | 2.00 | 1053 | 2165.1 | .431 | 1.323 | 22.07 | 1.696 | 334.0 |
| $p_c$ = 600 psia; percent fuel, 25.95; O/F, [illegible] | | | | | | | | |
| 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 | 95.3 |
| 1.504 | 398.88 | 3290 | 3439.6 | .534 | 1.253 | 1.031 | .583 | 114.3 |
| 1.805 | 332.40 | 3171 | 3375.9 | .534 | 1.254 | 1.000 | .694 | 130.[illegible] |
| 2.254 | 265.92 | 3030 | 3301.0 | .532 | 1.256 | 1.029 | .807 | 150.[illegible] |
| 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 | 3.39 | 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 | 2523.9 | .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 | 2304.7 | .439 | 1.328 | 21.90 | 1.698 | 334.3 |
| $p_c$ = 600 psia; percent fuel, 25.95; O/F, [illegible] | | | | | | | | |
| 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 | 95.2 |
| 1.504 | 398.53 | 3202 | 3576.0 | .544 | 1.255 | 1.030 | .584 | 115.[illegible] |
| 1.807 | 332.11 | 3085 | 3515.3 | .544 | 1.257 | 1.000 | .696 | 137.[illegible] |
| 2.258 | 265.69 | 2947 | 3440.5 | .541 | 1.259 | 1.029 | .808 | 159.[illegible] |
| 10.000 | 60.00 | 2155 | 3021.3 | .516 | 1.274 | 2.13 | 1.262 | 247.5 |
| 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.[illegible] |
| 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 | 294.5 |
| 60.000 | 10.00 | 1446 | 2662.5 | .480 | 1.301 | 7.00 | 1.546 | 304.[illegible] |
| 100.000 | 6.00 | 1282 | 2589.1 | .469 | 1.311 | 10.00 | 1.601 | 315.[illegible] |
| 300.000 | 2.00 | 982 | 2451.5 | .448 | 1.332 | 21.64 | 1.695 | 333.[illegible] |
| $p_c$ = 600 psia; percent fuel, [illegible]; O/F, [illegible] | | | | | | | | |
| 1.000 | 600.00 | 3258 | 3998.3 | 0.571 | 1.258 | -------- | -------- | -------- |
| 1.040 | 576.92 | 3231 | 3983.4 | .570 | 1.259 | 2.437 | .185 | 97.[illegible] |
| 1.509 | 397.64 | 2992 | 3847.7 | .565 | 1.262 | 1.030 | .582 | 113.[illegible] |
| 1.811 | 331.37 | 2881 | 3784.9 | .562 | 1.264 | 1.000 | .698 | 135.[illegible] |
| 2.263 | 265.09 | 2751 | 3711.3 | .559 | 1.267 | 1.029 | .809 | 159.[illegible] |
| 10.000 | 60.00 | 1998 | 3366.8 | .532 | 1.293 | 2.12 | 1.260 | 246.4 |
| 20.000 | 30.00 | 1711 | 3196.3 | .517 | 1.304 | 3.24 | 1.391 | 271.[illegible] |
| 20.414 | 29.392 | 1703 | 3184.2 | .517 | 1.304 | 3.28 | 1.395 | 272.[illegible] |
| 40.000 | 15.00 | 1459 | 3021.8 | .501 | 1.315 | 5.13 | 1.493 | 291.[illegible] |
| 40.827 | 14.696 | 1452 | 3018.1 | .501 | 1.315 | 5.21 | 1.496 | 292.[illegible] |
| 60.000 | 10.00 | 1325 | 2955.6 | .492 | 1.323 | 6.[illegible] | 1.543 | 301.[illegible] |
| 100.000 | 6.00 | 1172 | 2880.9 | .481 | 1.334 | [illegible] | 1.597 | 311.[illegible] |
| 300.000 | 2.00 | 890 | 2748.8 | .459 | 1.354 | 21.17 | 1.689 | 329.7 |



TABLE IV. - CONCLUDED. THEORETICAL ROCKET PERFORMANCE FOR PRESSURE RATIOS FROM 1 TO 100

FOR LIQUID METHANE WITH VARIOUS FLUORINE-OXYGEN MIXTURES

[Performance results assuming isentropic expansion from combustion-chamber pressure of 100 lb/sq in. abs.]

(e) Percent fluorine in oxidant by weight, 54.23

| Pressure ratio, $p_c/p$ | Static pressure, p, lb/sq in. abs | Temperature, T, °R | Enthalpy, h, Btu/lb | Specific heat, $c_p$, Btu/(lb)(°R) | Isentropic exponent, $\gamma$ | Area ratio, $\epsilon$ | Thrust coefficient, $C_F$ | Specific impulse, I, lb-sec/lb |
|---|---|---|---|---|---|---|---|---|
| $p_c$ = 600 psia; percent fuel, [illegible]; O/F, [illegible] | | | | | | | | |
| 1.000 | 600.00 | 3957 | 3100.6 | 0.476 | 1.271 | -------- | -------- | -------- |
| 1.040 | 576.92 | 3924 | 3084.9 | .475 | 1.271 | 2.444 | 0.185 | 96.9 |
| 1.515 | 396.05 | 3540 | 2941.1 | .471 | 1.274 | 1.030 | .591 | 117.6 |
| 1.818 | 330.04 | 3481 | 2875.5 | .469 | 1.276 | 1.000 | .702 | 139.9 |
| 2.272 | 264.03 | 3316 | 2798.7 | .467 | 1.278 | 1.028 | .813 | 162.1 |
| 10.000 | 60.00 | 2388 | 2373.6 | .448 | 1.293 | 2.10 | 1.261 | 251.5 |
| 20.000 | 30.00 | 2037 | 2218.4 | .437 | 1.302 | 3.25 | 1.389 | 277.1 |
| 20.414 | 29.392 | 2028 | 2214.2 | .437 | 1.302 | 3.30 | 1.393 | 277.7 |
| 40.000 | 15.00 | 1731 | 2084.2 | .426 | 1.313 | 5.15 | 1.490 | 297.1 |
| 40.827 | 14.696 | 1723 | 2082.6 | .425 | 1.313 | 5.23 | 1.492 | 297.6 |
| 60.000 | 10.00 | 1571 | 2018.4 | .419 | 1.320 | 6.79 | 1.539 | 306.9 |
| 100.000 | 6.00 | 1386 | 1942.0 | .409 | 1.329 | 9.65 | 1.592 | 317.5 |
| 300.000 | 2.00 | 1049 | 1807.1 | .390 | 1.351 | 20.74 | 1.682 | 335.5 |
| $p_c$ = 600 psia; percent fuel, [illegible]; O/F, [illegible] | | | | | | | | |
| 1.000 | 600.00 | 3917 | 3238.7 | 0.485 | 1.270 | -------- | -------- | -------- |
| 1.040 | 576.92 | 3885 | 3222.9 | .485 | 1.270 | 2.444 | 0.185 | 97.4 |
| 1.515 | 396.15 | 3595 | 3077.3 | .483 | 1.273 | 1.030 | .590 | 118.5 |
| 1.817 | 330.19 | 3447 | 3010.9 | .481 | 1.275 | 1.000 | .701 | 140.5 |
| 2.272 | 264.10 | 3285 | 2931.0 | .479 | 1.277 | 1.028 | .813 | 163.1 |
| 10.000 | 60.00 | 2366 | 2502.1 | .459 | 1.292 | 2.10 | 1.261 | 253.2 |
| 20.000 | 30.00 | 2019 | 2344.7 | .448 | 1.301 | 3.25 | 1.389 | 276.9 |
| 20.414 | 29.392 | 2010 | 2340.5 | .448 | 1.302 | 3.30 | 1.393 | 279.6 |
| 40.000 | 15.00 | 1716 | 2210.7 | .437 | 1.312 | 5.16 | 1.490 | 296.1 |
| 40.827 | 14.696 | 1708 | 2207.1 | .436 | 1.313 | 5.23 | 1.493 | 299.6 |
| 60.000 | 10.00 | 1557 | 2141.9 | .429 | 1.319 | 6.80 | 1.539 | 308.9 |
| 100.000 | 6.00 | 1374 | 2064.4 | .419 | 1.329 | 9.66 | 1.592 | 319.7 |
| 300.000 | 2.00 | 1040 | 1927.8 | .400 | 1.351 | 20.76 | 1.683 | 337.8 |
| $p_c$ = 600 psia; percent fuel, [illegible]; O/F, [illegible] | | | | | | | | |
| 1.000 | 600.00 | 3454 | 3373.1 | 0.499 | 1.275 | -------- | -------- | -------- |
| 1.040 | 576.92 | 3432 | 3357.1 | .499 | 1.275 | 2.444 | 0.185 | 97.3 |
| 1.515 | 396.17 | 3136 | 3210.2 | .496 | 1.278 | 1.030 | .590 | 119.1 |
| 1.817 | 330.14 | 3000 | 3143.1 | .492 | 1.279 | 1.000 | .701 | 141.5 |
| 2.272 | 264.11 | 2850 | 3064.5 | .487 | 1.277 | 1.028 | .814 | 165.9 |
| 10.000 | 60.00 | 2334 | 2629.6 | .469 | 1.292 | 2.10 | 1.261 | 254.4 |
| 20.000 | 30.00 | 1992 | 2470.8 | .459 | 1.302 | 3.25 | 1.389 | 280.2 |
| 20.414 | 29.392 | 1982 | 2466.4 | .459 | 1.302 | 3.30 | 1.393 | 280.9 |
| 40.000 | 15.00 | 1693 | 2335.5 | .446 | 1.313 | 5.16 | 1.490 | 300.5 |
| 40.827 | 14.696 | 1684 | 2331.8 | .445 | 1.313 | 5.23 | 1.493 | 301.0 |
| 60.000 | 10.00 | 1536 | 2266.1 | .438 | 1.320 | 6.80 | 1.539 | 310.4 |
| 100.000 | 6.00 | 1355 | 2187.8 | .428 | 1.330 | 9.66 | 1.592 | 321.1 |
| 300.000 | 2.00 | 1025 | 2049.0 | .404 | 1.351 | 20.74 | 1.682 | 339.3 |
| $p_c$ = 600 psia; percent fuel, [illegible]; O/F, [illegible] | | | | | | | | |
| 1.000 | 600.00 | 3798 | 3503.9 | .511 | 1.270 | -------- | -------- | -------- |
| 1.040 | 576.92 | 3766 | 3487.8 | .510 | 1.270 | 2.444 | 0.185 | 97.4 |
| 1.515 | 396.11 | 3475 | 3340.0 | .505 | 1.274 | 1.030 | .590 | 119.4 |
| 1.818 | 330.09 | 3341 | 3272.8 | .503 | 1.275 | 1.000 | .702 | 141.9 |
| 2.276 | 264.07 | 3184 | 3193.5 | .500 | 1.277 | 1.028 | .815 | 164.3 |
| 10.000 | 60.00 | 2293 | 2756.4 | .472 | 1.293 | 2.10 | 1.261 | 255.2 |
| 20.000 | 30.00 | 1951 | 2596.8 | .462 | 1.303 | 3.25 | 1.389 | 280.9 |
| 20.414 | 29.392 | 1946 | 2592.5 | .462 | 1.303 | 3.30 | 1.393 | 281.6 |
| 40.000 | 15.00 | 1661 | 2461.0 | .454 | 1.314 | 5.15 | 1.490 | 301.2 |
| 40.827 | 14.696 | 1653 | 2457.3 | .454 | 1.314 | 5.22 | 1.493 | 301.8 |
| 60.000 | 10.00 | 1506 | 2391.3 | .447 | 1.321 | 6.78 | 1.539 | 311.1 |
| 100.000 | 6.00 | 1328 | 2312.8 | .439 | 1.331 | 9.64 | 1.592 | 321.9 |
| 300.000 | 2.00 | 1004 | 2174.5 | .416 | 1.353 | 20.68 | 1.682 | 340.1 |
| $p_c$ = 600 psia; percent fuel, [illegible]; O/F, [illegible] | | | | | | | | |
| 1.000 | 600.00 | 3628 | 3755.1 | 0.531 | 1.272 | -------- | -------- | -------- |
| 1.040 | 576.92 | 3598 | 3739.0 | .531 | 1.273 | 2.446 | 0.185 | 97.4 |
| 1.516 | 395.76 | 3317 | 3590.9 | .525 | 1.276 | 1.030 | .591 | 119.[illegible] |
| 1.819 | 329.40 | 3183 | 3527.5 | .523 | 1.278 | 1.000 | .702 | 142.[illegible] |
| 2.274 | 263.84 | 3037 | 3444.6 | .520 | 1.280 | 1.028 | .815 | 164.9 |
| 10.000 | 60.00 | 2181 | 3008.7 | .486 | 1.297 | 2.09 | 1.261 | 254.[illegible] |
| 20.000 | 30.00 | 1857 | 2844.9 | .474 | 1.312 | 3.24 | 1.392 | 281.[illegible] |
| 20.414 | 29.392 | 1848 | 2840.6 | .473 | 1.312 | 3.28 | 1.396 | 281.[illegible] |
| 40.000 | 15.00 | 1574 | 2715.0 | .460 | 1.319 | 5.12 | 1.499 | 300.6 |
| 40.827 | 14.696 | 1567 | 2711.3 | .460 | 1.319 | 5.19 | 1.501 | 301.4 |
| 60.000 | 10.00 | 1426 | 2645.9 | .452 | 1.327 | 6.74 | 1.537 | 310.7 |
| 100.000 | 6.00 | 1256 | 2568.1 | .441 | 1.337 | 9.58 | 1.591 | 321.4 |
| 300.000 | 2.00 | 946 | 2431.4 | .419 | 1.357 | 20.46 | 1.679 | 339.[illegible] |

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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, 75.0)

| Pressure ratio, $P_c/P$ | Static pressure, P, lb/sq in. abs | Temperature, T, °R | Enthalpy, h, Btu/lb | Specific heat, $c_p$, $\frac{cal}{(gm)(°K)}$ | Isentropic exponent, γ | Area ratio, ε | Thrust coefficient, $C_F$ | Specific impulse, I, $\frac{lb\text{-}sec}{lb}$ |
|---|---|---|---|---|---|---|---|---|
| F, 1.40; percent fuel, 17.22; O/F, 1.806 | | | | | | | | |
| 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 | 98.6 |
| 1.527 | 392.88 | 3921 | 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 | 2042 | 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 | 307.2 |
| 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 | 1027 | 1811.4 | .378 | 1.381 | 19.45 | 1.665 | 344.9 |
| F, 1.40; percent fuel, 19.00; O/F, 4.000 | | | | | | | | |
| 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 | 98.0 |
| 1.527 | 392.88 | 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 | 171.4 |
| 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 | 1.384 | 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 | 308.6 |
| 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 | .387 | 1.380 | 19.48 | 1.666 | 347.6 |
| F, 1.40; percent fuel, 19.00; O/F, 4.000 | | | | | | | | |
| 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 | 98.8 |
| 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 | 2.04 | 1.260 | 262.8 |
| 20.000 | 30.00 | 2020 | 2457.0 | .440 | 1.328 | 3.17 | 1.385 | 287.9 |
| 20.414 | 29.392 | 2010 | 2452.5 | .439 | 1.328 | 3.21 | 1.388 | 288.6 |
| 40.000 | 15.00 | 1698 | 2317.4 | .428 | 1.340 | 4.97 | 1.482 | 308.2 |
| 40.827 | 14.696 | 1689 | 2313.6 | .428 | 1.340 | 5.04 | 1.485 | 308.8 |
| 60.000 | 10.00 | 1531 | 2248.4 | .421 | 1.348 | 6.52 | 1.530 | 318.1 |
| 100.000 | 6.00 | 1340 | 2166.9 | .412 | 1.358 | 9.20 | 1.581 | 328.7 |
| 300.000 | 2.00 | 996 | 2028.4 | .394 | 1.380 | 19.48 | 1.666 | 347.5 |
| F, 1.40; percent fuel, 20.00; O/F, 4.000 | | | | | | | | |
| 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 | 98.9 |
| 1.526 | 393.07 | 3646 | 3351.4 | .485 | 1.296 | 1.029 | .599 | 124.9 |
| 1.832 | 327.56 | 3497 | 3276.2 | .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 | 1.316 | 2.06 | 1.260 | 263.0 |
| 20.000 | 30.00 | 1981 | 2570.1 | .448 | 1.328 | 3.16 | 1.385 | 288.1 |
| 20.414 | 29.392 | 1971 | 2565.6 | .448 | 1.329 | 3.21 | 1.388 | 289.0 |
| 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 | 319.1 |
| 100.000 | 6.00 | 1313 | 2279.7 | .419 | 1.359 | 9.19 | 1.581 | 329.0 |
| 300.000 | 2.00 | 976 | 2141.2 | .402 | 1.381 | 19.45 | 1.666 | 347.7 |



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 600 lb/sq in. abs.]

(e, Percent fluorine in oxidant by weight, 75.0)

| Pressure ratio, $P_c/P$ | Static pressure, P, lb/sq in. abs | Temperature, T, °R | Enthalpy, h, Btu/lb | Specific heat, $c_p$, $\frac{cal}{(gm)(°K)}$ | Isentropic exponent, γ | Area ratio, ε | Thrust coefficient, $C_F$ | Specific impulse, I, $\frac{lb\text{-}sec}{lb}$ |
|---|---|---|---|---|---|---|---|---|
| F, 1.40; percent fuel, 17.22; O/F, 1.806 | | | | | | | | |
| 1.000 | 600.00 | 4133 | 3317.3 | 0.466 | 1.293 | | | |
| 1.040 | 576.92 | 4203 | 3344.4 | .459 | 1.297 | 2.459 | 0.187 | 98.7 |
| 1.529 | 391.84 | 3921 | 3124.8 | .455 | 1.307 | 1.029 | .602 | 127.0 |
| 1.834 | 326.40 | 3757 | 3054.8 | .453 | 1.309 | 1.000 | .712 | 151.2 |
| 2.294 | 261.12 | 3584 | 2987.3 | .450 | 1.311 | 1.027 | .822 | 174.6 |
| 10.000 | 60.00 | 2496 | 2495.5 | .433 | 1.328 | 2.04 | 1.259 | 267.3 |
| 20.000 | 30.00 | 2088 | 2325.4 | .423 | 1.339 | 3.13 | 1.383 | 293.4 |
| 20.414 | 29.392 | 2088 | 2326.8 | .423 | 1.339 | 3.17 | 1.387 | 294.5 |
| 40.000 | 15.00 | 1759 | 2182.8 | .412 | 1.351 | 4.90 | 1.479 | 314.2 |
| 40.827 | 14.696 | 1749 | 2179.0 | .411 | 1.351 | 4.97 | 1.482 | 314.7 |
| 60.000 | 10.00 | 1581 | 2111.5 | .405 | 1.359 | 6.41 | 1.526 | 324.1 |
| 100.000 | 6.00 | 1374 | 2026.8 | .397 | 1.369 | 9.04 | 1.576 | 334.7 |
| 300.000 | 2.00 | 1019 | 1886.0 | .382 | 1.392 | 19.09 | 1.659 | 352.4 |
| F, 1.40; percent fuel, 18.00; O/F, 4.000 | | | | | | | | |
| 1.000 | 600.00 | 4204 | 3372.8 | .465 | 1.293 | | | |
| 1.040 | 576.92 | 4259 | 3396.5 | .464 | 1.297 | 2.459 | 0.187 | 98.7 |
| 1.532 | 391.72 | 3991 | 3184.0 | .460 | 1.307 | 1.029 | .602 | 127.0 |
| 1.834 | 326.43 | 3828 | 3109.0 | .457 | 1.309 | 1.000 | .712 | 151.4 |
| 2.294 | 261.15 | 3636 | 3021.0 | .453 | 1.311 | 1.027 | .822 | 174.9 |
| 10.000 | 60.00 | 2477 | 2564.3 | .437 | 1.328 | 2.04 | 1.259 | 267.6 |
| 20.000 | 30.00 | 2083 | 2393.0 | .427 | 1.339 | 3.13 | 1.383 | 294.2 |
| 20.414 | 29.392 | 2073 | 2389.4 | .427 | 1.339 | 3.17 | 1.387 | 294.8 |
| 40.000 | 15.00 | 1744 | 2245.1 | .416 | 1.351 | 4.90 | 1.479 | 314.6 |
| 40.827 | 14.694 | 1735 | 2241.2 | .415 | 1.351 | 4.97 | 1.482 | 315.1 |
| 60.000 | 10.00 | 1569 | 2172.8 | .409 | 1.359 | 6.41 | 1.526 | 324.5 |
| 100.000 | 6.00 | 1369 | 2085.7 | .400 | 1.369 | 9.02 | 1.576 | 335.1 |
| 300.000 | 2.00 | 1011 | 1943.4 | .386 | 1.392 | 19.09 | 1.659 | 353.4 |
| F, 1.40; percent fuel, 19.00; O/F, 4.000 | | | | | | | | |
| 1.000 | 600.00 | 4248 | 3472.1 | 0.470 | 1.293 | | | |
| 1.040 | 576.92 | 4190 | 3445.6 | .470 | 1.298 | 2.459 | 0.187 | 98.7 |
| 1.533 | 391.38 | 3883 | 3264.1 | .465 | 1.310 | 1.029 | .603 | 127.1 |
| 1.841 | 325.11 | 3726 | 3188.2 | .463 | 1.311 | 1.000 | .713 | 151.5 |
| 2.310 | 261.91 | 3624 | 3140.7 | .461 | 1.312 | 1.027 | .823 | 175.0 |
| 10.000 | 60.00 | 2537 | 2626.4 | .443 | 1.321 | 2.04 | 1.259 | 267.7 |
| 20.000 | 30.00 | 2133 | 2454.2 | .431 | 1.341 | 3.12 | 1.384 | 294.5 |
| 20.414 | 29.394 | 2120 | 2448.2 | .430 | 1.341 | 3.16 | 1.386 | 295.0 |
| 40.000 | 15.00 | 1789 | 2304.4 | .419 | 1.353 | 4.89 | 1.479 | 314.6 |
| 40.827 | 14.694 | 1779 | 2302.5 | .419 | 1.353 | 4.95 | 1.481 | 315.0 |
| 60.000 | 10.00 | 1609 | 2234.2 | .407 | 1.361 | 6.39 | 1.525 | 324.2 |
| 100.000 | 6.00 | 1398 | 2147.7 | .398 | 1.371 | 8.99 | 1.575 | 334.6 |
| 300.000 | 2.00 | 1031 | 1994.3 | .382 | 1.394 | 18.99 | 1.658 | 352.5 |
| F, 1.40; percent fuel, 19.50; O/F, 4.000 | | | | | | | | |
| 1.000 | 600.00 | 4327 | 3515.4 | .473 | 1.293 | | | |
| 1.040 | 576.92 | 4342 | 3527.0 | .472 | 1.296 | 2.459 | 0.187 | 98.8 |
| 1.533 | 391.11 | 3971 | 3273.3 | .466 | 1.310 | 1.029 | .603 | 127.2 |
| 1.842 | 325.17 | 3811 | 3201.7 | .464 | 1.311 | 1.000 | .713 | 151.7 |
| 2.310 | 261.04 | 3614 | 3113.3 | .464 | 1.313 | 1.027 | .823 | 175.1 |
| 10.000 | 60.00 | 2549 | 2636.6 | .445 | 1.321 | 2.04 | 1.259 | 267.8 |
| 20.000 | 30.00 | 2143 | 2464.3 | .432 | 1.341 | 3.12 | 1.384 | 294.6 |
| 20.414 | 29.394 | 2134 | 2464.7 | .432 | 1.341 | 3.16 | 1.386 | 295.1 |
| 40.000 | 15.00 | 1798 | 2312.5 | .421 | 1.353 | 4.89 | 1.479 | 314.8 |
| 40.827 | 14.694 | 1788 | 2312.2 | .420 | 1.353 | 4.95 | 1.481 | 315.2 |
| 60.000 | 10.00 | 1608 | 2234.2 | .408 | 1.361 | 6.39 | 1.525 | 324.3 |
| 100.000 | 6.00 | 1394 | 2143.4 | .391 | 1.371 | 8.99 | 1.575 | 334.8 |
| 300.000 | 2.00 | 1024 | 1983.4 | .376 | 1.394 | 18.99 | 1.658 | 352.6 |
| F, 1.40; percent fuel, 20.00; O/F, 4.000 | | | | | | | | |
| 1.000 | 600.00 | 4351 | 3536.0 | .477 | 1.293 | | | |
| 1.040 | 576.92 | 4312 | 3517.4 | .476 | 1.297 | 2.459 | 0.187 | 98.8 |
| 1.534 | 391.07 | 3932 | 3264.3 | .472 | 1.307 | 1.029 | .603 | 127.3 |
| 1.842 | 326.52 | 3773 | 3188.5 | .469 | 1.309 | 1.000 | .713 | 151.8 |
| 2.294 | 261.11 | 3579 | 3099.4 | .468 | 1.311 | 1.027 | .823 | 175.4 |
| 10.000 | 60.00 | 2567 | 2646.8 | .450 | 1.320 | 2.04 | 1.259 | 267.9 |
| 20.000 | 30.00 | 2158 | 2474.7 | .436 | 1.339 | 3.12 | 1.383 | 294.7 |
| 20.414 | 29.394 | 2147 | 2474.2 | .435 | 1.339 | 3.17 | 1.387 | 295.4 |
| 40.000 | 15.00 | 1805 | 2319.4 | .425 | 1.351 | 4.90 | 1.479 | 315.0 |
| 40.827 | 14.694 | 1795 | 2317.4 | .425 | 1.351 | 4.97 | 1.482 | 315.4 |
| 60.000 | 10.00 | 1597 | 2234.1 | .412 | 1.359 | 6.41 | 1.526 | 324.6 |
| 100.000 | 6.00 | 1392 | 2143.7 | .394 | 1.369 | 9.02 | 1.576 | 335.6 |
| 300.000 | 2.00 | 1028 | 1984.1 | .379 | 1.392 | 19.09 | 1.659 | 353.1 |

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.]

(n) Percent fluorine in oxidant by weight, ±0.15

| 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 |
|---|---|---|---|---|---|---|---|---|
| F, 1.000; percent fuel, 14.67; O/F, 5.442 | | | | | | | | |
| 1.000 | 600.00 | 4440 | 3207.7 | 0.447 | 1.366 | ------- | ------- | ------- |
| 1.040 | 576.92 | 4396 | 3184.5 | .444 | 1.367 | 2.467 | 0.187 | 39.7 |
| 1.534 | 391.25 | 4015 | 3014.6 | .442 | 1.310 | 1.028 | .603 | 128.3 |
| 1.840 | 326.05 | 3844 | 2943.6 | .440 | 1.312 | 1.000 | .715 | 151.6 |
| 2.300 | 260.86 | 3645 | 2854.2 | .437 | 1.314 | 1.027 | .824 | 174.6 |
| 10.000 | 60.00 | 2547 | 2384.3 | .421 | 1.331 | 2.04 | 1.258 | 267.7 |
| 20.000 | 30.00 | 2139 | 2214.8 | .411 | 1.342 | 3.12 | 1.383 | 294.0 |
| 20.414 | 29.392 | 2128 | 2210.1 | .411 | 1.342 | 3.16 | 1.386 | 294.6 |
| 40.000 | 15.00 | 1789 | 2072.4 | .401 | 1.356 | 4.88 | 1.479 | 314.3 |
| 40.827 | 14.696 | 1780 | 2068.6 | .400 | 1.356 | 4.94 | 1.481 | 314.8 |
| 60.000 | 10.00 | 1608 | 2000.8 | .394 | 1.362 | 6.38 | 1.524 | 324.1 |
| 100.000 | 6.00 | 1402 | 1920.0 | .384 | 1.372 | 8.97 | 1.575 | 334.7 |
| 300.000 | 2.00 | 1034 | 1780.9 | .370 | 1.365 | 18.99 | 1.658 | 353.4 |
| F, 1.429; percent fuel, 13.04; O/F, 6.672 | | | | | | | | |
| 1.000 | 600.00 | 4431 | 3229.8 | 0.444 | 1.366 | ------- | ------- | ------- |
| 1.040 | 576.92 | 4390 | 3211.4 | .444 | 1.366 | 2.467 | 0.187 | 39.6 |
| 1.533 | 391.29 | 4007 | 3046.4 | .444 | 1.313 | 1.028 | .603 | 128.4 |
| 1.840 | 326.05 | 3837 | 2965.3 | .442 | 1.312 | 1.000 | .715 | 151.7 |
| 2.300 | 260.86 | 3638 | 2877.8 | .440 | 1.314 | 1.027 | .824 | 174.1 |
| 10.000 | 60.00 | 2543 | 2404.7 | .423 | 1.331 | 2.04 | 1.258 | 267.5 |
| 20.000 | 30.00 | 2136 | 2234.7 | .413 | 1.341 | 3.12 | 1.383 | 294.3 |
| 20.414 | 29.392 | 2125 | 2230.1 | .413 | 1.342 | 3.16 | 1.386 | 294.6 |
| 40.000 | 15.00 | 1786 | 2092.2 | .402 | 1.354 | 4.88 | 1.479 | 314.6 |
| 40.827 | 14.696 | 1777 | 2088.3 | .402 | 1.354 | 4.93 | 1.481 | 315.0 |
| 60.000 | 10.00 | 1606 | 2019.9 | .394 | 1.361 | 6.37 | 1.524 | 324.5 |
| 100.000 | 6.00 | 1400 | 1939.3 | .384 | 1.372 | 8.96 | 1.575 | 335.1 |
| 300.000 | 2.00 | 1033 | 1799.8 | .370 | 1.364 | 18.97 | 1.658 | 352.7 |
| F, 1.333; percent fuel, 13.04; O/F, 6.672 | | | | | | | | |
| 1.000 | 600.00 | 4428 | 3251.8 | 0.451 | 1.364 | ------- | ------- | ------- |
| 1.040 | 576.92 | 4386 | 3233.3 | .450 | 1.365 | 2.466 | .187 | 39.7 |
| 1.539 | 391.40 | 3987 | 3063.3 | .444 | 1.309 | 1.028 | .603 | 128.4 |
| 1.840 | 326.17 | 3819 | 2986.1 | .444 | 1.311 | 1.000 | .715 | 151.5 |
| 2.299 | 260.94 | 3621 | 2900.7 | .442 | 1.313 | 1.027 | .822 | 174.4 |
| 10.000 | 60.00 | 2533 | 2428.6 | .424 | 1.330 | 2.04 | 1.258 | 267.6 |
| 20.000 | 30.00 | 2128 | 2254.8 | .415 | 1.341 | 3.12 | 1.383 | 294.5 |
| 20.414 | 29.392 | 2117 | 2250.2 | .414 | 1.341 | 3.16 | 1.386 | 294.6 |
| 40.000 | 15.00 | 1780 | 2112.4 | .404 | 1.353 | 4.88 | 1.479 | 314.3 |
| 40.827 | 14.696 | 1771 | 2112.4 | .404 | 1.353 | 4.93 | 1.481 | 314.8 |
| 60.000 | 10.00 | 1600 | 2044.3 | .394 | 1.363 | 6.39 | 1.524 | 324.1 |
| 100.000 | 6.00 | 1396 | 1963.8 | .383 | 1.371 | 8.98 | 1.575 | 334.8 |
| 300.000 | 2.00 | 1031 | 1824.3 | .369 | 1.364 | 18.91 | 1.658 | 352.8 |
| (n) Percent fluorine in oxidant by weight, ±0.4 | | | | | | | | |
| F, 1.000; percent fuel, 13.04; O/F, 6.672 | | | | | | | | |
| 1.000 | 600.00 | 4498 | 3113.3 | 0.436 | 1.309 | ------- | ------- | ------- |
| 1.040 | 576.92 | 4456 | 3095.2 | .435 | 1.309 | 2.469 | 0.187 | 39.6 |
| 1.535 | 390.88 | 4063 | 2924.8 | .431 | 1.313 | 1.028 | .604 | 128.1 |
| 1.844 | 325.74 | 3890 | 2850.3 | .429 | 1.315 | 1.000 | .714 | 151.3 |
| 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 | 293.9 |
| 20.414 | 29.392 | 2145 | 2122.7 | .401 | 1.345 | 3.15 | 1.386 | 293.8 |
| 40.000 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 40.827 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 60.000 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 100.000 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 300.000 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| F, 1.333; percent fuel, 13.04; O/F, 6.672 | | | | | | | | |
| 1.000 | 600.00 | 4493 | 3135.5 | 0.438 | 1.308 | ------- | ------- | ------- |
| 1.040 | 576.92 | 4452 | 3117.4 | .437 | 1.309 | 2.469 | 0.187 | 39.7 |
| 1.535 | 390.93 | 4060 | 2946.8 | .433 | 1.313 | 1.028 | .604 | 128.3 |
| 1.844 | 325.74 | 3887 | 2871.8 | .431 | 1.314 | 1.000 | .714 | 151.5 |
| 2.302 | 260.62 | 3684 | 2784.6 | .428 | 1.317 | 1.027 | .823 | 174.8 |
| 10.000 | 60.00 | 2568 | 2313.0 | .412 | 1.334 | 2.04 | 1.259 | 267.2 |
| 20.000 | 30.00 | 2156 | 2144.3 | .403 | 1.344 | 3.11 | 1.382 | 293.8 |
| 20.414 | 29.392 | 2145 | 2141.7 | .403 | 1.344 | 3.15 | 1.386 | 293.1 |
| 40.000 | 15.00 | 1801 | 2005.0 | .393 | 1.356 | 4.88 | 1.479 | 313.8 |
| 40.827 | 14.696 | 1792 | 2001.2 | .393 | 1.357 | 4.93 | 1.480 | 314.2 |
| 60.000 | 10.00 | 1618 | 1933.5 | .387 | 1.364 | 6.38 | 1.524 | 323.6 |
| 100.000 | 6.00 | 1410 | 1853.7 | .379 | 1.375 | 8.93 | 1.576 | 334.0 |
| 300.000 | 2.00 | 1038 | 1715.8 | .365 | 1.367 | 18.74 | 1.656 | 351.5 |
| F, 1.429; percent fuel, 13.04; O/F, 6.672 | | | | | | | | |
| 1.000 | 600.00 | 4476 | 3137.7 | 0.440 | 1.308 | ------- | ------- | ------- |
| 1.040 | 576.92 | 4435 | 3119.6 | .440 | 1.309 | 2.468 | 0.187 | 39.7 |
| 1.534 | 391.06 | 4045 | 2949.1 | .435 | 1.312 | 1.028 | .604 | 128.1 |
| 1.841 | 325.88 | 3873 | 2874.4 | .433 | 1.314 | 1.000 | .714 | 151.4 |
| 2.301 | 260.71 | 3672 | 2787.3 | .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 | 2164.0 | .405 | 1.343 | 3.11 | 1.383 | 293.3 |
| 20.414 | 29.392 | 2140 | 2161.5 | .405 | 1.344 | 3.15 | 1.386 | 294.0 |
| 40.000 | 15.00 | 1798 | 2027.7 | .395 | 1.355 | 4.87 | 1.479 | 313.8 |
| 40.827 | 14.696 | 1788 | 2023.9 | .395 | 1.356 | 4.93 | 1.481 | 314.1 |
| 60.000 | 10.00 | 1615 | 1956.1 | .389 | 1.363 | 6.38 | 1.524 | 323.5 |
| 100.000 | 6.00 | 1405 | 1876.3 | .380 | 1.374 | 8.95 | 1.576 | 333.9 |
| 300.000 | 2.00 | 1037 | 1738.2 | .365 | 1.366 | 18.80 | 1.657 | 351.4 |



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

FOR LIQUID METHANE WITH SEVERAL FLUORINE-OXYGEN MIXTURES

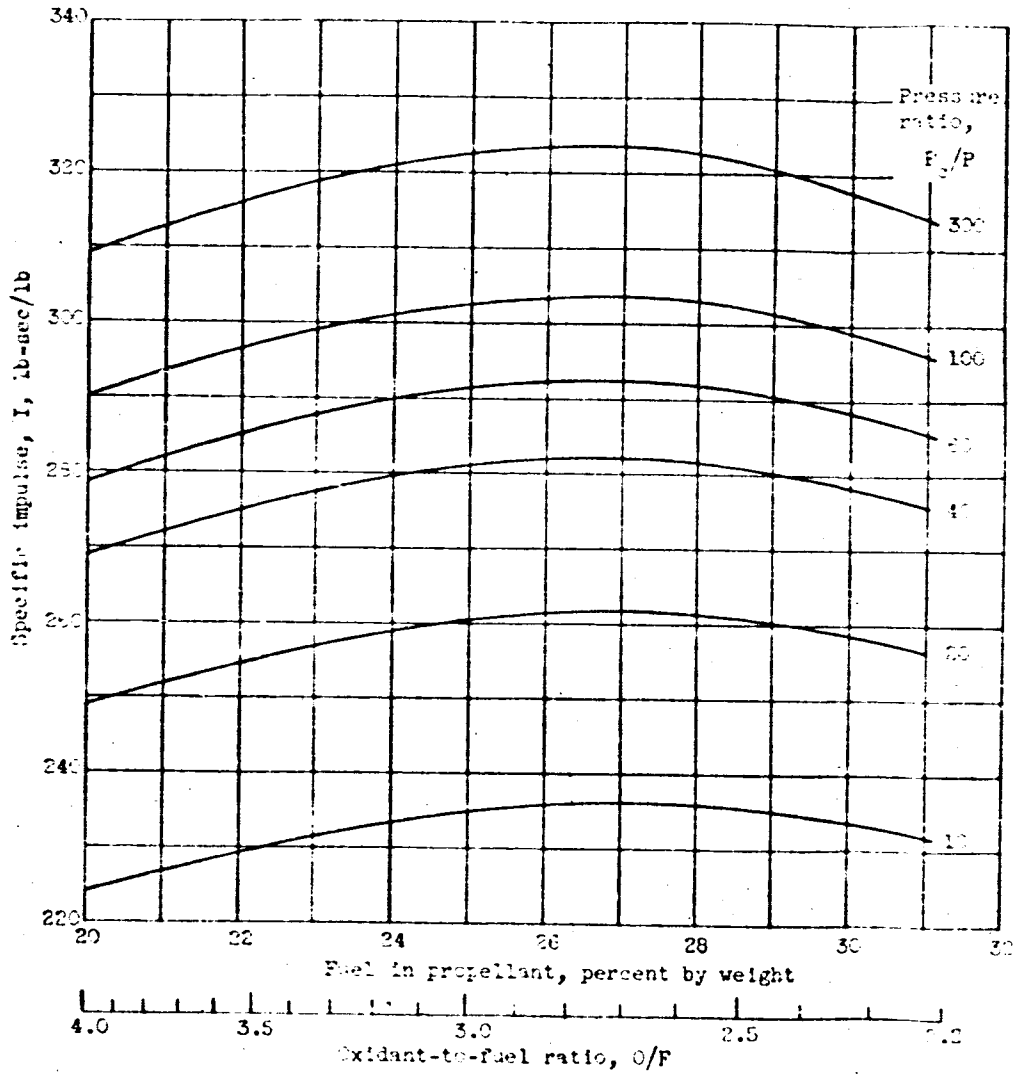
[Frozen composition assumed during isentropic expansion from combustion-chamber pressure of 600 lb/sq in. abs.]

(n) Percent fluorine in oxidant by weight, ±0.01

| 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 |
|---|---|---|---|---|---|---|---|---|
| F, 1.000; percent fuel, 14.67; O/F, 5.442 | | | | | | | | |
| 1.000 | 600.00 | 4527 | 3019.9 | 0.425 | 1.312 | ------- | ------- | ------- |
| 1.040 | 576.92 | 4485 | 3002.0 | .425 | 1.313 | 2.471 | 0.187 | 39.4 |
| 1.537 | 390.44 | 4085 | 2832.9 | .420 | 1.317 | 1.028 | .606 | 127.5 |
| 1.844 | 325.37 | 3910 | 2759.2 | .419 | 1.319 | 1.000 | .715 | 150.6 |
| 2.305 | 260.29 | 3704 | 2673.4 | .416 | 1.321 | 1.027 | .824 | 173.6 |
| 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 |
| F, 1.333; percent fuel, 14.67; O/F, 5.442 | | | | | | | | |
| 1.000 | 600.00 | 4528 | 3057.2 | 0.429 | 1.311 | ------- | ------- | ------- |
| 1.040 | 576.92 | 4486 | 3039.2 | .428 | 1.312 | 2.470 | 0.187 | 39.6 |
| 1.536 | 390.57 | 4087 | 2869.2 | .424 | 1.316 | 1.028 | .605 | 127.9 |
| 1.843 | 325.47 | 3911 | 2795.0 | .422 | 1.318 | 1.000 | .715 | 151.0 |
| 2.304 | 260.38 | 3706 | 2708.6 | .420 | 1.320 | 1.027 | .824 | 174.2 |
| 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 |
| F, 1.429; percent fuel, 13.04; O/F, 6.672 | | | | | | | | |
| 1.000 | 600.00 | 4480 | 3131.0 | 0.436 | 1.307 | ------- | ------- | ------- |
| 1.040 | 576.92 | 4438 | 3113.1 | .436 | 1.307 | 2.467 | 0.187 | 39.5 |
| 1.534 | 391.16 | 4049 | 2944.3 | .431 | 1.311 | 1.028 | .604 | 127.4 |
| 1.841 | 325.97 | 3877 | 2870.3 | .430 | 1.313 | 1.000 | .713 | 150.6 |
| 2.301 | 260.77 | 3676 | 2784.1 | .427 | 1.315 | 1.027 | .823 | 173.7 |
| 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 | 1724.5 | .362 | 1.395 | 18.83 | 1.657 | 349.9 |
| F, 1.333; percent fuel, 13.04; O/F, 6.672 | | | | | | | | |
| 1.000 | 600.00 | 4395 | 3239.7 | 0.448 | 1.300 | ------- | ------- | ------- |
| 1.040 | 576.92 | 4356 | 3221.9 | .443 | 1.300 | 2.463 | 0.187 | 39.3 |
| 1.530 | 392.09 | 3982 | 3055.7 | .443 | 1.302 | 1.029 | .601 | 126.5 |
| 1.836 | 326.74 | 3816 | 2982.2 | .441 | 1.306 | 1.000 | .711 | 149.7 |
| 2.295 | 261.32 | 3622 | 2896.5 | .439 | 1.308 | 1.027 | .821 | 172.8 |
| 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 | 3.19 | 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 | 19.14 | 1.662 | 349.7 |

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

| Equivalence ratio, $\phi$, $\frac{4(C)+(H)}{2(O)+(F)}$ | Fuel, percent by weight | Oxidant-to-fuel weight ratio, O/F | Combustion temperature, $T_c$, °K | Equilibrium composition (mole fractions) | | |

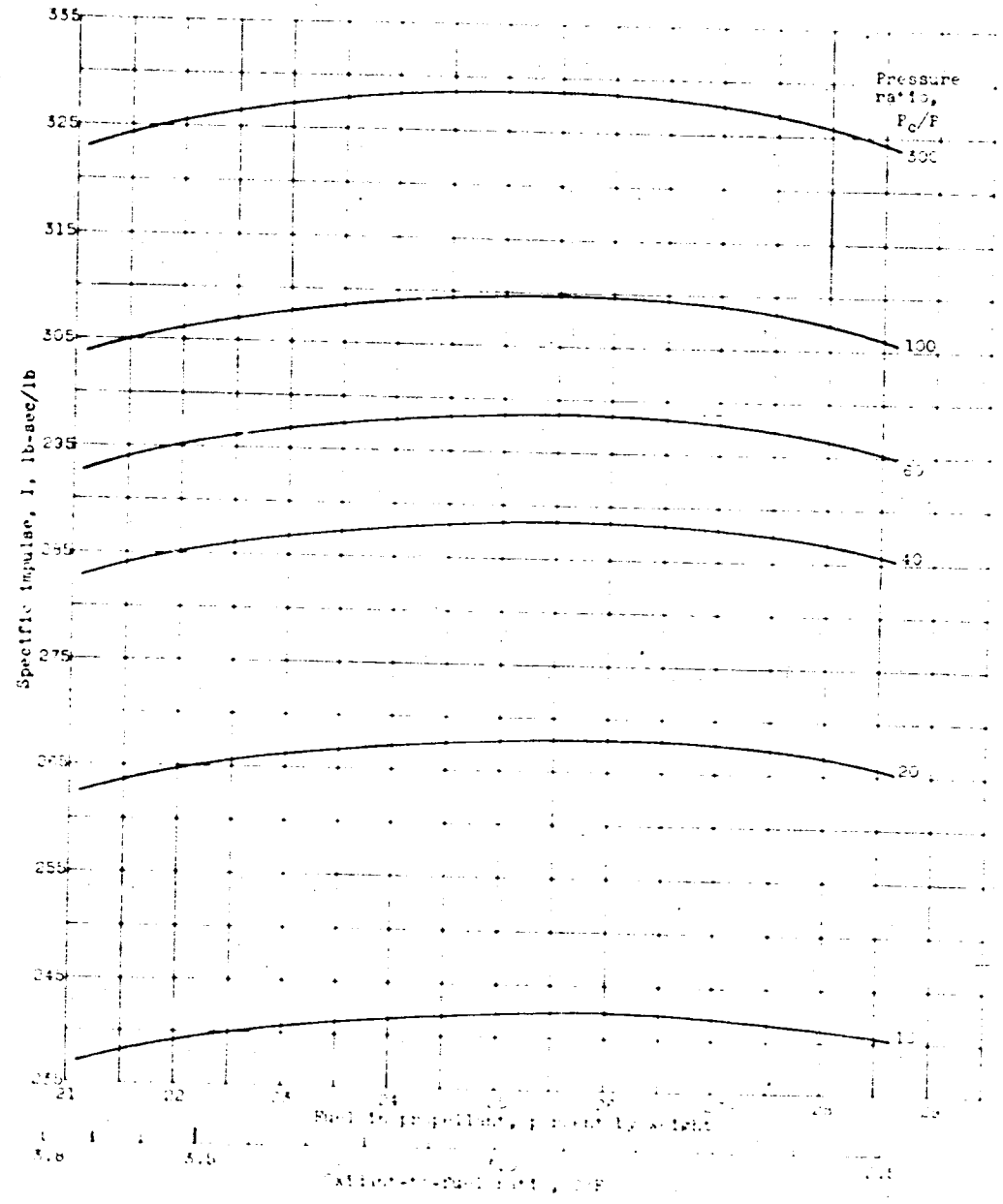



(a) Percent fluorine in oxidant by weight, 0 (100 percent oxygen).

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.

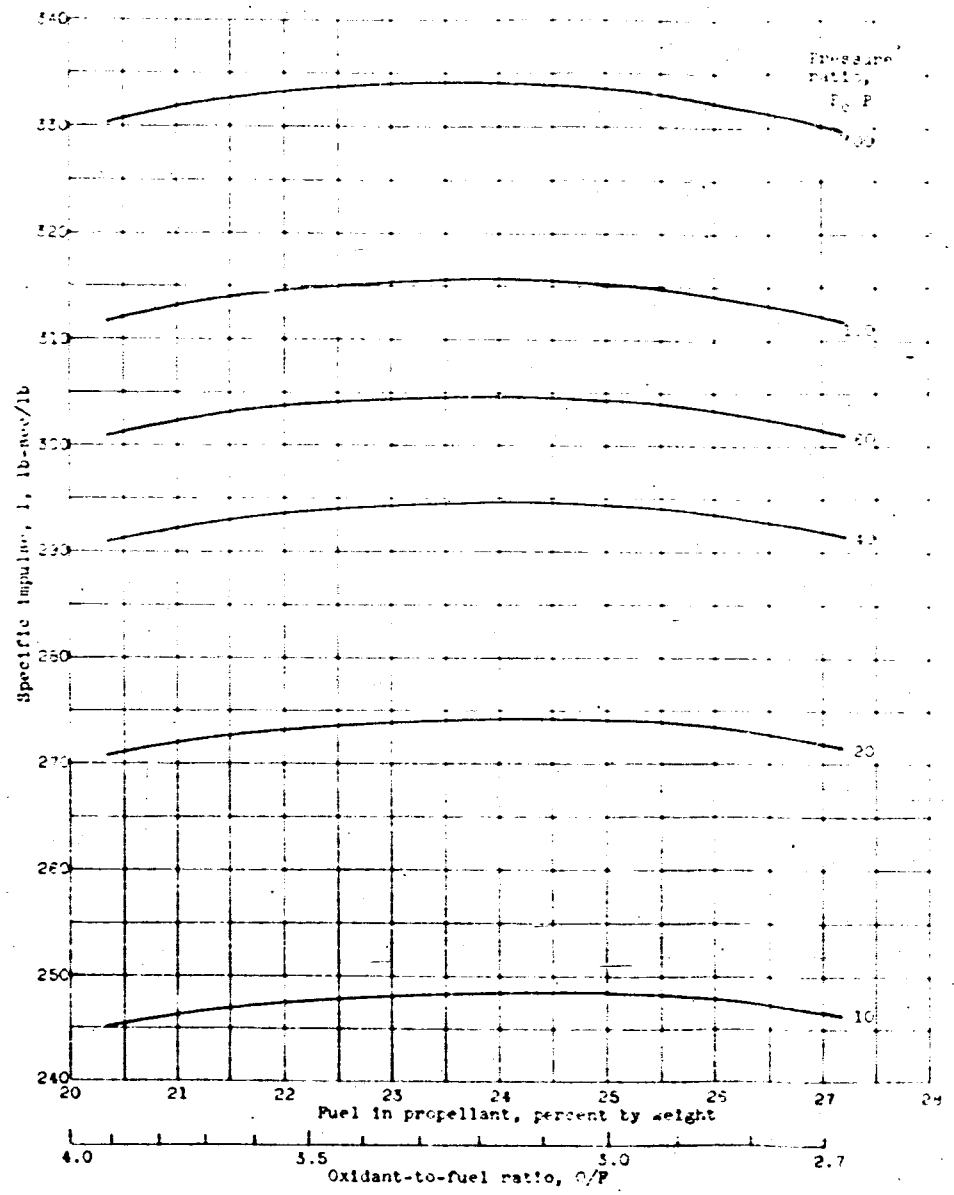
4762






(b) Percent fluorine in oxidant by weight, 1.0.

Figure 1. - Continued.

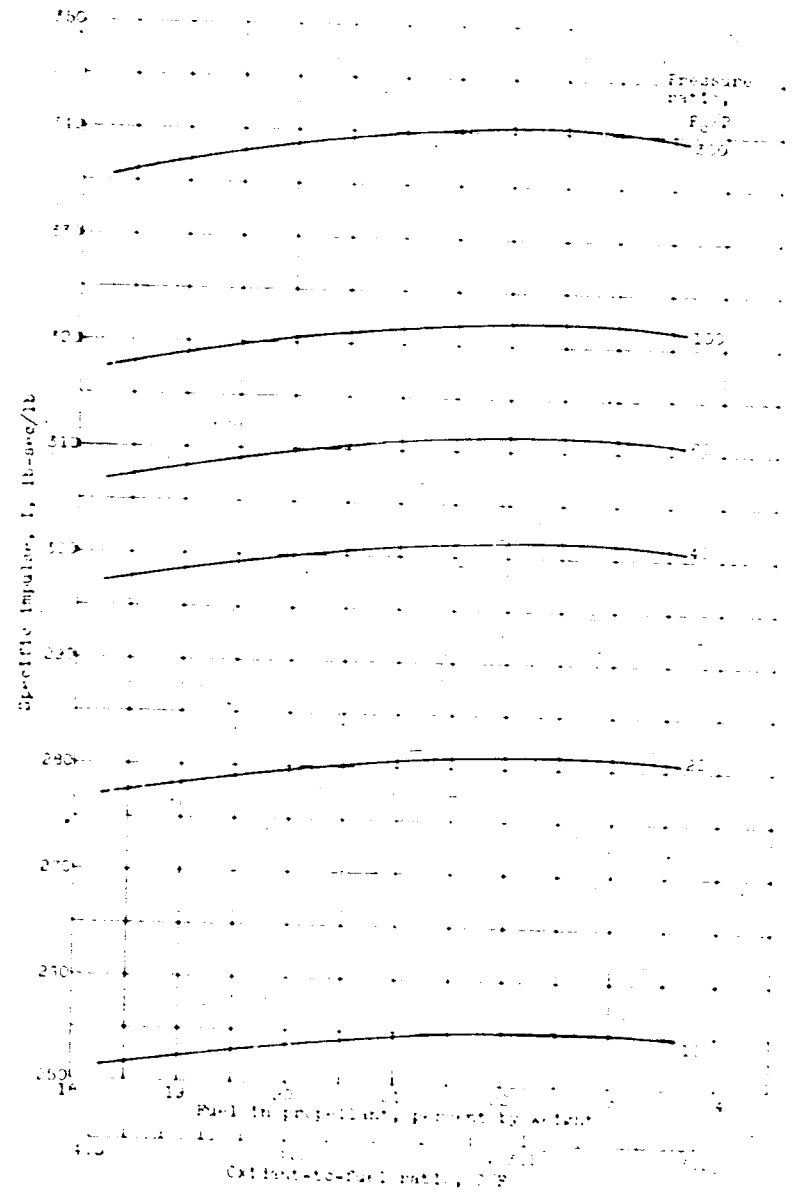



(c) Percent fluorine in oxidant by weight, 57.25.

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.

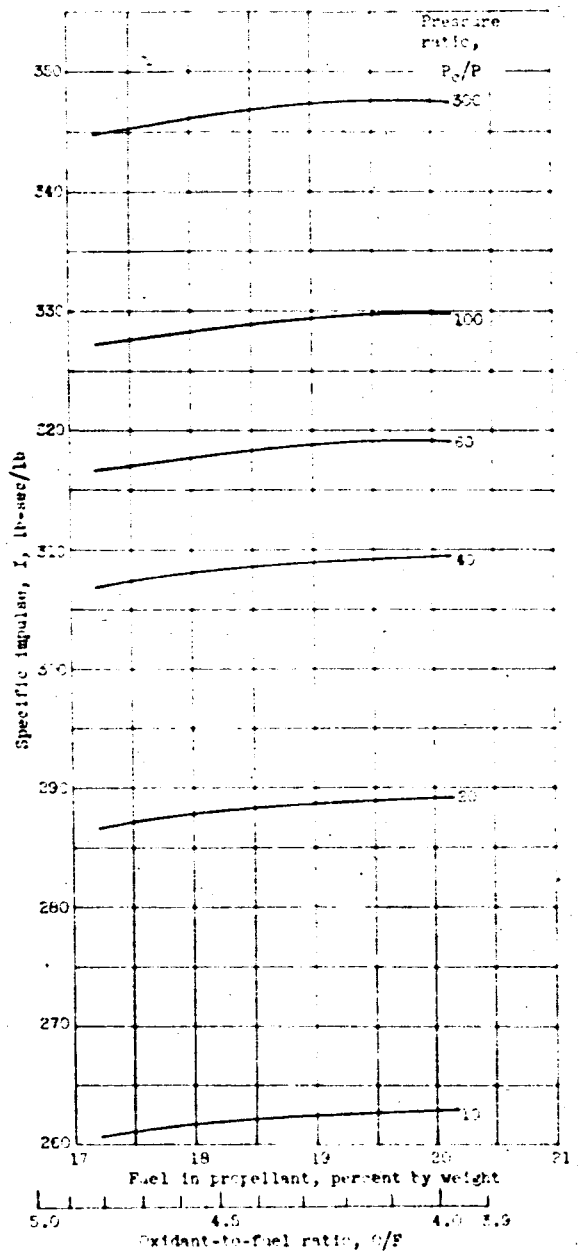
4102






(d) Percent fluorine in oxidant by weight, [illegible].

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

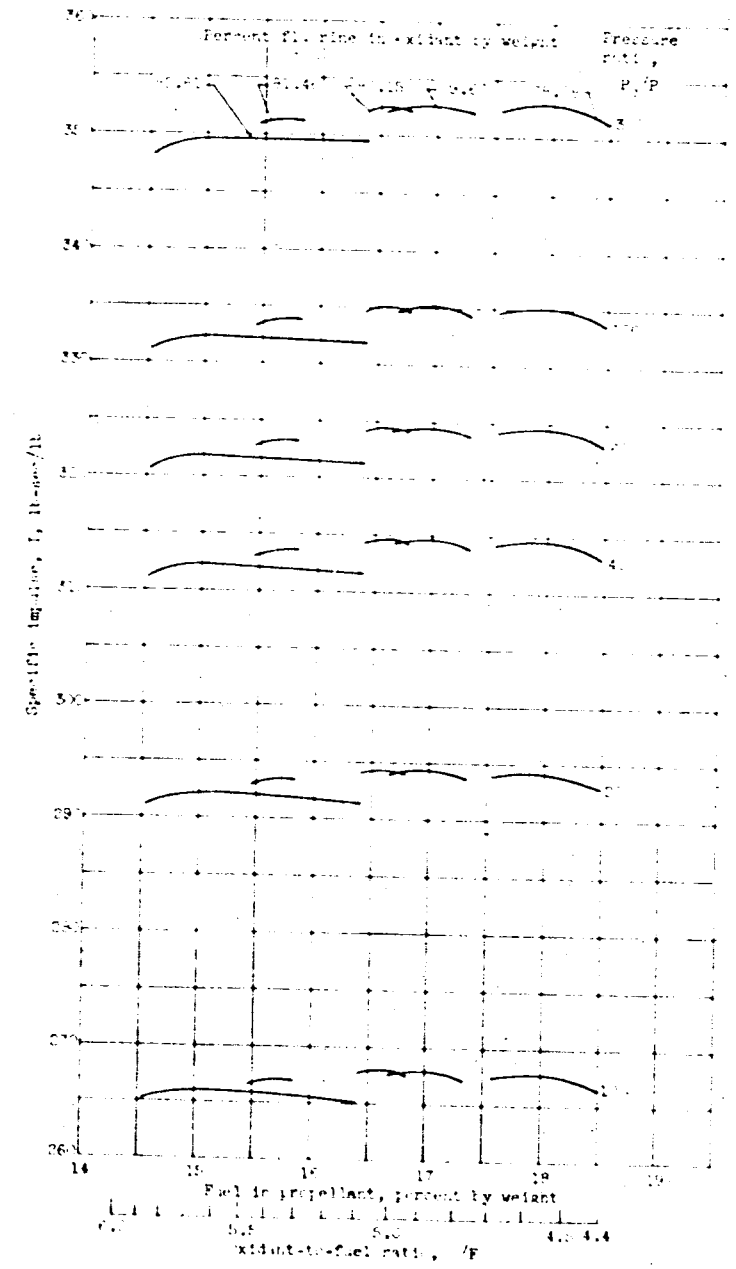



(e) Percent fluorine in oxidant by weight, 70.37.

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

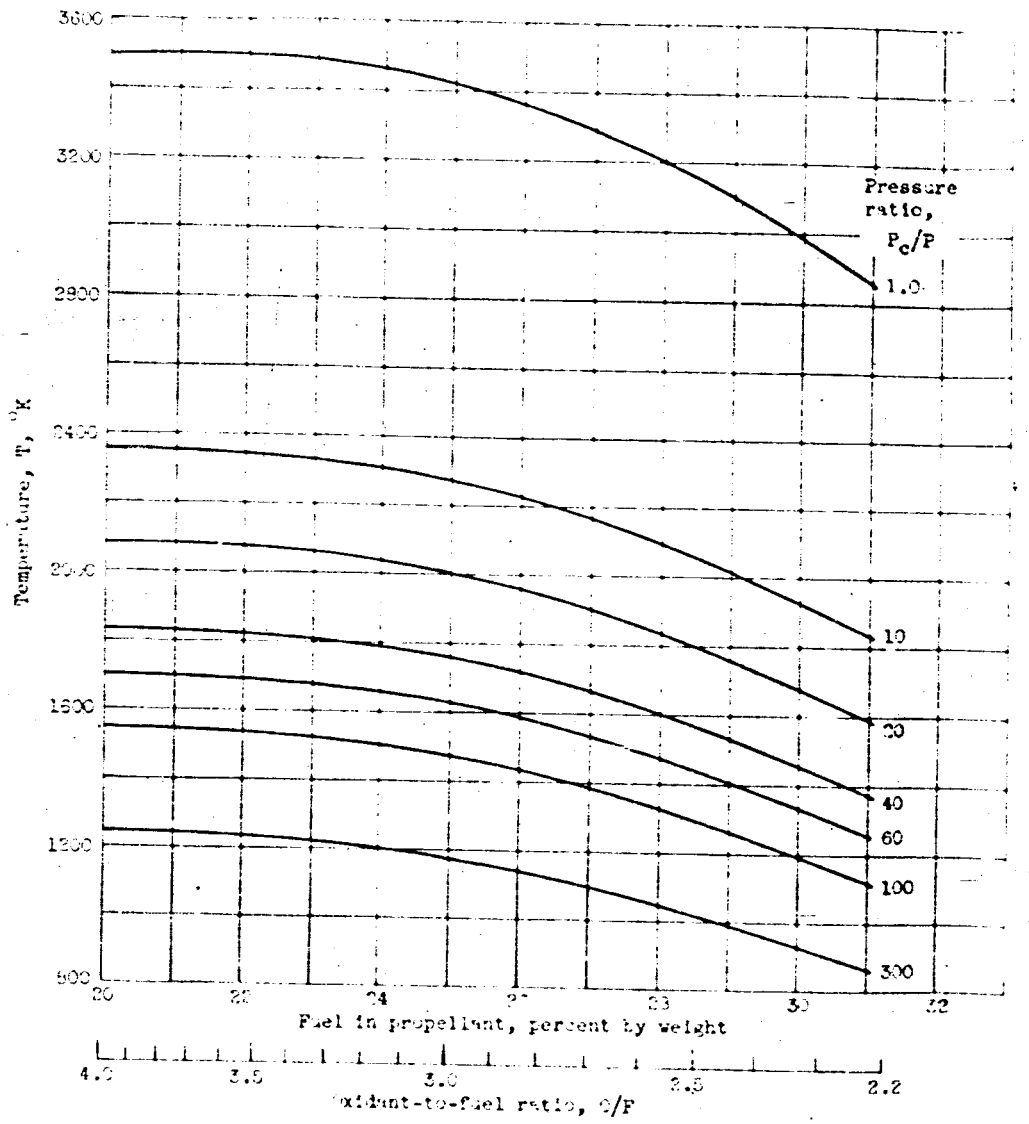


4762




(f) Percent fluorine in oxidant by weight, [illegible].

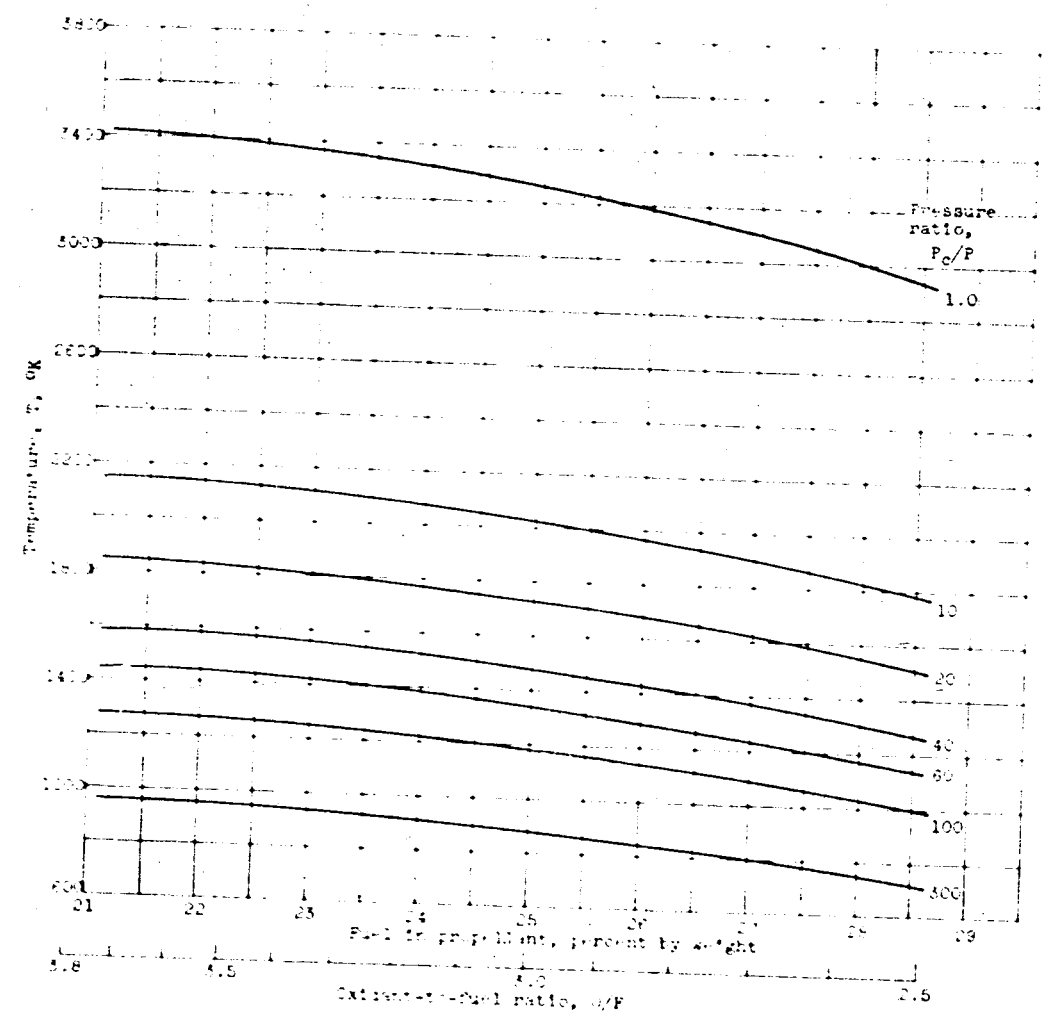
Figure 1. - Concluded. Theoretical specific impulse of liquid methane with several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from combustion-chamber pressure of [illegible] pounds per square inch absolute to pressure ratio indicated.




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

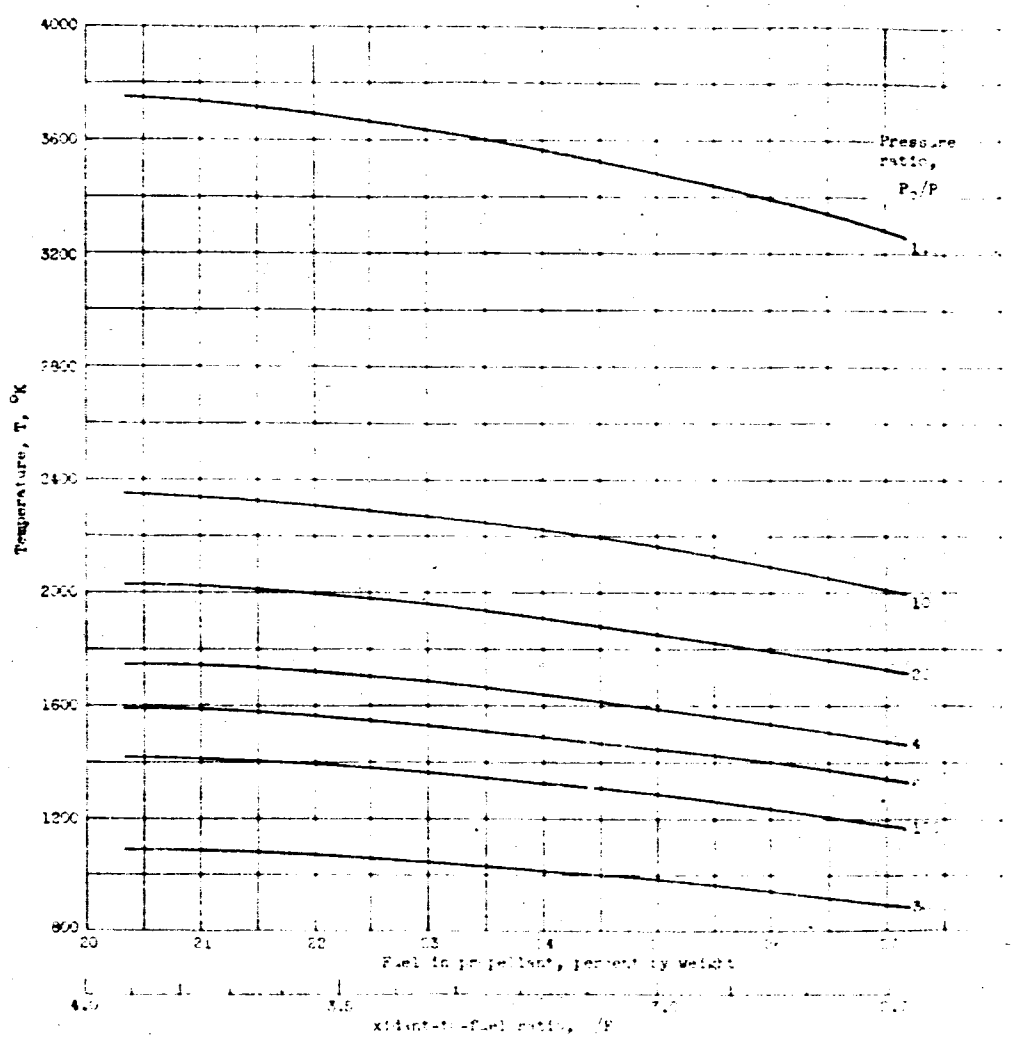
Figure 2. - The ratio of combustion-chamber temperature and nozzle-exit temperature for liquid methane and several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from a constant combustion-chamber pressure of 600 pounds per square inch absolute to pressure ratio indicated.






(b) Percent fluorine in oxidant by weight, 10-19.

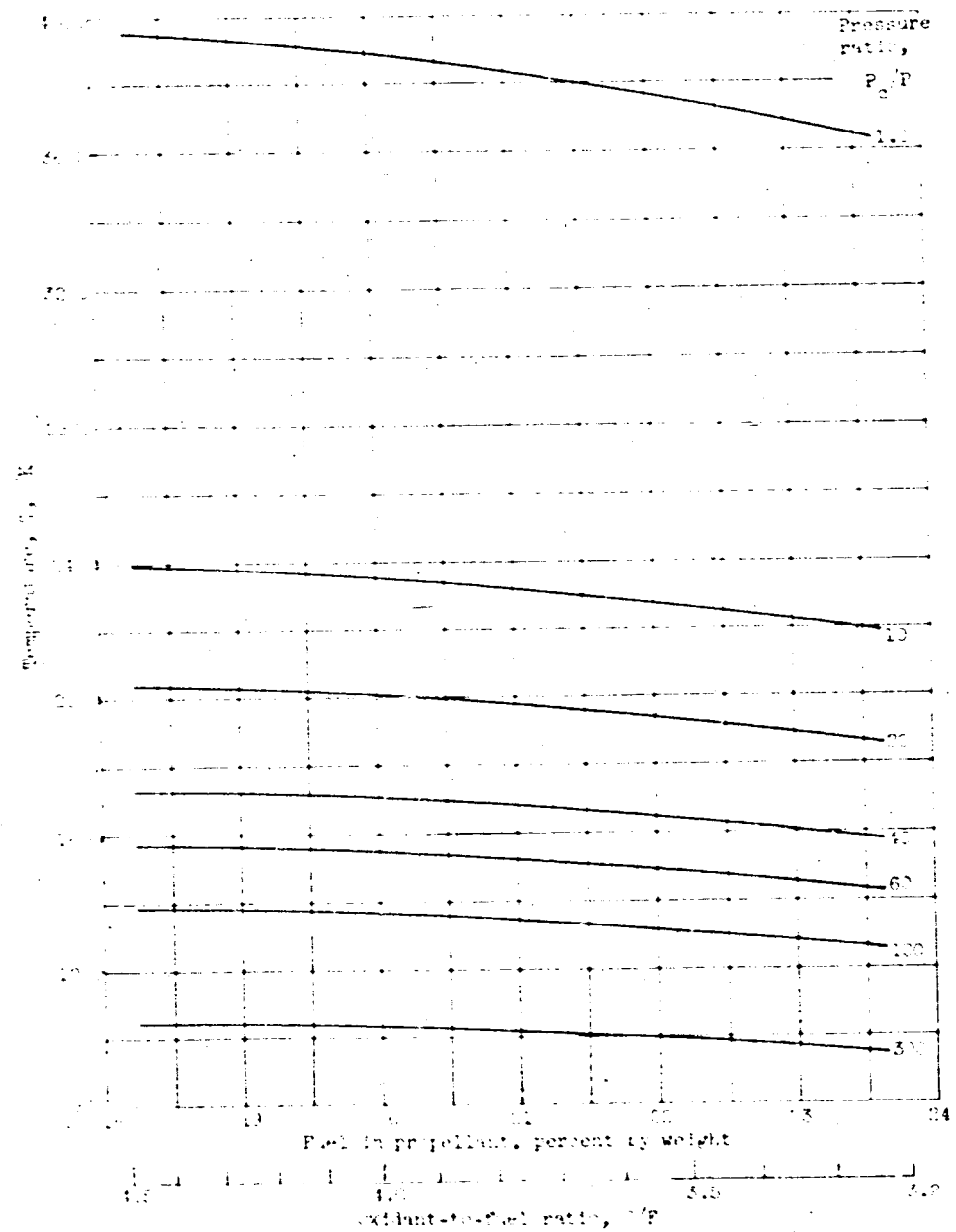
Figure 2. - Continued. The ratio of combustion-chamber temperature and nozzle-exit temperature for liquid methane and several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from a constant combustion-chamber pressure of 600 pounds per square inch absolute to pressure ratio indicated.




(a) Percent fluorine in oxidant by weight, 24.0.

Figure 5. - Continued. The ratio of adiabatic-chamber temperature and nozzle-exit temperature for liquid methane and several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from adiabatic-chamber pressure of 600 pounds per square inch absolute to pressure ratio indicated.

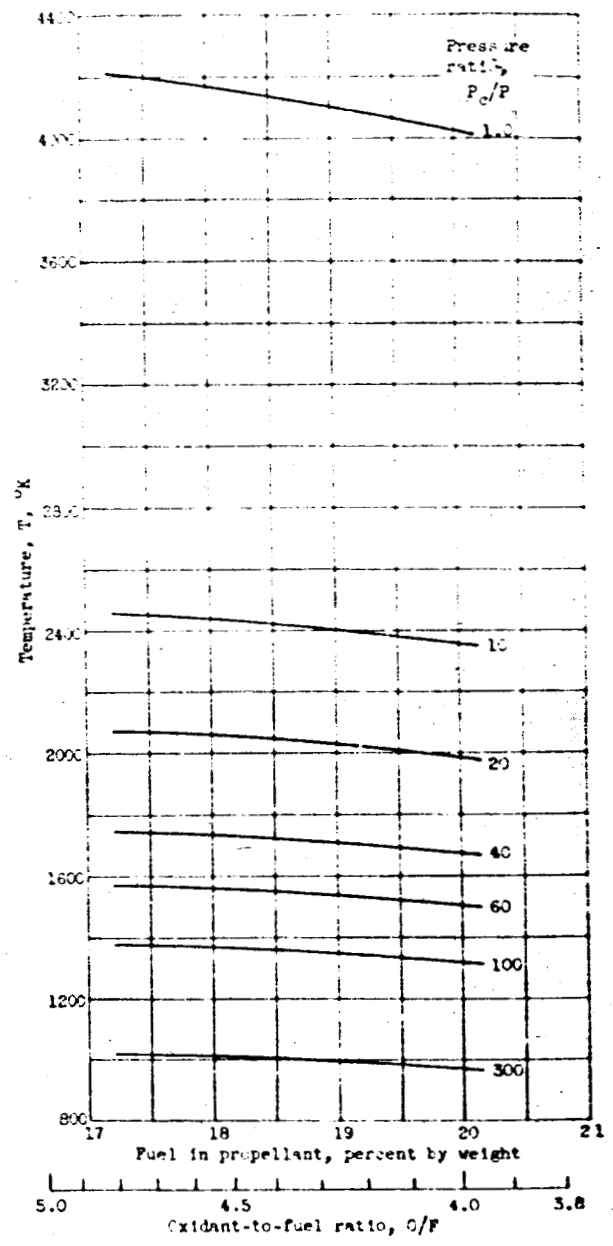





(d) Percent fluorine in oxidant by weight, 24.0.

Figure 5. - Continued. The ratio of adiabatic-chamber temperature and nozzle-exit temperature for liquid methane and several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from adiabatic-chamber pressure of 600 pounds per square inch absolute to pressure ratio indicated.

4762

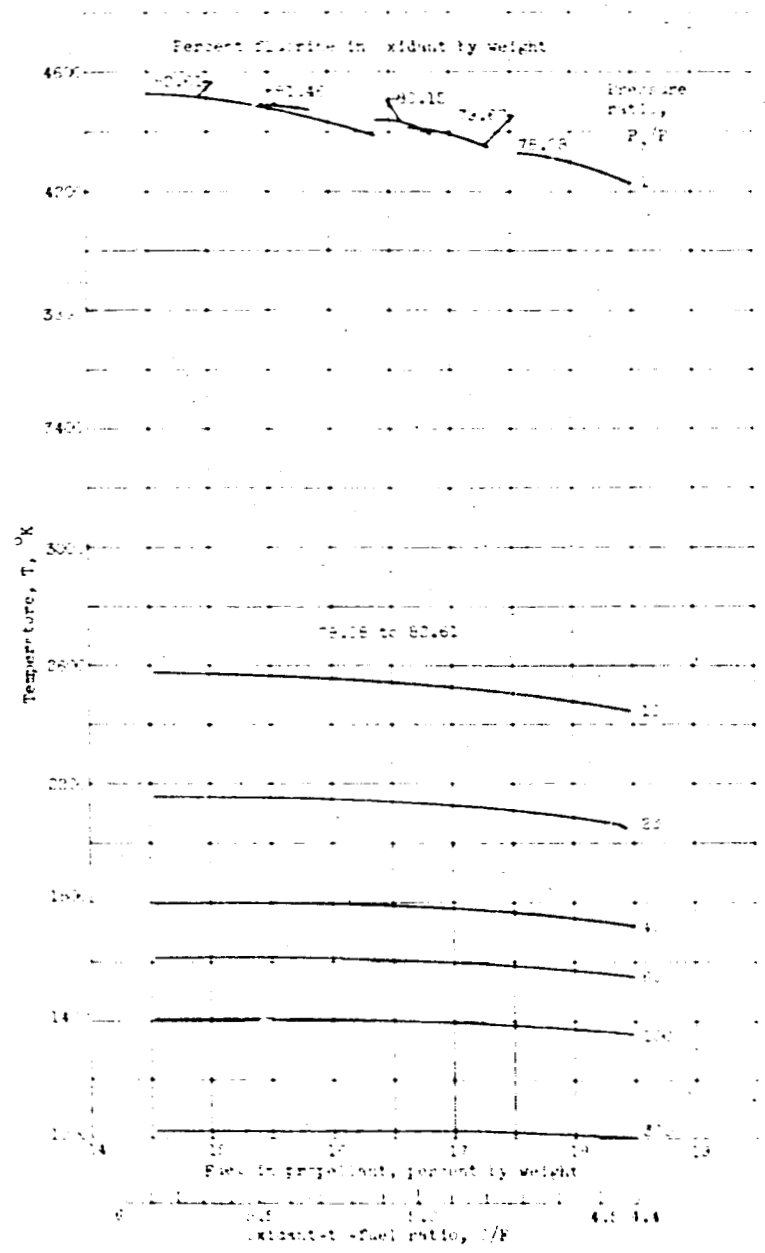



(e) Percent fluorine in oxidant by weight, 70.37.

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.



4762




(f) Percent fluorine in oxidant by weight, [illegible].

Figure [illegible]. - 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 [illegible] pounds per square inch absolute to pressure ratio indicated.

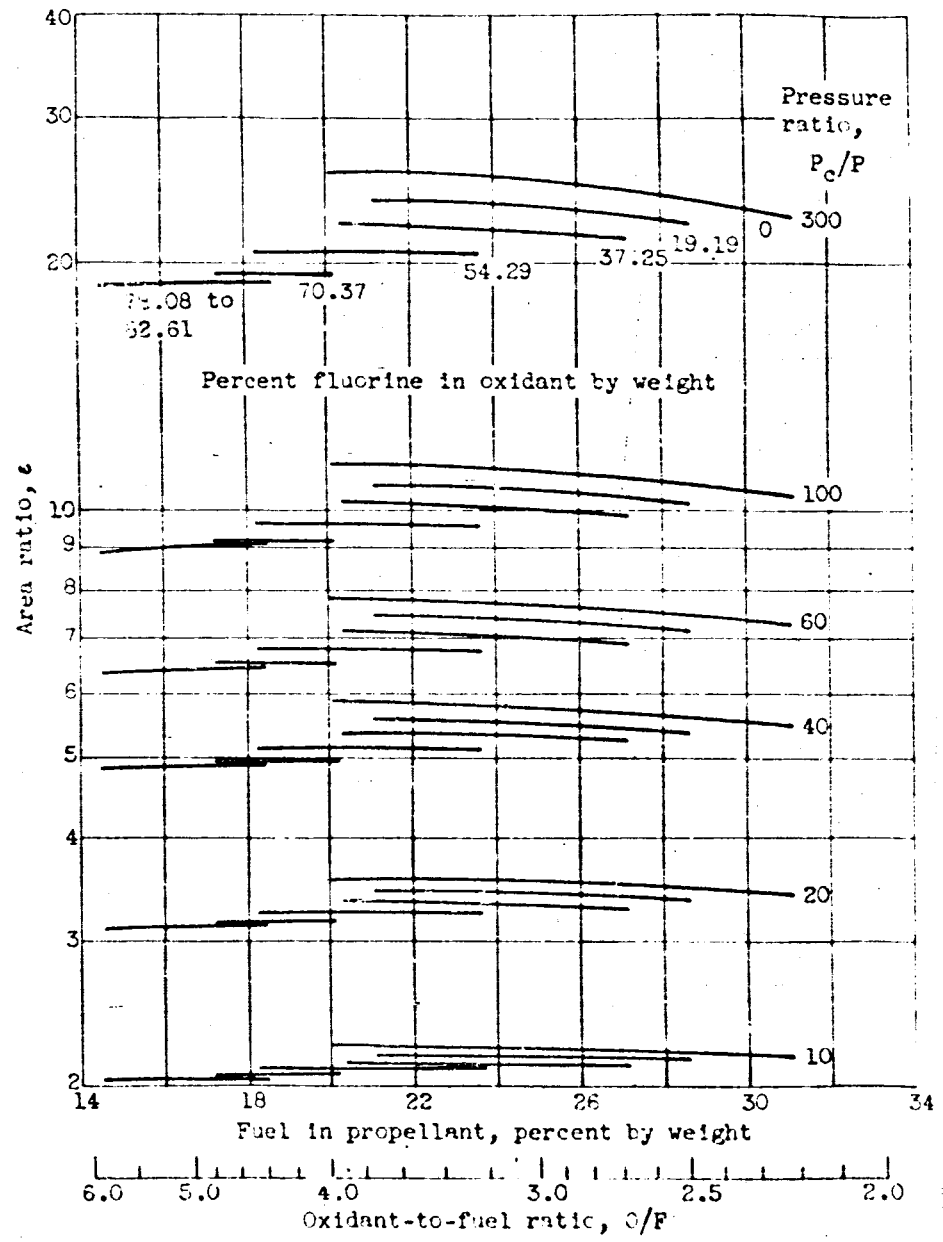



Figure 3. - Theoretical ratio of nozzle area to throat area for liquid methane with several fluorine-oxygen mixtures. Frozen composition during isentropic expansion from combustion-chamber pressure of 600 pounds per square inch absolute to pressure ratio indicated.



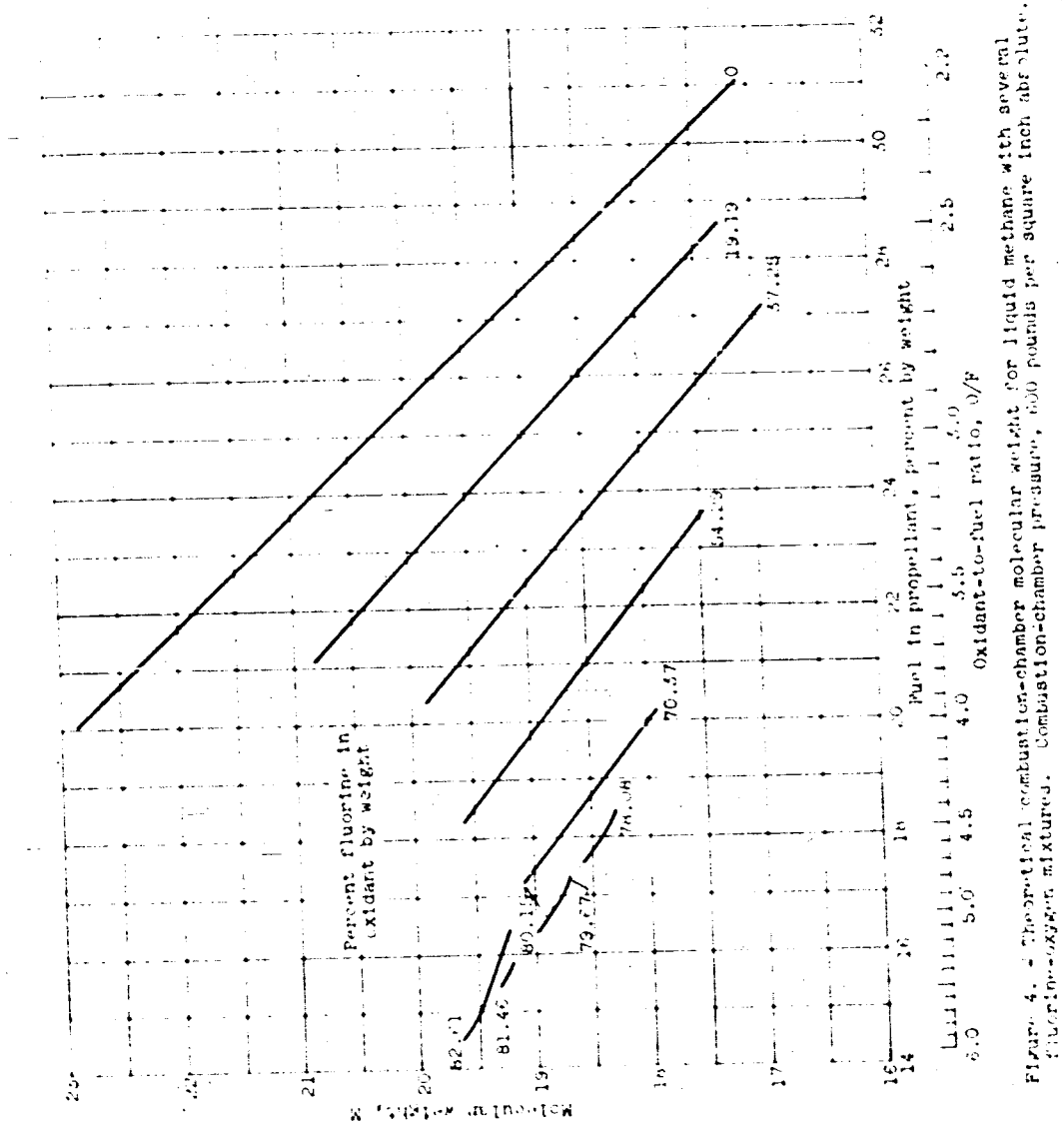



Figure 4. - Theoretical combustion-chamber molecular weight for liquid methane with several fluorine-oxygen mixtures. Combustion-chamber pressure, 600 pounds per square inch absolute.

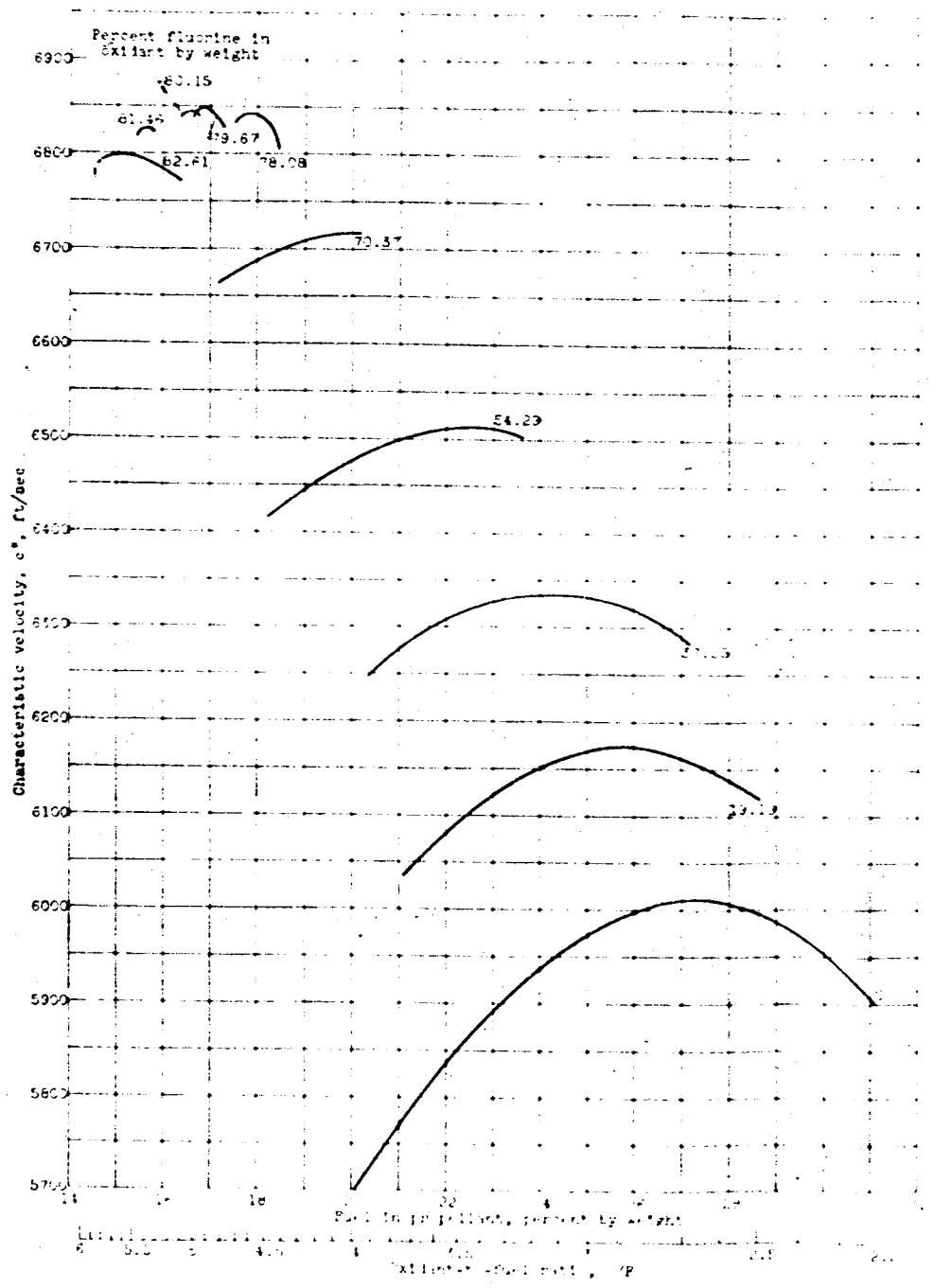



Figure 5. - Theoretical characteristic velocity for liquid methane with several fluorine-oxygen mixtures. Isentropic expansion assuming frozen composition from combustion-chamber pressure of 600 pounds per square inch absolute to exit pressure of 1 atmosphere.



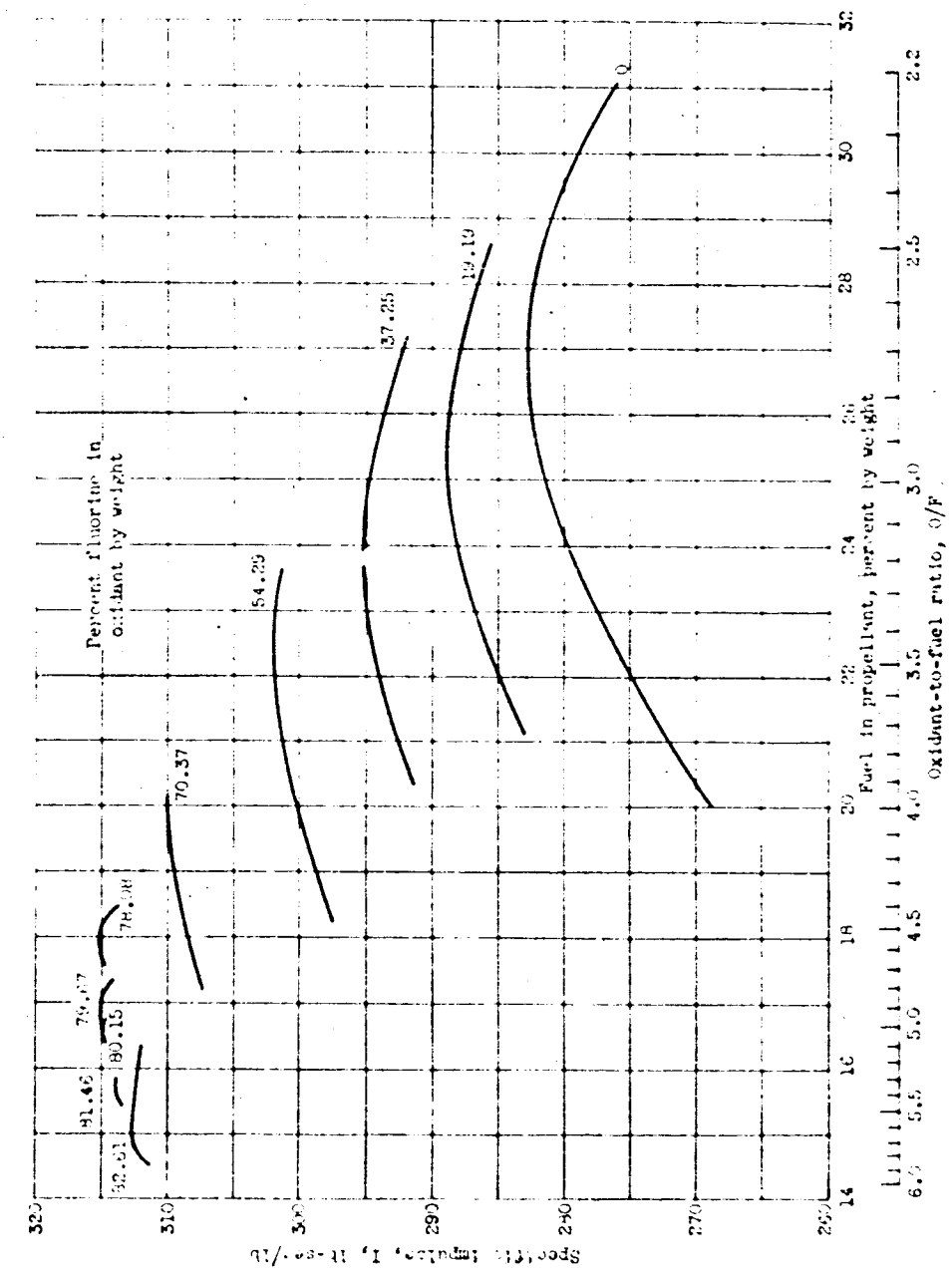



Figure 6. - Theoretical specific impulse for liquid methane with several fluorine-oxygen mixtures. Isentropic expansion assuming frozen composition from combustion-chamber pressure of 600 pounds per square inch absolute to exit pressure of 1 atmosphere.

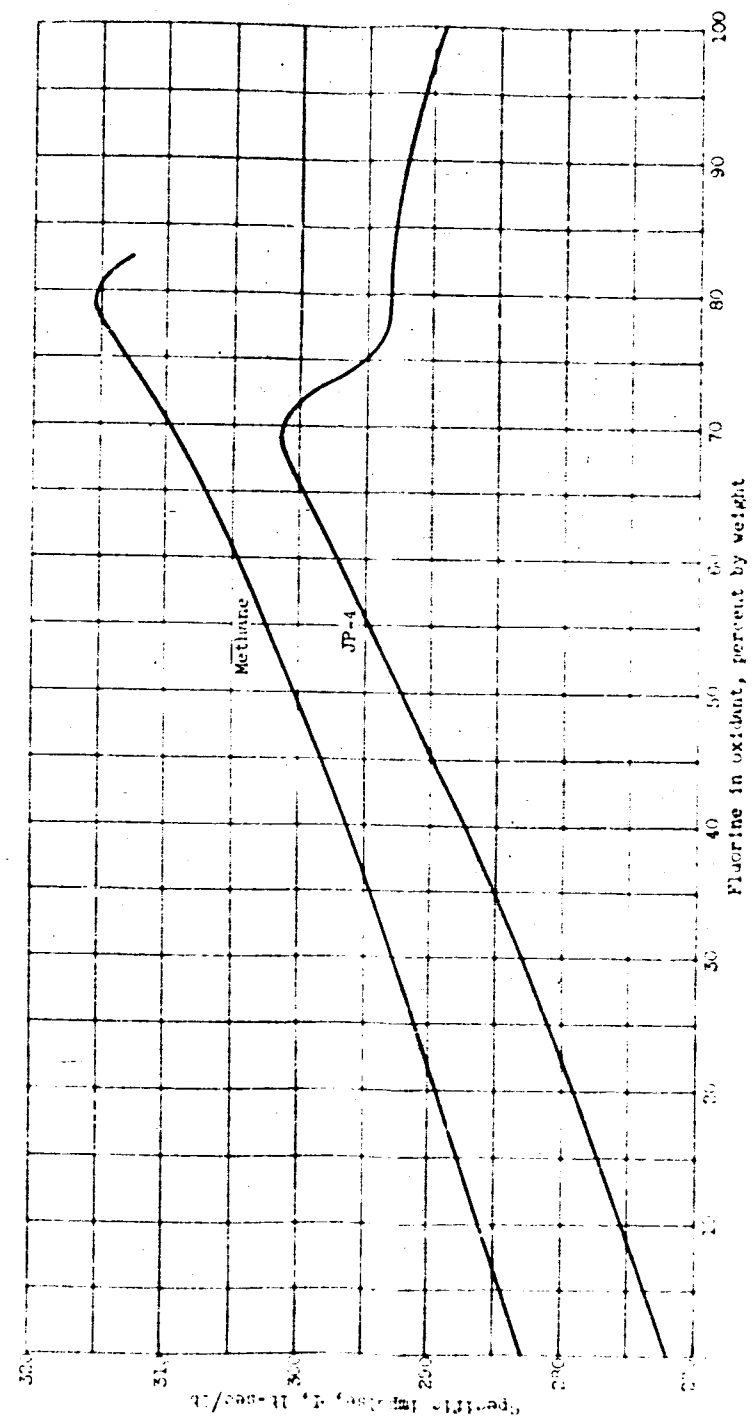



Figure 4.- Comparison of theoretical specific impulse of liquid methane with that of JP-4 fuel both with fluorine-oxygen mixtures at equivalence ratios for which specific impulse is maximum. Frozen composition assumed during isentropic expansion from combustion-chamber pressure of 600 pounds per square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