R. & M. No. 3099
(13,672, 15,211 and 17,345)
A.R.C. Monograph

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL
REPORTS AND MEMORANDA

Thermodynamic Data for the Calculation of Gas Turbine Performance

By

D. FIELDING and J. E. C. TOPPS

LONDON: HER MAJESTY'S STATIONERY OFFICE

PRICE £2 5s 0d NET

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL
REPORTS AND MEMORANDA

Thermodynamic Data for the Calculation of Gas Turbine Performance

By

D. FIELDING and J. E. C. TOPPS

LONDON: HER MAJESTY'S STATIONERY OFFICE
1959

Printed and published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
York House, Kingsway, London w.c.2
423 Oxford Street, London w.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
39 King Street, Manchester 2
Tower Lane, Bristol 1
2 Edmund Street, Birmingham 3
80 Chichester Street, Belfast
or through any bookseller

Printed in Great Britain

LIST OF CONTENTS

Page

1. Introduction 1

2. The Calculation of the Properties of Mixed Gases 2
   2.1. General 2
   2.2. Calculation of the Properties of General Reactants 4
      2.2.1. Composition of a general reactant 4
      2.2.2. Molecular weight 4
      2.2.3. Thermodynamic properties 4
   2.3. Calculation of the Properties of the Products of Complete Combustion of a General Fuel in a General Medium 6
      2.3.1. Composition of the products 6
      2.3.2. Molecular weight of the products 8
      2.3.3. Thermodynamic properties of the products 9

3. Combustion Temperature Rise Calculations 12
   3.1. Heat of Reaction and Calorific Value 12
   3.2. Effective Calorific Value 13
   3.3. Effective Calorific Value of a General Reactant 14
   3.4. General Combustion Temperature Rise Calculations 15
   3.5. Incomplete Combustion 18

4. Gas Turbine Performance Calculations 20
   4.1. Definitions of Efficiency 22
      4.1.1. Compression and expansion processes 22
      4.1.2. Combustion efficiency 23
   4.2. Construction of Data Sheets.—Standard Data for Comparison of Gas Turbine performance 24
      4.2.1. Standard fuel and its combustion products 24
      4.2.2. Range of applicability of standard fuel data 26
   4.3. Use of Tabulated Data for Gas Turbine Performance Calculation 26
      4.3.1. Determination of temperature from total heat or entropy function ψ 26
      4.3.2. Determination of combustion temperature rise 27

5. The Calculation of Gas Flow 28
   5.1. The Equations for One-dimensional Gas Flow 28
      5.1.1. Dimensional basis 28
      5.1.2. Definitions and assumptions 29
      5.1.3. Flow at subsonic velocities 30
      5.1.4. Flow at supersonic velocities 31
   5.2. Presentation of Data 32

Acknowledgement 37

APPENDICES

Appendix

I Constants and Notation 38

II The Effects of Random Error in Thermodynamic Data 40

TABLES

Table

1 Properties of Dry Air 42

2 Total Heat Ω Functions 61

3 True Specific Ω Functions 63

4 Ω Functions for ψ (Entropy Function) 65

5 Total Heat θ Functions.. .. 67

6 True Specific Heat θ Functions 69

7 θ Functions for ψ (Entropy Function) 71

8 Effective Calorific Value θ Functions 73

9 Flame Temperature from Product Analyses 75

10 The Combustion of Standard Fuel in Dry Air 76

11 General flow and Expansion Functions for any Gas 78

12 Flow and Expansion Functions for Air and the Combustion Products of Standard Fuel in Dry Air.. 80

Thermodynamic Data for the Calculation of Gas Turbine Performance

By

D. Fielding, of Metropolitan Vickers Electrical Co., Ltd.,

and

J. E. C. Topps, of The National Gas Turbine Establishment

Communicated by the Principal Director of Scientific Research (Air), Ministry of Supply

Reports and Memoranda No. 3099

June, 1954

1. *Introduction.*—The essential features of a practical method of determining gas turbine performance are that it shall be suitable for accurate routine calculation, and that it is capable of simple modification in order to deal with a range of fuels or with complex cycles. It is the opinion of the authors that the exactitude of the method should also be demonstrable, within the limits imposed by the scales employed, and that it should require only the use of parameters physically intelligible to the average engineer, and a sequence of operations which can be followed by a computer. The calculation should not, moreover, be onerous, involving the use of large or complex charts, or interpolation in tables.

Experience has shown that cycle analysis is most efficiently carried out by numerical evaluation of the energy change involved in each stage of the process, so that corrections for plant efficiency and for losses due to friction, to imperfect combustion, to the use of air for cooling, etc., may be applied as they occur, and the data presented are selected with this in mind. The data required are therefore the total heat and entropy of gas mixtures, and the relations for the temperature rise on the combustion of fuel in air. The problem is to present such data compactly for a range of fuels, and the solution adopted is:

(*a*) The presentation of simple methods of calculating the properties of such mixtures and changes of temperature, so that users may prepare data for any fuel they wish, together with

(*b*) The properties and relations for a ' standard ' fuel of given composition and calorific value so that the performance of engines may be compared under definite conditions.

The method employed is the development of equations for the difference between a property of a gas mixture and the corresponding property of air. This difference is calculated as a function of temperature depending on either gas composition or, for combustion products, on fuel composition and fuel/air ratio. Consistency is thus obtained without recourse to highly accurate methods of computation.

The range of temperatures considered is 200°K to 2,000°K, so that not only may all likely commercial developments be treated, but processes in the combustion chamber, where local high temperatures exist, may be evaluated in many instances. As will be seen below, extension to higher temperature would render inaccurate some of the relations used, and a general treatment would otherwise suffer in loss of simplicity.

Gas dynamical data are included so that practical design calculations may also be undertaken. This is expressed in non-dimensional form, and is generalized through the use of molar specific heat as running parameter and the incorporation of a term involving molecular weight. The data is so presented that the latter correction is unnecessary for engines using ' standard ' fuel.

The accuracy believed to be desirable in the calculation of engine performance is that specific fuel consumption may be determined within $\pm$ 1·0 per cent. The data presented will permit this provided the combustion temperature rise exceeds 200°C, and an accuracy of $\pm$ 0·5 per cent is attainable when it exceeds 400°C.

The extensive use of gas turbines in aircraft requires a ' standard ' fuel which approximates to kerosene. A net calorific value at constant pressure of 10,300 C.H.U./lb and a composition

Carbon	0·8608 (by weight)
Hydrogen ..	0·1392 (by weight)

are therefore assumed. This composition bears no relation to any particular fuel, but is chosen because the molecular weight of the products of combustion is always equal to the molecular weight of air, irrespective of fuel/air ratio.

2. *The Calculation of the Properties of Mixed Gases.*—2.1. *General.*—The gases normally involved in the gas turbine engine are air and the products of the combustion of fuel in it. The latter are normally in relatively low concentration and at high temperature so the ideal state is presumed throughout. Their properties are therefore additive, *i.e.*,

$$F_m = aF_a + bF_b + \ldots.$$

where a, b, etc., are the masses of the component gases in unit mass of the mixture, and F_a, F_b, etc., are their individual properties.

This presumption, almost universally made, that the gas turbine working fluid is a perfect gas is only an approximation. At pressures $\geqslant$ 200 lb/in.^{2} deviations in the properties of air are noticeable up to 300°C, and to even higher temperatures for water vapour and carbon dioxide.

This effect is principally of importance in isentropic processes, where differences in total heat only are significant. The difference in total heat between various conditions was evaluated according to tables of real gas properties, and compared with those determined from tables of ideal gas properties. The discrepancy was found to be within the experimental error for the real gas data at normal gas-turbine temperatures. Since the incorporation of any correction for such differences is not possible in a generalized presentation, results for high compression ratio engines under altitude conditions may have a slight systematic error.

The composition of combustion products may be evaluated by stoichiometry, and used to compute the various properties needed. It is apparent, however, that the result may differ from that of air by a small amount only, so that a high standard of mathematical accuracy is necessary for the precise evaluation of this difference. Simplicity and precision would be obtainable, however, given data which related the difference in value of a property with the composition and proportion of the fuel.

This principle has been developed, and data have been evaluated to permit the properties of reaction products in any system containing carbon, hydrogen, oxygen, nitrogen, sulphur and argon. In a system containing two reactants, one may be designated ' fuel ' and the other ' medium '. Their compositions by weight are accordingly considered as follows:

Component	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Water vapour	u	j	Residual (Air)
Weight fraction	$\bar{C}$	$\bar{H}$	$\bar{O}$	$\bar{N}$	$\bar{S}$	$\bar{W}$	$\bar{u}$	$\bar{j}$	$(1 - \bar{C} - \bar{H} - \text{etc.})$

where u represents any general combustible component and j any general incombustible component. Suffices $_F$ and $_m$ are applied to denote fuel and medium components respectively, and data are presented whereby calculations may be effected for all reactants with the above compositions, provided all combustible material is burned.

This consists of a Table of the properties of dry air from 200°K to 2,000°K in C.H.U., lb, °K units at 1°K intervals, and Tables of the functions needed to determine the additions required to convert the properties of air to the properties of the products of the above reactants. These Tables permit determination of total heat, true specific heat, and entropy function, the latter being derived as follows:

The entropy of a gas measured from an arbitrary zero at T_0 and unit pressure is

$$\int_{T_0}^{T} \frac{MC_p\, dT}{T} - R \log_e p \,,$$

where R is the universal gas constant and M is the molecular weight of the gas.

Accordingly, for an isentropic change

$$\int_{T_1}^{T_2} \frac{MC_p\, dT}{T} = R \log_e \frac{p_2}{p_1} .$$

The above relation may be converted into the form

$$\frac{\log_{10} e}{R} \int_{T_1}^{T_2} \frac{MC_p\, dT}{T} = \log_{10} \frac{p_2}{p_1}$$

The function

$$\frac{\log_{10} e}{R} \int_{T_0}^{T} \frac{MC_p\, dT}{T} ,$$

where T_0 refers to an arbitrary zero, taken here as 0°K, is designated ψ, the entropy function, *i.e.*,

$$\psi = \frac{\log_{10} e}{R} \int_{0}^{T} \frac{MC_p\, dT}{T} .$$

Hence $\psi_2 - \psi_1 = \log_{10} (p_2/p_1)$ for any ideal isentropic change.

The units used are the pound, the C.H.U. and the degree Kelvin.

The C.H.U. is defined as

$$1 \text{ C.H.U./lb} = 4{\cdot}1868 \text{ Joules/gram.}$$

The properties of the principal gases are derived from the values given by Wagman, Kilpatrick, Taylor, Pitzer and Rossini (*J. Res. Nat. Bur. Stand.* 34. Vol. 14. 1945).

While the principal use of gas turbines is for aircraft propulsion it is desirable to consider air of the composition obtaining at altitude as the residual component. Absence of water and carbon dioxide is presumed, and the composition by volume is taken as

Nitrogen = 78·030 per cent

Oxygen = 20·990 per cent

Argon = 0·980 per cent

The corresponding composition by weight is:

Nitrogen $= 75 \cdot 463$ per cent

Oxygen $= 23 \cdot 186$ per cent

Argon $= 1 \cdot 351$ per cent

and the molecular weight is $28 \cdot 969$.

The total heat above 0°K, true specific heat, entropy function, and the total heat of air above 15°C are given in Table 1 at intervals of 1°K.

The methods of calculation of gas properties were originally devised to simplify the calculation of the properties of products of combustion. They are equally applicable to the calculation of the properties of gas mixtures, and since in a gas turbine gaseous fuels must be compressed to at least the same extent as the air (or medium), a method whereby the energy needed may be calculated is necessary.

It is evident and desirable that both fuel and medium types of reactant may be considered in a general manner, and air is again used as the residual component of a general reactant.

The properties of a general reactant are dependent on the proportions and physical states of its components. A component of a reactant mixture cannot be substituted by its ultimate constituents. For example methane has to be considered as methane and cannot be considered as a carbon-hydrogen mixture. Conversely when the properties of the products after combustion are deduced, it is permissible and indeed advantageous to consider combustible components as a proportional mixture of their elements.

2.2. *Calculation of the Properties of General Reactants.*—2.2.1. *Composition of a general reactant.*—Let the reactant composition lb/lb be

Component	j_1	j_2	j_3	..	..	..	..	Air
Weight	$\bar{j}_1$	$\bar{j}_2$	$\bar{j}_3$	..	..	..	..	$(1 - \bar{j}_1 - \bar{j}_2 - \bar{j}_3 \ldots)$

where j_1, j_2, . . . are any arbitrary components. The composition is expressed for mathematical convenience as:

$$1 \text{ lb of air} + \bar{j}_1(1 \text{ lb of } j_1 - 1 \text{ lb air}) + \bar{j}_2(1 \text{ lb of } j_2 - 1 \text{ lb air}) + \ldots\ldots$$

2.2.2. *Molecular weight.*—The molecular weight of a general reactant may be deduced from the above composition as

$$M' = \frac{M_{\text{air}}}{M} = 1 + \bar{j}_1 k_{j1} + \bar{j}_2 k_{j2} + \ldots \qquad (1)$$

where

$$k_{j1} = \frac{M_{\text{air}}}{M_{j1}} - 1, \text{ etc.,} \qquad (2)$$

and the value of M_{air} is $28 \cdot 969$.

Values of k_j are given in Tables 4 and 7 (*see* Section 2.2.3).

2.2.3. *Thermodynamic properties.*—If f is a general property of a reactant then its value is given by $\Sigma \bar{x} f_x$, where x is taken over all constituents and $\bar{x}$ is the weight of the component x in one pound of reactant. Application of this procedure to the composition of the general reactant gives the following result:

$$f = f_{\text{air}} + \sum_j \bar{j} \Omega_j \qquad (3)$$

where

$$\Omega_j = f_j - f_{\text{air}} . \qquad (4)$$

Equations (3) and (4) are directly applicable to the calculation of true specific heat and total heat. The entropy function ψ involves also molecular weight and is calculated as $M'\psi$. Equation (3) becomes

$$M'\psi = \psi_{air} + \sum_j \bar{j}\Omega_j \qquad (5)$$

where

$$\Omega_j = \psi_j \frac{M_{air}}{M_j} - \psi_{air} \qquad (6)$$

with the ratio M' as given by equation (1).

The Ω functions are dependent on temperature only and values for common gaseous fuel components are presented at intervals of 20°K in Tables 2, 3 and 4 for total heat, true specific heat and entropy function. Table 4 includes also k functions for the determination of molecular weight. Ω functions for oxygen, nitrogen, water vapour and carbon dioxide have the same values as the corresponding θ functions in Tables 5, 6 and 7 (*see* Section 2.3.3), and may be read from there (*Note:* The θ functions for hydrogen must not be used in the calculation of the properties of mixtures containing hydrogen. Values of Ω and θ functions are only the same for incombustible materials).

Use of the Ω functions in conjunction with values of the properties of air, Table 1, is illustrated by the following example:

Example (a)

Determine the value of ψ at 300°K, for a reactant whose composition by weight is, Water vapour 2 per cent, Oxygen 10 per cent, Nitrogen 20 per cent, Carbon Dioxide 30 per cent, Air 38 per cent.

From Table 1 ψ_{air} at 300°K = 10·1415.

Substitution in equation (5) with values of Ω functions from Table 7 gives

$$M'\psi = 10\cdot1415 + \begin{Bmatrix} 0\cdot02 \times & 5\cdot726 \\ +\,0\cdot10 \times & -\,0\cdot436 \\ +\,0\cdot20 \times & 0\cdot211 \\ +\,0\cdot30 \times & -\,2\cdot789 \end{Bmatrix}$$

$$= 10\cdot1415 - 0\cdot7236$$

$$= 9\cdot4179\,.$$

Using equation (1) with appropriate values for k

$$M' = 1 + 0\cdot02 \times 0\cdot06080 - 0\cdot10 \times 0\cdot0947 + 0\cdot20 \times 0\cdot0340 - 0\cdot30 \times 0\cdot3418$$

$$= 0\cdot9070\,.$$

Therefore

$$\psi = 9\cdot4179/0\cdot9070 = 10\cdot3836\,.$$

The properties of any reactant with components CO_2, O_2, N_2, H_2O and Air can be calculated in a like manner, using the data presented. This technique simplifies the calculation of compressor performance using atmospheric moist air, and with allowance for latent heat and rate of evaporation, calculations involving the use of water injection. Should other eventualities arise, the appropriate Ω and k functions are easily calculated by substitution in equations (4) or (6) and (2) respectively. Appropriate thermodynamic data are required for the new component only since the data for air may be obtained from Table 1.

The following example illustrates such a calculation and also shows that the physical state of the components of a reactant have to be considered.

Example (*b*)

Calculate the true specific heat of the following mixtures at 360°K:

(i) Air 97 per cent, Water vapour 3 per cent

(ii) Air 97 per cent, Liquid water 3 per cent,

assuming the true specific heat of water at 360°K is 1·0000 C.H.U./lb °K.

(i) At 360°K using equation (3), Table 1 and Table 6:

$$\begin{aligned} C_p &= 0{\cdot}2409 + 0{\cdot}030\Omega_W \\ &= 0{\cdot}2409 + 0{\cdot}03 \times 0{\cdot}2088 \\ &= 0{\cdot}2409 + 0{\cdot}0063 \\ &= 0{\cdot}2472 \text{ C.H.U./lb °K.} \end{aligned}$$

(ii) At 360°K using equation (3) and Table 1:

$$C_p = 0{\cdot}2409 + 0{\cdot}030\Omega_{W\,\text{liq}}.$$

$\Omega_{W\,\text{liq}}$ is not equal to Ω_w and is obtained by use of equation (4) and Table 1 as

$$\Omega_{W\,\text{liq}} = 1{\cdot}0000 - 0{\cdot}2409 = 0{\cdot}7591\,.$$

Therefore

$$\begin{aligned} C_p &= 0{\cdot}2409 + 0{\cdot}03 \times 0{\cdot}7591 \\ &= 0{\cdot}2409 + 0{\cdot}0228 \\ &= 0{\cdot}2637 \text{ C.H.U./lb °K.} \end{aligned}$$

2.3. *Calculation of the Properties of the Products of Complete Combustion of a General Fuel in a General Medium.*—The composition of the products of complete combustion of a general fuel in a general medium are dependent only on fuel and medium composition and fuel/medium ratio. The chemical structure and physical state of the fuel and medium have no effect on product composition since differing chemical combinations of the same basic components give identical products on complete combustion (for example, all hydrocarbons may be considered simply as hydrogen and carbon irrespective of the chemical or physical form of the hydrocarbon). It will be seen that this technique considerably simplifies the determination of general combustion product properties.

2.3.1. *Composition of the products.*—Let q lb of the reactant F of composition lb/lb

Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Water vapour	u	j	Air
$\bar{C}_F$	$\bar{H}_F$	$\bar{O}_F$	$\bar{N}_F$	$\bar{S}_F$	$\bar{W}_F$	$\bar{u}_F$	$\bar{j}_F$	$(1 - \bar{C}_F - \bar{H}_F - \text{etc,})$

be burned in one pound of reactant m of composition lb/lb:

Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Water vapour	u	j	Air
$\bar{C}_m$	$\bar{H}_m$	$\bar{O}_m$	$\bar{N}_m$	$\bar{S}_m$	$\bar{W}_m$	$\bar{u}_m$	$\bar{j}_m$	$(1 - \bar{C}_m - \bar{H}_m - \text{etc.})$

where j is any general incombustible component and u any general combustible component such that 1 lb of u requires v lb of oxygen and gives $(1 + v)$ lb of product w on complete combustion.

Then the composition lb/lb of the products of complete combustion may be deduced from the usual stoichiometric relationships as follows:

Water vapour

$$\frac{q}{1+q}\bar{W}_F \qquad \text{(from fuel } F\text{)}$$

$$\frac{\bar{W}_m}{1+q} \qquad \text{(from medium } m\text{)}$$

$$8\cdot9365\,\frac{q}{1+q}\bar{H}_F + 8\cdot9365\,\frac{\bar{H}_m}{1+q} \qquad \text{(from reaction)}$$

Carbon dioxide

$$3\cdot6645\,\frac{q}{1+q}\bar{C}_F + 3\cdot6645\,\frac{\bar{C}_m}{1+q} \qquad \text{(from reaction)}$$

Sulphur dioxide

$$1\cdot9978\,\frac{q}{1+q}\bar{S}_F + 1\cdot9978\,\frac{\bar{S}_m}{1+q} \qquad \text{(from reaction)}$$

Nitrogen

$$\frac{q}{1+q}\bar{N}_F \qquad \text{(from fuel } F\text{)}$$

$$\frac{\bar{N}_m}{1+q} \qquad \text{(from medium } m\text{)}$$

w

$$(1+v)\,\frac{q}{1+q}\bar{u}_F + (1+v)\,\frac{\bar{u}_m}{1+q} \qquad \text{(from reaction)}$$

j

$$\frac{q}{1+q}\bar{j}_F \qquad \text{(from fuel } F\text{)}$$

$$\frac{\bar{j}_m}{1+q} \qquad \text{(from medium } m\text{)}$$

Oxygen

$$\frac{q}{1+q}\bar{O}_F \qquad \text{(from fuel } F\text{)}$$

$$\frac{\bar{O}_m}{1+q} \qquad \text{(from medium } m\text{)}$$

$$\text{(minus)}\ \frac{q}{1+q}(7\cdot9365\bar{H}_F + 2\cdot6645\bar{C}_F + 0\cdot9978\bar{S}_F + v\bar{u}_F)$$

$$\text{(minus)}\ \frac{1}{1+q}(7\cdot9365\bar{H}_m + 2\cdot6645\bar{C}_m + 0\cdot9978\bar{S}_m + v\bar{u}_m) \qquad \text{(from reaction)}$$

Dry air

$$\frac{q}{1+q}(1 - \bar{C}_F - \bar{H}_F - \bar{O}_F - \bar{N}_F - \bar{S}_F - \bar{W}_F - \bar{u}_F - \bar{j}_F) \qquad \text{(from fuel } F\text{)}$$

$$\frac{1}{1+q}(1 - \bar{C}_m - \bar{H}_m - \bar{O}_m - \bar{N}_m - \bar{S}_m - \bar{W}_m - \bar{u}_m - \bar{j}_m) \qquad \text{(from medium } m\text{)}$$

Total 1 lb.

It is arranged for convenience as terms arising from the reactant components:

$$\bar{C}_F \text{ and } \bar{C}_m \quad \left\{\frac{q\bar{C}_F}{1+q} + \frac{\bar{C}_m}{1+q}\right\} \{3 \cdot 6645 \text{ lb } CO_2 - 2 \cdot 6645 \text{ lb } O_2 \quad - 1 \text{ lb air}\}$$

$$\bar{H}_F \text{ and } \bar{H}_m \quad \left\{\frac{q\bar{H}_F}{1+q} + \frac{\bar{H}_m}{1+q}\right\} \{8 \cdot 9365 \text{ lb } H_2O - 7 \cdot 9365 \text{ lb } O_2 - 1 \text{ lb air}\}$$

$$\bar{O}_F \text{ and } \bar{O}_m \quad \left\{\frac{q\bar{O}_F}{1+q} + \frac{\bar{O}_m}{1+q}\right\} \{1 \text{ lb } O_2 \qquad - 1 \text{ lb air}\}$$

$$\bar{N}_F \text{ and } \bar{N}_m \quad \left\{\frac{q\bar{N}_F}{1+q} + \frac{\bar{N}_m}{1+q}\right\} \{1 \text{ lb } N_2 \qquad - 1 \text{ lb air}\}$$

$$\bar{S}_F \text{ and } {}_m\bar{S} \quad \left\{\frac{q\bar{S}_F}{1+q} + \frac{\bar{S}_m}{1+q}\right\} \{1 \cdot 9978 \text{ lb } SO_2 - 0 \cdot 9978 \text{ lb } O_2 - 1 \text{ lb air}\}$$

$$\bar{W}_F \text{ and } \bar{W}_m \quad \left\{\frac{q\bar{W}_F}{1+q} + \frac{\bar{W}_m}{1+q}\right\} \{1 \text{ lb } H_2O \qquad - 1 \text{ lb air}\}$$

$$\bar{u}_F \text{ and } \bar{u}_m \quad \left\{\frac{q\bar{u}_F}{1+q} + \frac{\bar{u}_m}{1+q}\right\} \{1 + v) \text{ lb } w - v \text{ lb } O_2 \qquad - 1 \text{ lb air}\}$$

$$\bar{j}_F \text{ and } \bar{j}_m \quad \left\{\frac{q\bar{j}_F}{1+q} + \frac{\bar{j}_m}{1+q}\right\} \{1 \text{ lb } j \qquad - 1 \text{ lb air}\}$$

$$\text{Residual (Air)} \left\{\frac{q}{1+q} + \frac{1}{1+q}\right\} \{1 \text{ lb air}\}.$$

2.3.2. *Molecular weight of the products.*—The molecular weight of the generalized combustion products may be deduced from the above values and expressed as

$$M' = \frac{q}{1+q}\left(1 + \sum k_j\bar{j}_F + \sum k_u\bar{u}_F\right) + \frac{1}{1+q}\left(1 + \sum k_j\bar{j}_m + \sum k_u\bar{u}_m\right) \quad .. \quad (7)$$

where

$$k_u = M_{\text{air}}\left\{\frac{1+v}{M_w} - \frac{1}{M_{\text{air}}} - \frac{v}{M_{O_2}}\right\} \quad .. \quad (8)$$

$$k_j = \frac{M_{\text{air}}}{M_j} - 1 \quad .. \quad (9)$$

and the value of M_{air} is 28·969.

Equation (7) may alternatively be written as

$$M' = 1 + \frac{q}{1+q}\left(\sum k_j\bar{j}_F + \sum k_u\bar{u}_F\right) + \frac{1}{1+q}\left(\sum k_j\bar{j}_m + \sum k_u\bar{u}_m\right). \quad .. \quad (10)$$

The values of k for the principal reactant components are given in Tables 4 and 7 (*see* Section 2.3.3).

2.3.3. *Thermodynamic properties of the products.*—If f represents a general additive property of combustion products, its value is given by $\Sigma \bar{x} f_x$ where x is taken over all product constituents and $\bar{x}$ is the weight of the constituent x in one pound of the products.

This summation may be applied to the product compositions as expressed above, thus permitting summation in terms of the reactant composition as follows:

$$f = f_{air} + \frac{q}{1+q}\left(\sum \bar{j}_F \theta_j + \sum \bar{u}_F \theta_u\right) + \frac{1}{1+q}\left(\sum \bar{j}_m \theta_j + \sum \bar{u}_m \theta_u\right) \quad .. \quad (11)$$

where

$$\theta_u = (1+v) f_w - v f_{O_2} - f_{air}$$
$$\theta_j = f_j \qquad - f_{air}$$

and specifically

$$\left.\begin{aligned} \theta_C &= 3{\cdot}6645 f_{CO_2} - 2{\cdot}6645 f_{O_2} - f_{air} \\ \theta_H &= 8{\cdot}9365 f_{H_2O} - 7{\cdot}9365 f_{O_2} - f_{air} \\ \theta_O &= f_{O_2} - f_{air} \\ \theta_N &= f_{N_2} - f_{air} \\ \theta_S &= 1{\cdot}9978 f_{SO_2} - 0{\cdot}9978 f_{O_2} - f_{air} \\ \theta_W &= f_{H_2O} - f_{air} \end{aligned}\right\} \quad .. \quad .. \quad .. \quad .. \quad .. \quad (12)$$

Equations (11) and (12) are directly applicable to the calculation of true and mean specific heats and of total heat. The entropy function ψ, involves also molecular weight and is calculated in terms of $M'\psi$. The relevant relations are:

$$M'\psi = \psi_{air} + \frac{q}{1+q}\left\{\bar{C}_F \theta_C + \bar{H}_F \theta_H + \ldots\right\} + \frac{1}{1+q}\left\{\bar{C}_m \theta_C + \bar{H}_m \theta_H + \ldots\right\} \quad (11a)$$

where

$$\theta_C = 3{\cdot}6645 \psi_{CO_2} \frac{M_{air}}{M_{CO_2}} - 2{\cdot}6645 \psi_{O_2} \frac{M_{air}}{M_{O_2}} - \psi_{air} \quad .. \quad .. \quad .. \quad .. \quad (12a)$$

$$\theta_H = 8{\cdot}9365 \psi_{H_2O} \frac{M_{air}}{M_{H_2O}} - 7{\cdot}9365 \psi_{O_2} \frac{M_{air}}{M_{O_2}} - \psi_{air} \qquad \text{etc.}$$

Values of the θ functions for calculating the total heat, true specific heat and entropy function of products of combustion are given at 20°K intervals in Tables 5, 6 and 7 respectively.

Although it will be found that high accuracy is not necessary in the calculation of the quantity to be added, the division by the factor M' must be carried out with 6-figure accuracy in order to eliminate unacceptable random error when constructing tables of ψ. Only 4-figure accuracy is necessary, however, for calculations of compression or expansion, since the difference in $M'\psi$ may be determined, and then divided by M'. This calculation is shown in example (*d*).

The properties of all current commercial fuel combustion products may be deduced by means of the above Tables and methods. Other compositions may be treated by substituting the thermodynamic properties of the elements and their products of combustion in the manner indicated for the arbitrary components u and j.

The values of these properties are precise for undissociated products of combustion. Dissociation, however, affects these values at temperatures above 1,400°K, and its effects cannot be allowed for in a generalized presentation of data, since it is dependent upon fuel composition, temperature, pressure and fuel/air ratio. The variation with the latter is especially complex, since reduction of fuel/air ratio increases the formation of nitric oxide and reduces the formation of carbon monoxide, hydrogen, etc. Dissociation leads to changes in heat capacity and molecular weight, and consequently in total heat and in entropy. The changes are small, however, under conditions usually found in gas turbine engines and may be neglected. Thus for instance the difference between the total heats between 400°K and 1,600°K of equivalent quantities of oxygen and nitrogen and nitric oxide is about 45 C.H.U. per mol nitric oxide. At least 0·02 lb of fuel would be needed per pound of air for this temperature to be reached and no more than 0·0002 mol nitric oxide would be formed. Consequently the difference in total heat between the dissociated and undissociated products is not greater than 0·009 C.H.U./lb air, *i.e.*, negligible. Similarly molecular weight is not significantly affected by the dissociation occurring below 2,000°K.

The total heat and the molecular weight of the products of incomplete combustion will also differ from those of the ideal products, but the order of difference is again small. For design purposes combustion efficiencies of 95 per cent or 98 per cent are generally assumed. The cause of small losses is normally mainly the formation of some carbon monoxide. At a fuel/air ratio of 0·020 an efficiency of 95 per cent would result in a decrease in molecular weight of about 0·2 per cent, if all the loss were due to carbon monoxide or hydrogen. Since the presence of hydrocarbon vapour is likely also, this change would probably be reduced. It follows that calculations involving combustion systems likely to give large losses should be made by special methods if precise answers are needed. The effect on total heat is, as before, negligible, the difference in total heats between 1,800°K and 400°K for a fuel/air ratio of 0·02 burned perfectly and with 95 per cent efficiency, being about 0·005 per cent only.

Use of the Tables of θ functions is illustrated in the following examples:

Example (*c*)

Find the total heat/lb at 1,000°K of the products of combustion of a fuel/humid air mixture ($q = 0 \cdot 02$), the fuel composition by weight being Carbon 50 per cent, Hydrogen 20 per cent, Oxygen 10 per cent, Nitrogen 20 per cent, and the water-vapour content of the air being 1·5 per cent by weight.

From Table 1 total heat of air at 1,000°K is 249·84 C.H.U./lb. Substituting in equation (11) with values of θ functions from Table 5 the required total heat is given by

$$H = 249 \cdot 84 + \frac{0 \cdot 02}{1 \cdot 02} \left\{ \begin{array}{rr} 0 \cdot 50 \times & -22 \cdot 9 \\ +\, 0 \cdot 20 \times & 2144 \cdot 9 \\ +\, 0 \cdot 10 \times & -15 \cdot 7 \\ +\, 0 \cdot 20 \times & 7 \cdot 1 \end{array} \right\} + \frac{1}{1 \cdot 02}(0 \cdot 015 \times 226 \cdot 1)$$

$$= 249 \cdot 84 + 8 \cdot 18 + 3 \cdot 33$$

$$= 261 \cdot 4 \text{ C.H.U./lb}.$$

Example (*d*)

A fuel ($\bar{C} = 0 \cdot 500$, $\bar{H} = 0 \cdot 100$, $\bar{N} = 0 \cdot 400$) is burned ($q = 0 \cdot 02$) in humid air containing 1 per cent water vapour by weight. The products of combustion at 1,000°K are expanded isentropically to 700°K. Determine the pressure ratio required.

Substitution in equation (10) gives

$$M' = 1 + \frac{0 \cdot 02}{1 \cdot 02} \left\{ \begin{array}{l} -\, 1 \cdot 0000 \times 0 \cdot 500 \\ +\, 6 \cdot 1848 \times 0 \cdot 100 \\ +\, 0 \cdot 0340 \times 0 \cdot 400 \end{array} \right\} + \frac{0 \cdot 01}{1 \cdot 02} \times 0 \cdot 6080$$

$$= 1 + 0 \cdot 0026 + 0 \cdot 0060$$

$$= 1 \cdot 0086.$$

Using equation (11a), Table 1 and Table 7 at 1,000°K

$$M'\psi_1 = 12\cdot0566 + \frac{0\cdot02}{1\cdot02}\begin{Bmatrix} 0\cdot500 \times -8\cdot819 \\ +0\cdot100 \times 71\cdot162 \\ +0\cdot400 \times 0\cdot261 \end{Bmatrix} + \frac{0\cdot01}{1\cdot02} \times 7\cdot481$$

$$= 12\cdot0566 + 0\cdot0551 + 0\cdot0733$$

$$= 12\cdot1850\,.$$

Similarly

$$M'\psi_2 = 11\cdot4591 + \frac{0\cdot02}{1\cdot02}\begin{Bmatrix} 0\cdot500 \times -9\cdot035 \\ +0\cdot100 \times 65\cdot787 \\ +0\cdot400 \times 0\cdot248 \end{Bmatrix} + \frac{0\cdot01}{1\cdot02} \times 6\cdot901$$

$$= 11\cdot4591 + 0\cdot1101 = 11\cdot5692\,.$$

Therefore

$$M'(\psi_1 - \psi_2) = 12\cdot1850 - 11\cdot5692 = 0\cdot6158 = 1\cdot0086 \log_{10}\frac{p_1}{p_2}\,.$$

Therefore

$$\log_{10}\frac{p_1}{p_2} = 0\cdot61055\,.$$

Therefore

$$\frac{p_1}{p_2} = 4\cdot079\,.$$

Note (i).—It is apparent from the magnitude of the correction that its calculation is not onerous and requires few significant figures only.

Note (ii).—Use of θ functions for 1,020°K in example (c) would have given corrections of 8·41 and 3·41 C.H.U./lb, giving a total error of 0·3 C.H.U./lb. Since precision to 0·1 C.H.U./lb only is normally necessary, linear interpolation between the intervals given will lead to negligible error.

When the fuel used is a mixture of two or more fuels, the mean composition and properties of the mixture may be found by direct proportion from those of the individual fuels. The above methods are then applicable, treating the fuel as having the mean composition and properties thus found.

A similar method is also recommended when the products of the primary combustion are reheated by the use of a different fuel. It is derived as follows:

Let a general fuel F_1 burn in a general medium m with fuel/medium ratio q_1, (where medium $= m$), and in the products so formed let a general fuel F_2 be burned with fuel/medium ratio q_2 (where the medium = primary products). Then consideration of the primary and reheat process as one single process requires the equivalent fuel/medium ratio q_3 (where medium $= m$) and the properties of the equivalent fuel to be calculated as

$$q_3 = q_1 + q_2(1 + q_1) \qquad (13)$$

$$q_3F_3 = q_1F_1 + q_2(1 + q_1)F_2\,. \qquad (14)$$

These relations are easily proved by observing that for one pound of medium m, q_1 lb of fuel F_1 are used; and q_2 lb of fuel F_2 are used for 1 lb of primary products, or $q_2(1 + q_1)$ lb are used per lb of medium m. Thus for 1 lb medium m, $q_1 + q_2(1 + q_1)$ lb of fuel are used and hence this is the fuel/medium ratio q_3 of the equivalent fuel; from which it follows that the composition of the equivalent fuel F_3 is given by $q_3F_3 = q_1F_1 + q_2(1 + q_1)F_2$.

3. *Combustion Temperature Rise Calculations.*—3.1. *Heat of Reaction and Calorific Value.*— The combustion of fuel in air or other supporting media may be treated as any other exothermic chemical reaction, and accordingly the temperature rise is only dependent upon the heat of reaction and the sensible heats of the reactants, products and diluents.

Heat of reaction is exactly defined only when the states, pressures and temperatures of the reactants and products are defined, and a value stated for a given temperature implies that the reactants and products are both at this temperature.

The value ideally desirable for gas turbine calculations is the heat of reaction or heat of combustion for the fuel at constant pressure giving gaseous water, all materials being in their standard states. Specifications of fuels are normally in terms of gross calorific value, however. This is the heat released per unit weight of fuel burned in oxygen in a bomb at a fairly high pressure under defined conditions. These conditions are such that a gross calorific value of a typical kerosene differs negligibly from its heat of combustion at constant volume, with water liquid. The theoretical error for fuels ranging from hydrocarbons to coal and coke does not exceed about $+ 0 \cdot 05$ per cent, and since the standard error for the determination of calorific value normally exceeds this, these differences may be neglected. The result is normally expressed in cal/gm or B.Th.U./lb rounded to the nearest 5 cal/gm or 10 B.Th.U./lb. Various calories and B.Th.U.'s are used; some, notably the 'thermochemical' calorie ($= 4 \cdot 1840$ joules) and the mean B.Th.U. (equivalent to $1 \cdot 8 \times 4 \cdot 1897$ joules/gm), are not exactly equivalent to the C.H.U. as defined here.

Calorific values have been until recently expressed for a temperature of 60°F, but modern practice is to express them for 25°C. Values at 25°C may be corrected to 15°C for use in conjunction with the data presented here by making empirical additions as follows:

Solid fuels, tar and aromatic hydrocarbons	Add 2 C.H.U./lb
Diesel and fuel oils	Add 7 C.H.U./lb
Light paraffinic hydrocarbons	Add 9 C.H.U./lb.

Care is necessary in ensuring that the appropriate value of the calorific value of coal or coke is used. In particular the calorific value on the 'dry ash-free basis' should not be used, and results on the 'as analysed' basis must be converted to the 'as sampled' basis (for details *see* BS.1016, Part 5. 1957).

The reduction of gross calorific value at constant volume at 15°C to net calorific value at constant pressure ('net' implies water in the gaseous state), is made by means of the relation

$$\begin{Bmatrix}\text{Net calorific value at} \\ \text{constant pressure}\end{Bmatrix} = \begin{Bmatrix}\text{Gross calorific value} \\ \text{at constant volume}\end{Bmatrix} - (5095\bar{H} + 18\bar{O} + 586\bar{W}_L),$$

where $\bar{H}$, $\bar{O}$, and $\bar{W}_L$ are the hydrogen, oxygen and liquid water content, respectively, of the fuel, as used (this adjustment is made after the gross calorific value is adjusted for any difference between the conditions of the fuel as used and the conditions at which gross calorific value at constant volume is measured). Similar corrections to lower calorific value have to be applied for other liquid (or solid) incombustible diluents.

The calorific value of gases is always, unless otherwise stated, the gross calorific value (water liquid) at constant pressure, and is expressed in different ways in various countries. It is always on a volumetric basis; the European practice is as K.cal/m^3, measured at either 15°C and saturated with water, or at 0°C and dry, the pressure being 760 mm mercury, measured at 0°C.

In the United States it is expressed in B.Th.U./ft^3 measured at 60°F dry, the pressure being 30 in. mercury measured at 60°F, and town gas in Great Britain is measured at 60°F with saturation by water vapour.

Change in the British definition is expected shortly, and it is necessary to know according to which specification the calorific value of a given gas is defined. The British Thermal Unit used in relation to the supply of town gas is the mean B.Th.U., and the definition takes no account of differences due to different local gravities at different altitudes and latitudes. It is doubtful, however, if the accuracy of typical determinations justifies corrections being made. The calorific value of commercial gases does not vary with temperature, so the corrections necessary are accordingly for water-vapour content and for the effects of any gas imperfections (when converting to a weight basis).

The calorific value of a gas saturated with water vapour presumes only the water formed by combustion to be in the liquid state afterwards. Accordingly, in the calculation of net calorific value at constant pressure it is necessary only to allow for the latent heat of this water. This is equal to $5237\bar{H}$ where $\bar{H}$ is the proportion of hydrogen by weight in the dry gas.

3.2. *Effective Calorific Value.*—The variation of net calorific value at constant pressure with temperature may be deduced from considerations of a simple combustion process as follows:

Let q lb of fuel F at temperature T_F °K be burned in 1 lb of air initially at temperature T_1°K giving products at temperature T_2°K. Then, if h_{p,T_2} is the constant-pressure net calorific value of the fuel at T_2 °K, heat balance considerations together with the definition of calorific value give

$$\Big[H_{\text{air}}\Big]_{T_1}^{T_2} + q\Big[H_F\Big]_{T_F}^{T_2} = h_{p,T_2} \qquad (16)$$

or rearranging,

$$q = \frac{\Big[H_{\text{air}}\Big]_{T_1}^{T_2}}{h_{p,T_2} - \Big[H_F\Big]_{T_F}^{T_2}}. \qquad (17)$$

Alternatively, if $h_p{}^o$ is the constant pressure net calorific value of the fuel at some standard datum temperature T^o °K, heat balance considerations together with the definition of calorific value give

$$\Big[H_{\text{air}}\Big]_{T^o}^{T_1} + q\Big[H_F\Big]_{T^o}^{T_F} + qh_p{}^o = (1+q)\Big[H_{\text{products}}\Big]_{T^o}^{T_2}. \qquad (18)$$

The $(1+q)$ lb of products may be expressed as

$$1 \text{ lb (air)} - qa \text{ lb (air)} + q(a+1) \text{ lb (Stoichiometric products)},$$

where 1 lb of fuel reacts with a lb of air to give $(a+1)$ lb of stoichiometric products.

Accordingly equation (18) may be written as

$$\Big[H_{\text{air}}\Big]_{T^o}^{T_1} + q\Big[H_F\Big]_{T^o}^{T_F} + qh_p{}^o = \Big[H_{\text{air}}\Big]_{T^o}^{T_2} - qa\Big[H_{\text{air}}\Big]_{T^o}^{T_2} + q(a+1)\Big[H_S\Big]_{T^o}^{T_2} \qquad (19)$$

where S refers to the stoichiometric products of the fuel F burned in dry air. Rearranging equation (19)

$$q = \frac{\Big[H_{\text{air}}\Big]_{T_1}^{T_2}}{h_p{}^o + a\Big[H_{\text{air}}\Big]_{T^o}^{T_2} - (a+1)\Big[H_S\Big]_{T^o}^{T_2} + \Big[H_F\Big]_{T^o}^{T_F}}. \qquad (20)$$

On elimination of q between equations (17) and (20)

$$h_{p,T_2} - \Big[H_F\Big]_{T_F}^{T_2} = h_p{}^o + a\Big[H_{\text{air}}\Big]_{T^o}^{T_2} - (a+1)\Big[H_S\Big]_{T^o}^{T_2} + \Big[H_F\Big]_{T^o}^{T_F} \qquad (21)$$

or

$$h_{p,T_2} = h_p{}^o + a\Big[H_{\text{air}}\Big]_{T^o}^{T_2} - (a+1)\Big[H_S\Big]_{T^o}^{T_2} + \Big[H_F\Big]_{T^o}^{T_2}. \qquad (22)$$

Calorific values have usually been determined and quoted at 15°C or 288·16°K and this temperature will be taken as the standard datum temperature T° °K, so that equation (22) then gives the calorific value at any other temperature in terms of the standard 15°C calorific value.

The first three terms on the right-hand side of equation (22) are designated the effective calorific value of the fuel, E.C.V.$_{T_2}$, for combustion to give temperature T_2,

i.e.,
$$\text{E.C.V.}_{T_2} = h_{p,\,288\cdot16} + a\left[H_{\text{air}}\right]_{288\cdot16}^{T_2} - (a+1)\left[H_S\right]_{288\cdot16}^{T_2} . \qquad (23)$$

Effective calorific value is clearly a single function of temperature for a given fuel used at a given temperature, and physically its value at temperature T_2 °K is equal to the constant-pressure net calorific value at T_2 °K except that the fuel is initially at 15°C and not at temperature T_2. This is evident from equation (22) which may be written

$$h_{p,\,T_2} = \text{E.C.V.}_{T_2} + \left[H_F\right]_{288\cdot16}^{T_2} . \qquad (24)$$

Simple combustion temperature rise calculations thus proceed according to the modified form of equation (20), namely,

$$q = \frac{\left[H_{\text{air}}\right]_{T_1}^{T_2}}{\text{E.C.V.}_{T_2} + \left[H_F\right]_{288\cdot16}^{T_F}} . \qquad (25)$$

It follows from the above that the combustion heat balance is more simply expressed in terms of either the constant-pressure net calorific value at the final temperature or the effective calorific value at this temperature, than in terms of a fixed constant-pressure net calorific value at a datum temperature, and accordingly these forms will be more suitable for a general expression where variation in fuel composition is considered. Since, however, the former may contain physically unreal quantities, *e.g.*, fuel specific heats at very high temperature, the general development is best accomplished in terms of effective calorific value.

3.3. *Effective Calorific Value of a General Reactant.*—The effective calorific value of a general reactant at a given temperature depends upon its constant-pressure net calorific value, $h_{p,\,288\cdot16}$, at the datum temperature (15°C) and on its composition.

The general relations may be deduced as follows:

Let $q_s = 1/a$ be the stoichiometric fuel/air ratio of the general reactant ($\bar{\text{C}}\ \bar{\text{H}}\ \bar{\text{O}}\ \bar{\text{N}}\ \bar{\text{S}}\ \bar{\text{W}}\ \bar{u}\ \bar{j}$ air) burned in dry air and in this Section (unless limits are specifically stated) let the symbol $[x]$ denote the difference in the parameter x from 288·16°K to T °K, so that equation (23) becomes

$$\text{E.C.V.}_T = h_{p,\,288\cdot16} + \frac{1}{q_s}\left[H_{\text{air}}\right] - \frac{1+q_s}{q_s}\left[H_S\right] . \qquad (26)$$

H_S in this equation may be deduced by using equation (11) (Section 2.3), in which the medium reactant is dry air so that

$$\left[H_S\right] = \left[H_{\text{air}}\right] + \frac{q_s}{1+q_s}\left[\bar{\text{C}}\theta_{\text{C}} + \bar{\text{H}}\theta_{\text{H}} + \bar{\text{O}}\theta_{\text{O}} + \bar{\text{N}}\theta_{\text{N}} + \bar{\text{S}}\theta_{\text{S}} + \bar{\text{W}}\theta_{\text{W}} + \bar{u}\theta_u + \bar{j}\theta_j\right] \qquad (27)$$

where the θ functions are those for total heat as given by equation (12).

The absence of terms in $1/(1+q_s)$ in equation (27) is due to the medium component consisting entirely of the residual component, dry air.

Elimination of H_S between equations (26) and (27) then gives

$$\text{E.C.V.}_T = h_{p,\,288\cdot16} - \Big[H_{\text{air}}\Big] - \bar{\text{C}}\Big[\theta_{\text{C}}\Big] - \bar{\text{H}}\Big[\theta_{\text{H}}\Big] - \bar{\text{O}}\Big[\theta_{\text{O}}\Big] - \bar{\text{N}}\Big[\theta_{\text{N}}\Big] - \bar{\text{S}}\Big[\theta_{\text{S}}\Big] - \bar{\text{W}}\Big[\theta_{\text{W}}\Big]$$

$$- \bar{u}\Big[\theta_u\Big] - \bar{j}\Big[\theta_j\Big] \quad \ldots \quad (28)$$

where, as in equation (12)

$$\Big[\theta_{\text{C}}\Big] = 3\cdot6645\Big[H_{\text{CO}_2}\Big] - 2\cdot6645\Big[H_{\text{O}_2}\Big] - \Big[H_{\text{air}}\Big] \quad \ldots \quad (29)$$

$[\theta_{\text{C}}]$, etc., are designated the θ functions for effective calorific value. They are simply related to the θ functions for total heat in that they represent the change in the latter for a temperature change 288·16°K to T°K and accordingly equation (28) for the property E.C.V. is the equivalent of equation (11) for other properties.

The θ functions for effective calorific value $[\theta_{\text{C}}]$, etc., will hereafter be referred to simply as θ_{C}, etc., since in any equation the appropriate θ functions are those of the property under consideration. Values for the effective calorific value θ functions are given in Table 8 as a function of temperature, the total heat of air above 15°C being given in Table 1.

Example (*e*)

The constant-pressure net calorific value of a fuel at 15°C is 9,000 C.H.U./lb. Determine its effective calorific value at 900°K given that the fuel composition by weight is $\bar{\text{H}} = 0\cdot10$, $\bar{\text{O}} = 0\cdot50$, $\bar{\text{C}} = 0\cdot40$.

With values from Tables 1 and 8 substitution in equation (28) gives

$$\begin{aligned}\text{E.C.V.}_{900} &= 9{,}000 - 153\cdot96 - 0\cdot40 \times 22\cdot4 - 0\cdot10 \times 1327\cdot1 - 0\cdot50 \times 8\cdot0\\ &= 9{,}000 - 153\cdot96 - 137\cdot67\\ &= 8{,}708 \text{ C.H.U./lb.}\end{aligned}$$

3.4. *General Combustion Temperature Rise Calculations.*—An effective calorific value of any reactant R, combustible or incombustible, may be calculated from equation (28), though the term effective calorific value applied to an incombustible reactant is artificial. Substitution of $h_{p,\,288\cdot16} = 0$ and $a = 0$ in equation (23) gives

$$\text{E.C.V.}_{T_2} = -\Big[H_R\Big]_{288\cdot16}^{T_2} \quad \ldots \quad (30)$$

so that in any general combustion temperature rise equation the parameter E.C.V.$_{T_2}$ should be replaced by $\Big[-H_R\Big]_{288\cdot16}^{T_2}$ for an incombustible reactant. This latter parameter is calculated in the same manner for any unburned reactant property in accordance with equations (3) and (4) (Section 2.2.3).

Let q lb of reactant F at temperature T_F be burned in 1 lb of reactant m initially at temperature T_1 giving products at temperature T_2.

Then, if $h_{p(F),\,2}$, $h_{p(m),\,2}$ are respectively the constant-pressure net calorific values of F and m at temperature T_2 °K, heat-balance considerations together with the definition of calorific value give

$$q\Big[H_F\Big]_{T_F}^{T_2} + \Big[H_m\Big]_{T_1}^{T_2} = q h_{p(F),\,2} + h_{p(m),\,2} \quad \ldots \quad (31)$$

or

$$q = \frac{-\left(h_{p(m),\,2} - \Big[H_m\Big]_{T_1}^{T_2}\right)}{h_{p(F),\,2} - \Big[H_F\Big]_{T_F}^{T_2}} \quad \ldots \quad (32)$$

Substituting effective calorific value for net calorific value in accordance with equation (24) the following general combustion temperature rise equation is obtained:

$$q = \frac{-\left(\text{E.C.V.}_{(m),\,2} + \Big[H_m\Big]_{288\cdot16}^{T_m}\right)}{\text{E.C.V.}_{(F),\,2} + \Big[H_F\Big]_{288\cdot16}^{T_F}} \qquad (33)$$

Equations (32) and (33) clearly show that values of either net calorific value or effective calorific value at the final temperature are appropriate to combustion temperature rise calculations, and that preheating of the reactants is simply allowed for by the terms in H_m and H_F.

In a medium such as concentrated hydrogen peroxide, which liberates heat when it decomposes, or air containing methane, the final temperature cannot be lower than that which would result from the decomposition alone, *i.e.*, equation (33) is meaningless at temperatures below that at which q is zero.

The combustion process in media which decompose with the absorption of heat, such as nitric acid, can be considered as a decomposition of the medium giving oxygen for the combustion of the fuel used. The combustion calculation proceeds according to equation (33) except that the medium must be considered as one with a negative calorific value and hence a negative effective calorific value.

Combustion in air with water injection may be similarly treated, the effective calorific value of the medium including the latent heat of evaporation of the water. This calculation is more simply made, however, by considering the fuel used and water injected as a wet fuel (Section 3.1) and calculating its effective calorific value.

When the reactant m is incombustible, equation (32) may be simplified by writing $h_{p(m),\,2} = 0$, which leads to:

$$q = \frac{\Big[H_m\Big]_{T_m}^{T2}}{\text{E.C.V.}_{(F),\,2} + \Big[H_F\Big]_{288\cdot16}^{T_F}} \qquad (34)$$

which is equivalent to equation (25).

Alternatively the same result may be obtained from equation (33) by substituting $\text{E.C.V.}_{m\,2}$ in accordance with equation (30).

All combustion temperature rise calculations may be effected by use of either equation (33) or equation (34). Two fundamental steps are required:

(i) The determination of E.C.V. at the desired final temperature (equation (28), Tables 1 and 8)

(ii) The determination of the total heat of the unburned reactants between appropriate limits (equation (3), Table 1 and Tables 2 or 3, and 5 or 6).

For a reheat calculation the reactant m consists of the products of a previous combustion, and the latter determination is then more conveniently effected by use of equation (11), Table 1, and Tables 5 and 6 as illustrated in the following example:

Example (f).

Combustion in air ($q = 0\cdot01$) of fuel A ($\bar{C} = 0\cdot310$, $\bar{H} = 0\cdot190$, $\bar{O} = 0\cdot200$, $\bar{N} = 0\cdot300$) gives combustion products which are to be reheated from 900°K to 1,100°K by means of fuel B ($\bar{C} = 0\cdot800$, $\bar{H} = 0\cdot100$, $\bar{O} = 0\cdot100$). Find the quantity of fuel B required per lb of fuel A products if fuel B is used at 105°C, if its true specific heat at 60°C is 0·60 C.H.U./lb°K and its constant pressure net calorific value at 15°C is 9,000 C.H.U./lb.

At 1,100°K using equation (28) and Tables 1 and 8:

$$\text{E.C.V.}_B = 9000 - 208\cdot45 - \begin{Bmatrix} 0\cdot800 \times & 45\cdot3 \\ +\,0\cdot100 \times & 1837\cdot5 \\ +\,0\cdot100 \times & -\,10\cdot5 \end{Bmatrix}$$

$$= 9000 - 208\cdot45 - 218\cdot94 = 8{,}573 \text{ C.H.U./lb}$$

$$\Big[H_B\Big]_{15^\circ\text{C}}^{105^\circ\text{C}} = 90 \times 0\cdot60 = 54\cdot0 \text{ C.H.U./lb.}$$

Since the temperature rise of the medium is 200°K, true specific heat at the mean temperature may be used to determine $\Big[H_m\Big]_{900}^{1,100}$. This value of true specific heat at 1,000°K is calculated by means of equation (11) and Tables 1 and 6 with the result

$$C_p = 0\cdot2725 + \frac{0\cdot01}{1\cdot01}\begin{Bmatrix} 0\cdot310 \times & 0\cdot1151 \\ +\,0\cdot190 \times & 2\cdot5542 \\ +\,0\cdot200 \times & -\,0\cdot0121 \\ +\,0\cdot300 \times & 0\cdot0064 \end{Bmatrix}$$

$$= 0\cdot2725 + 0\cdot0051$$

$$= 0\cdot2776\,.$$

Substituting values in equation (33) gives

$$q = \frac{200 \times 0\cdot2776}{8{,}573 + 54\cdot0}$$

i.e., Fuel B per lb of Fuel A products $= 0\cdot006436$ lb.

Any property of the final products may now be calculated in accordance with Section 2.3.4.

The following example illustrates the use of the more general combustion temperature rise equation:

Example (*g*)

The composition by weight of the working medium of a gas turbine is air 97 per cent, methane 1 per cent, water vapour 2 per cent. Fuel ($\bar{\text{H}} = 0\cdot1392$, $\bar{\text{C}} = 0\cdot8608$, $h_{p,\,288\cdot16} = 10{,}300$ C.H.U./lb) at 45°C is burnt in this medium, the temperature rising from 300°K to 800°K, the fuel and methane being completely burned. Find the total heat of the products of combustion at 800°K.

Assume the constant pressure net calorific value of methane at 15°C to be 12,000 C.H.U./lb and the true specific heat of the fuel at 30°C to be 0·5000 C.H.U./lb.

The mean composition of the working medium is

Component	Air	Water vapour	Carbon	Hydrogen
Weight/lb	0·97	0·02	$0\cdot01 \times \frac{12\cdot010}{16\cdot042}$	$0\cdot01 \times \frac{4\cdot032}{16\cdot042}$

i.e., $\bar{\text{W}}_m = 0\cdot0200$, $\bar{\text{C}}_m = 0\cdot0075$, $\bar{\text{H}}_m = 0\cdot0025$.

The mean constant-pressure net calorific value of the medium at 15°C is

$$0\cdot01 \times 12{,}000 = 120\cdot00 \text{ C.H.U./lb.}$$

At 800°K using equation (28) and Tables 1 and 8

$$E.C.V._{m,800} = 120\cdot00 - 127\cdot45 - \begin{Bmatrix} 0\cdot0075 \times 12\cdot8 \\ +\,0\cdot0025 \times 1089\cdot0 \\ +\,0\cdot0200 \times 115\cdot5 \end{Bmatrix}$$

$$= 120\cdot00 - 127\cdot45 - 5\cdot16$$

$$= -\,12\cdot61 \text{ C.H.U./lb.}$$

Similarly

$$E.C.V._{F,800} = 10{,}300 - 127\cdot45 - \begin{Bmatrix} 0\cdot8608 \times 12\cdot8 \\ +\,0\cdot1392 \times 1089\cdot0 \end{Bmatrix}$$

$$= 10{,}300 - 127\cdot45 - 162\cdot61$$

$$= 10{,}010 \text{ C.H.U./lb.}$$

At $(300 + 288\cdot16)/2 = 294\cdot08$°K using equations (3) and (4), Tables 1, 3 and 6, the true specific heat of the medium is given by

$$C_p = 0\cdot2397 + 0\cdot0200\Omega_W + 0\cdot0100\Omega_{\text{methane}}$$

$$= 0\cdot2397 + 0\cdot0200 \times 0\cdot2050 + 0\cdot01 \times 0\cdot2894$$

$$= 0\cdot2397 + 0\cdot0041 + 0\cdot0029$$

$$= 0\cdot2467\,.$$

Hence

$$\Big[H_m\Big]_{288\cdot16}^{300} = 11\cdot84 \times 0\cdot2467 = 2\cdot92 \text{ C.H.U./lb ,}$$

$$\Big[H_F\Big]_{15°C}^{45°C} = 0\cdot5000 \times 30 = 15\cdot0 \text{ C.H.U./lb.}$$

Substituting values in equation (33)

$$q = \frac{-(-\,12\cdot61 + 2\cdot92)}{10{,}010 + 15\cdot00} = \frac{9\cdot69}{10{,}025}$$

$$= 0\cdot000967\,.$$

At 800°K using equation (11), Table 1 and Table 5, total heat of the products of combustion is given by

$$H = 196\cdot32 + \frac{0\cdot000967}{1\cdot000967}\begin{Bmatrix} 0\cdot8608 \times -\,43\cdot5 \\ +\,0\cdot1392 \times 1657\cdot6 \end{Bmatrix} + \frac{1}{1\cdot000967}\begin{Bmatrix} 0\cdot0075 \times -\,43\cdot5 \\ +\,0\cdot0025 \times 1657\cdot6 \\ +\,0\cdot0200 \times 173\cdot5 \end{Bmatrix}$$

$$= 196\cdot32 + 0\cdot19 + 7\cdot28$$

$$= 203\cdot79 \text{ C.H.U./lb.}$$

3.5. *Incomplete Combustion.*—The effect of normal losses on product properties is small and may be neglected (*see* Section 2.3.3). When necessary, however, it may be determined in the following manner:

Consider a hydrocarbon fuel ($\bar{H}$, $\bar{C}$). Suppose in the combustion process that a fraction X of the carbon is burned to CO, the rest being burned to CO_2.

Then the fuel used may be considered to have the following composition/lb:

$\bar{H}$ lb of hydrogen completely burned to H_2O,

$X\bar{C}$ lb of carbon′ burned to CO,

$(1 - X)\ \bar{C}$ lb of carbon burned to CO_2.

Carbon′ may be considered as a general component u of the fuel having CO for its oxide on 'complete' combustion. Determination of product properties then proceeds according to the methods of preceding Sections.

The effective calorific value relevant to the combustion process must be modified to take into account:

(i) The changed total heat of the products (equation (28) with $\bar{u} = X\bar{C}$)

(ii) The reduction of net calorific value due to incomplete combustion.

These changes are jointly equivalent to the effective calorific value of the unburnt constituents being deducted from the effective calorific value of the fuel. Losses per lb of hydrogen, carbon monoxide, kerosene (as vapour), and methane to be deducted from the effective calorific value of the fuel are given in Table 9*a*. It will be seen that the variation with temperature is slight. Consequently in the estimation of combustion temperature rise from exhaust gas composition a constant factor may normally be assumed for each component. For accurate work it is necessary at high temperatures to include allowance for the equilibrium concentration of components which are not readily measured (nitric oxide, hydroxyl radicals, hydrogen and oxygen atoms). Values for pressures of 0·25, 1·0 and 4·0 Atm appropriate to kerosene losses are given in Table 9*b*.

Example (*h*)

Combustion products of kerosene ($\bar{C} = 0{\cdot}8608$, $\bar{H} = 0{\cdot}1392$) in air at 300°K are analysed as 0·0720 lb CO_2, 0·0041 lb CO, 0·0003 lb H_2, 0·0021 lb kerosene/lb dry gases. Determine the flame temperature.

$$\text{lb carbon/lb gases} = 12{\cdot}01\left(\frac{0{\cdot}0720}{44{\cdot}01} + \frac{0{\cdot}0041}{28{\cdot}01} + \frac{0{\cdot}0021 \times 0{\cdot}8608}{12{\cdot}01}\right) = 0{\cdot}023215$$

$$\text{lb hydrogen/lb gases} = 0{\cdot}0003 + 0{\cdot}0021 \times 0{\cdot}1392 = 0{\cdot}0005923$$

$$\text{lb fuel/lb gases} = \frac{0{\cdot}023215}{0{\cdot}8608} = 0{\cdot}02697$$

$$\text{lb water/lb gases} = \frac{18{\cdot}016}{2{\cdot}016}(0{\cdot}02697 \times 0{\cdot}1392 - 0{\cdot}0005923) = 0{\cdot}028257\,.$$

1·02857 lb products are formed from 0·02697 lb fuel

$$\text{Therefore fuel/air ratio} = \frac{0{\cdot}02697}{1{\cdot}02857 - 0{\cdot}02697} = 0{\cdot}02694\,.$$

Assume flame temperature T_2 = 1,200°K;

then E.C.V. = 9,720 C.H.U./lb (Table 10)

Loss C.H.U. (H_2) = 29,510 × 0·0003 = 8·85 C.H.U. (Table 10a)

Loss C.H.U. (CO) = 2,404 × 0·0041 = 9·86 C.H.U.

Loss C.H.U. (Fuel) = 10,506 × 0·0021 = 22·06 C.H.U.

Therefore loss per 0·02697 lb fuel = 40·77 C.H.U.

Therefore loss per lb fuel = 1,512 C.H.U.

Therefore $\left[H_{air}\right]_{300}^{T_2} = 0 \cdot 02694\ (9{,}720 - 1{,}512) = 221 \cdot 12$ C.H.U./lb

$H_{air, 300} = 71 \cdot 70$ C.H.U./lb

Therefore $H_{air, T_2} = 292 \cdot 82$ C.H.U./lb

Therefore $T_2 = 1{,}156°K$.

Assume $T_2 = 1{,}160°K$

Then E.C.V. $= 9{,}751$ C.H.U./lb.

Loss (H_2) $= 29{,}490 \times 0 \cdot 0003 = 8 \cdot 85$ C.H.U.

Loss (CO) $= 2{,}406 \times 0 \cdot 0041 = 9 \cdot 86$ C.H.U.

Loss (fuel) $= 10{,}503 \times 0 \cdot 0020 = 22 \cdot 06$ C.H.U.

Therefore loss C.H.U./lb fuel $= 1{,}512$ C.H.U./lb.

Therefore $\left[H_{air}\right]_{T_2}^{300} = 0 \cdot 02694\ (9{,}571 - 1{,}512) = 221 \cdot 96$ C.H.U./lb.

Therefore $H_{air, T_2} = 293 \cdot 66$ C.H.U./lb.

Therefore $T_2 = 1{,}159°K$.

Notes.—(1) The second estimate of the heat loss is clearly unnecessary.

(2) A further trial is unnecessary.

(3) *See* Example (j) (page 26) for a simpler calculation of flame temperature which may be used if the loss is small, and total heat data for the combustion products of the fuel are available.

4. *Gas Turbine Performance Calculations*.—The fundamental processes in an open-cycle gas turbine engine are:

(a) Adiabatic compression of air

(b) Transfer of heat to the air at constant pressure, so that its temperature is increased

(c) Expansion of the heated compressed air so that energy is released.

While these processes may be duplicated or take different forms in different engines, for instance energy may be released as kinetic energy or as work, there is no essential difference in principle whatever form they take.

Determination of gas turbine performance involves the evaluation of the energy changes of these processes. These processes are all subject to losses, and a clear understanding of the efficiencies involved is needed for the performance to be calculated accurately.

The evaluation of these processes devolves upon the following unit determinations:

(i) Determination of total heat from temperature, fuel/medium ratio and fuel composition

(ii) Determination of temperature from total heat, fuel/medium ration and fuel composition

(iii) Determination of entropy function ψ from temperature, fuel/medium ratio and fuel composition

(iv) Determination of temperature from entropy function ψ, fuel/medium ratio and fuel composition

(v) Determination of the fuel/medium ratio needed to produce a given temperature rise with given fuel composition and initial supporting medium temperature

(vi) Determination of temperature rise from a given fuel/medium ratio, fuel composition and initial supporting medium temperature.

In (i), (iii) and (v), where temperature is known the required properties are directly calculable by the methods given previously. The determination of temperature in cases (ii), (iv) and (vi) is, however, more complex as it is impossible to assign a precise value to the appropriate θ functions until the temperature has been ascertained.

Unless only a few calculations are to be made, it is advantageous to calculate the appropriate properties of the combustion products of the fuel concerned, total heat and entropy function, or total heat and specific heat, by the methods given earlier, and to plot the data on such a scale that accurate interpolation is possible. Since it is advantageous to compare the performance of power plants assuming the use of a standard fuel, data has been prepared for this purpose. Examples of its use are given.

It is necessary in all calculations to maintain the best possible accuracy. Error may be systematic or random, and the latter, which would arise primarily from uncertainty or inaccuracy in the reading of graphs, is the more serious. This is discussed in Appendix II with the conclusion that when the errors in determining total heat from temperature and temperature from entropy are equivalent, and if the former does not exceed 1/800 of the heat input, then the error in fuel consumption should not normally exceed 1 per cent.

An individual expansion or a compression may frequently be calculated with less error if a small systematic error is accepted in lieu of larger random error.

Isentropic change is frequently determined from true specific heat C_{pm} at the mean temperature T_m, or from mean specific heat between the temperatures before and after the change, in place of entropy. Comparison with accurate determinations on the entropy basis indicates that the pressure change determined for a given temperature ratio differs systematically when calculated in this manner, the error varying largely as the difference in true specific heats at the beginning and end of the process. The error for the second method can amount to little more than 1 per cent for a 10/1 pressure change and is greater for the first method particularly with high pressure ratios. For pressure ratios less than about 2/1 the systematic errors of both methods are almost identical and amount to no more than $0 \cdot 2$ per cent. For smaller pressure ratios the use of C_{pm} is recommended.

Error arising from the use of this approximation at higher pressure ratios may be compensated in part by definition of efficiencies in terms of 'ideal' performance calculated in this manner. It is obvious, however, that unless turbine efficiencies are determined under their working conditions full correction is impossible, and that the resultant performance calculation will be in error, the magnitude of the error being dependent upon pressure and temperature ratios. For 5/1 pressure ratio the error would probably be between 1 per cent and 3 per cent.

The specific heat of gases varies non-linearly with temperature, and consequently a difference in total heat between two temperatures is only approximately expressed as $(T_2 - T_1)C_{pm}$. A precise value is given only by $H_2 - H_1$. When, however, total heats are expressed to $0 \cdot 10$ C.H.U./lb, the random error due to two readings may exceed the systematic error involved in using $C_{pm}(T_2 - T_1)$. Practical test of the plotted data indicates that this is the case for temperature differences $\leqslant 200°K$. For this temperature difference the maximum systematic error of the approximation corresponds to an error in specific heat of $0 \cdot 0003$ C.H.U./lb°K (mean error $0 \cdot 0001$ C.H.U./lb°K above 500°K). Use of C_{pm} is therefore recommended for the determination of differences in total heat when the temperature difference does not exceed 200°K.

Dissociated products may be considered as behaving in one of two ways. The chemical composition of a dissociated gas mixture depends upon temperature, and as the temperature changes the composition will vary. At low temperatures the rate of change of composition is slow, and the composition is 'frozen' if the rate of expansion of a gas is sufficiently high. The conditions where this applies cannot be defined with certainty. It is likely however, that compositions will not change under typical gas turbine conditions unless the initial temperature exceeds 1,800°K.

Accordingly

(A) at temperatures below 1,800°K dissociation is ignored

(B) at temperatures above 1,800°K C_{pm} is evaluated as

$$C_{pm} = \frac{H_{T_1 s} - H_{T_2 s} + \Delta Q}{T_{1s} - T_{2s}}$$

where ΔQ is the heat released by re-association, and T_{1s}, T_{2s} are the static temperatures before and after expansion.

$(\gamma - 1)/\gamma$ is then evaluated in the usual way.

It will be noted that the energy released is not wholly recovered. An accurate calculation cannot be made in this way unless the molecular-weight change is small. If it is not, a temperature-entropy diagram for the mixture is needed.

Relaxation time, *i.e.*, the time needed for the various molecules to attain their equilibrium heat capacities at a given temperature is a further potential source of loss in rapid compressions and expansions. The only effect likely to be significant is the time needed for the adjustment of the vibrational heat capacities of nitrogen and carbon dioxide, and this is likely to be sufficiently short in the presence of normal atmospheric moisture for any loss arising in the compression or expansion of gases to be neglected. Data relevant to gases at high temperatures are in any case inadequate for a precise calculation to be made.

4.1. *Definitions of Efficiency.*—4.1.1. *Compression and expansion processes.*—Adiabatic and polytropic efficiency are both used to a considerable extent. The former has the merit of indicating directly the relation between the actual and the ideal quantities of energy involved in a process, but the latter is a more realistic measure of the extent to which a process approaches the ideal. The use of one form only cannot therefore be recommended.

Separate definitions of adiabatic efficiency are required for expansion and compression. The fundamental forms are:

$$\frac{\text{Actual work done}}{\text{Theoretical isentropic work done for the same pressure ratio}} \text{ (expansion)}$$

$$\frac{\text{Theoretical isentropic work required}}{\text{Actual work required for the same pressure ratio}} \text{ (compression).}$$

Use of these definitions, however, complicates the calculation of performance. Approximate forms of the definition may be substituted as follows:

$$\frac{\text{Actual temperature drop}}{\text{Theoretical isentropic temperature drop for the same pressure ratio}} \text{ (expansion)}$$

$$\frac{\text{Theoretical isentropic temperature rise}}{\text{Actual temperature rise for the same pressure ratio}} \text{ (compression).}$$

It is obviously important to state clearly the form in which any efficiency is assumed.

Polytropic efficiency is defined as the adiabatic efficiency relevant to an infinitesimal change in state during a process. This adiabatic efficiency is assumed constant throughout the process, in accordance with usual practice.

Polytropic efficiency is applied to pressure changes in either of the following ways:

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\left(\frac{\gamma-1}{\gamma}\right)\eta_{\text{pol}}} \qquad \text{(expansion)}$$

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\left(\frac{\gamma-1}{\gamma}\right)\frac{1}{\eta_{\text{pol}}}} \qquad \text{(compression)}$$

or

$$\psi_2 - \psi_1 = \frac{1}{\eta_{\text{pol}}} \log_{10} \frac{p_2}{p_1} \qquad \text{(compression)}$$

$$\psi_2 - \psi_1 = \eta_{\text{pol}} \log_{10} \frac{p_2}{p_1} \qquad \text{(expansion)},$$

where ψ_2 and ψ_1 are those values relevant to the real, as opposed to the isentropic, temperatures T_2, T_1.

4.1.2. *Combustion efficiency*.—In that an efficiency is a ratio of energy quantities, the absolute definition of combustion efficiency can only be expressed as the ratio of the heat actually released to that theoretically obtainable. This value of efficiency must be expressed in terms of a calorific value at a fixed temperature. In that a useful combustion process must produce wholly gaseous products, a net calorific value must be employed, and the constant pressure value is appropriate. An absolute combustion efficiency η is therefore obtained by dividing the calculated heat release at 288·16°K into the difference between this quantity and the heat of combustion at 288·16°K of the unburned products.

Practical definitions in common use are as follows:

$$(a)\ \eta_T = \frac{\text{Temperature rise}}{\text{Theoretical temperature rise for given fuel/air ratio}}$$

$$(b)\ \eta_F = \frac{\text{Theoretical fuel}}{\text{Actual fuel for a given temperature rise}}\,.$$

The first definition η_T differs from the exact one on account of the variation with temperature of the specific heat of the gases, increases with combustion temperature rise and is proportional to the loss. For 500°K rise the η_T is about 0·05 per cent per cent loss greater than the absolute efficiency defined above. The magnitude of this difference is, however, reduced through non-uniformity in the temperature of the gas stream, mean temperatures being determined as the average of the gas temperatures measured in a plane, and not as the temperature which would be obtained by homogenizing the stream.

The second definition η_F varies on account of the additional heat capacity of the combustion products due to the increased quantity of fuel needed to attain the temperature. The relation may be shown to be

$$\eta_F = \eta - q_0(1 - \eta)K\,,$$

where K is a constant having a value of approximately 2·2, depending upon the relation between the mean specific heat of air and of combustion products, and q_0 is the ideal fuel/air ratio.

Thus for $\eta = 0{\cdot}90$ and $q = 0{\cdot}03$, $\eta_F = 0{\cdot}894$

for $\eta = 0{\cdot}95$ and $q_0 = 0{\cdot}02$, $\eta_F = 0{\cdot}948$.

Thus $\eta_T \geqslant \eta \geqslant \eta_F$.

η_T and η_F may equally well be applied in performance calculations. When using η_F the ideal quantity of fuel for the given temperature rise is divided by η_F to determine the amount actually needed. When using η_T, the temperature rise required is divided by η_T, and the amount of fuel needed for this new temperature rise is determined. This is fundamentally, though negligibly.

in error, since it is presumed that the efficiencies at these two conditions are equal. Accordingly the use of η_F is recommended, as being the more simple and precise method of expressing combustion efficiency, though the additional accuracy is of no advantage, since owing to the experimental and systematic errors in the determination of combustion efficiency from temperature measurements, values of efficiency accurate to 1 per cent are exceptional.

Molecular weight changes arising through imperfect combustion are usually ignored for reasons given in Section 2.3.3.

4.2. *Construction of Data Sheets—Standard Data for Comparison of Gas Turbine Performance.*—4.2.1. *Standard fuel and its combustion products.*—Tables of the total heat, true specific heat, and entropy function of the products of perfect combustion may be prepared according to equations (11) and (11*a*). These calculations are for any fuel or medium composition and are demonstrated in Example (*c*), (page 10).

Figs. 1 to 18 have been prepared from values calculated in this way, for a fuel composition $\bar{C} = 0 \cdot 8608$, $\bar{H} = 0 \cdot 1392$, burned in dry air.

The composition of this fuel was decided arbitrarily. Since kerosene is the most commonly used fuel, a composition close to the above is obviously desirable, and the composition chosen has the additional merit that the mean molecular weight of the products of perfect combustion is always equal to the mean molecular weight of air.

This may be shown as follows. The combustion of q lb hydrocarbon of hydrogen content $\bar{H}$ in 1 lb air gives $\dfrac{1}{M_{air}} + \dfrac{q\bar{H}}{2M_{H_2}}$ mol products.

The molecular weight of the products of combustion is

$$M_p = \frac{(1+q)M_{air}}{1 + q\dfrac{\bar{H}}{2}\dfrac{(M_{air})}{(M_{H_2})}} .$$

Therefore if $\bar{H} \times \dfrac{M_{air}}{2 \times M_{H_2}}$ is equal to unity, the molecular weight of the products of combustion of this particular hydrocarbon fuel is independent of q and equal to the molecular weight of air.

θ functions for the combustion products of this standard fuel are summed in Table 10, so that values of functions may be calculated by the relation

$$f = f_{air} + \frac{q}{1+q}\,\theta_{f(S)} + \ldots \cdot \frac{1}{1+q}\left(\Sigma \dot{j}_m \theta_j + \Sigma \bar{u}_m \theta_u\right)$$

the last term being zero for combustion in dry air.

This tabulation also permits values of the functions more precise than those plotted to be determined when desired.

The net calorific value at constant pressure of the fuel is assumed arbitrarily to be 10,300 C.H.U./lb.

Its effective calorific value calculated by means of equation (28) is plotted in Fig. 19 and tabulated in Table 10, and has been used to construct combustion temperature rise charts for product temperatures up to 1,400°K (Figs. 21 to 26). These charts are for ideal or 100 per cent efficient combustion and therefore a factor for combustion efficiency should be included when relevant.

Combustion temperature rise is best calculated directly, however, in the following circumstances:

(*a*) When the temperature rise is less than 200°K

(*b*) When the sensible heat of the fuel is significant.

For temperature rises of less than 200°K the temperature rise charts do not give the accuracy required for precise calculations, and the fuel/air ratio should be determined directly from equation (25) using the true specific heat of air at the mean temperature $(T_2 + T_1)/2$ to determine the value of $\Big[H_{\text{air}}\Big]_{T_1}^{T_2}$ and effective calorific value (Table 10 or Fig. 19).

When the fuel temperature is appreciably different from 15°C the sensible heat/lb fuel above 15°C is added to the effective calorific value (*i.e.* equation (25) is used), the total heat of air being deduced by the appropriate method given in Section 4.

Use of the effective calorific value and specific heat or total heat data readily permits reheat calculations, using equation (34). Thus the difference in total heat of the products of the primary combustion between the inlet and final reheat temperatures, and the effective calorific value at the final reheat temperature permit the determination of the reheat fuel/primary products ratio, from which the reheat fuel/air ratio is simply obtained. The difference in total heat is obtained using Figs. 3 to 11, unless the temperature rise is less than 200° when, as above, the true specific heat C_{pm} at the mean temperature $(T_1 + T_2)/2$ should be used.

A correction for dissociation is desirable at higher temperatures, and combustion temperature rise should be calculated directly from effective calorific value, adjusted by means of the dissociation loss when higher product temperatures are required. Calculated values of this loss are given in Fig. 19 for pressures of 0·25, 1·0, and 4·0 Atm. The method is illustrated in Example (*i*).

Example (*i*)

Given standard fuel combustion products ($q = 0{\cdot}03$) at 1,200°K and 0·25 Atm pressure, to determine the total fuel/air ratio, after combustion of further standard fuel, temperature 120°C, sufficient to raise the temperature to 1,600°K.

Total heat of products ($q = 0{\cdot}03$) (Fig. 7) at 1,200°K	= 316·1 C.H.U./lb.
Total heat of products ($q = 0{\cdot}03$) at 1,600°K (Fig. 9)	= 437·1 C.H.U./lb.
Increase in total heat/lb products	= 121·0 C.H.U.
Increase in total heat/lb air = 121·0 × 1·03	= 124·7 C.H.U.
Effective calorific value at 1,600°K (T_F = 15°C, no dissociation) (Fig. 19)	= 9,388 C.H.U./lb.
Approximate additional fuel/air ratio	= 0·013
Approximate total fuel/air ratio	= 0·043
Dissociation correction per lb fuel (1,600°K, $q = 0{\cdot}043$) (Fig. 19)	= 27 C.H.U.
Sensible heat of fuel above 15°C = 105 × 0·60*	= 63 C.H.U./lb.
Overall effective calorific value of fuel = 9,388 + 63 − 27	= 9,424 C.H.U./lb.
Therefore additional fuel/air ratio = 124·7/9,424	= 0·01323
Therefore total fuel/air ratio	= 0·04323 .

The inverse calculation, *i.e.*, the determination of the product temperature knowing the original temperature and pressure and fuel/air ratio using equation (18) is illustrated by Example (*j*).

* This value for fuel specific heat is arbitrary, and for precise work using a definite fuel, the experimentally determined value should be used.

Example (j)

Kerosene is burned in dry air at 1 Atm pressure and 400°K. $q = 0 \cdot 03$. What is the ideal flame temperature :

Heat release C.H.U./lb air at 15°C in absence of dissociation $= 0 \cdot 03 \times 10{,}300$	= 309·0 C.H.U.
Sensible heat of materials above 15°C C.H.U./lb air	= 26·90 C.H.U.
Sensible heat of products above 15°C C.H.U./lb (309·0 + 26·9)/1·03	= 326·0 C.H.U.
Total heat of products at 15°C C.H.U./lb	= 69·80 C.H.U./lb
Total heat of products C.H.U./lb	= 395·80 C.H.U./lb
Therefore temperature	= 1465·5°K
Dissociation loss at 1465°K	= 21 C.H.U./lb
Heat release C.H.U./lb air at 15°C = $0 \cdot 03 \times 10{,}279$	= 308·4 C.H.U.
Sensible heat of products above 15°C C.H.U./lb (308·4 + 26·9)1·03	= 325·5 C.H.U.
Total heat of products C.H.U./lb	= 395·3 C.H.U.
Therefore temperature	= 1,464°K.

4.2.2. *Range of applicability of standard fuel data.*—Since there is a random error of 0·5 per cent to 1·0 per cent in the calculated fuel consumption of an engine arising from the limiting error in plotting and reading charts some systematic error is tolerable. It is considered that $\pm 0 \cdot 2$ per cent could be accepted in many instances, and analysis indicates that under the most unfavourable circumstances (at high temperature), such a systematic error in the output and specific consumption of an engine could arise from a variation of $\pm 0 \cdot 2$ per cent in the hydrogen content of the fuel.

Increase in hydrogen content gives increased output and specific fuel consumption and *vice versa*.

Direct use of the data for the standard fuel is therefore recommended for fuels containing 13·7 to 14·1 per cent hydrogen and of the standard calorific value ($h_p = 10{,}300$ C.H.U./lb).

Atmospheric moisture increases the specific heat of the working fluid, and so increases the work output per lb air, and the specific fuel consumption. It is estimated that the presence in the air of 1 per cent of moisture would increase the latter by about 1 per cent. Accordingly even in temperate latitudes a variation in efficiency will be noticeable. The variation being systematic, however, comparisons made for plant presuming dry air will still be valid under normal conditions of humidity.

4.3. *Use of Tabulated Data for Gas Turbine Performance Calculation.*—The determination of total heat and entropy function ψ from temperature, fuel consumption and fuel/medium ratio, are illustrated by Examples (*c*) and (*d*), pages 10 and 11. Likewise the determination of the fuel/medium ratio needed to produce a given temperature rise with given fuel composition and initial supporting medium temperature is illustrated in Examples (*f*) and (*i*), pages 16 and 25. The inverse calculations cannot be carried out directly, since precise values cannot be assigned to the θ functions until the temperature has been ascertained. Trial and error processes are easily applied, however, and are described below.

Compression and expansion processes and combustion temperature rise are evaluated using C_{pm} when the pressure ratio < 2, or the temperature difference is less than 200°C, respectively.

4.3.1. *Determination of temperature from total heat or entropy function* ψ.—For determination of temperature from total heat or entropy function the process consists of:

(i) estimation of a likely value of temperature

(ii) evaluation of the appropriate θ functions for this temperature

(iii) substitution in equation (11) or (11*a*) to give the corresponding property of air

(iv) determination of temperature from this air property.

Example (k)

Determine the temperature of combustion products of a fuel ($\bar{C} = 0{\cdot}50$, $\bar{H} = 0{\cdot}20$, $\bar{O} = 0{\cdot}1$, $\bar{N} = 0{\cdot}2$) in air originally containing 1·5 per cent water vapour for $q = 0{\cdot}02$, given that the total heat is 261·4 C.H.U./lb (the correct answer from Example (*c*) is 1,000°K).

$$\text{Assume } T = 900°\text{K}.$$

From Table 5 and equation (11) the total heat of air at the unknown temperature is given by

$$261{\cdot}4 = H_{\text{air}} + \frac{0{\cdot}02}{1{\cdot}02}\left\{\begin{matrix} 0{\cdot}50 \times -33{\cdot}9 \\ +\,0{\cdot}20 \times 1{,}895{\cdot}7 \\ +\,0{\cdot}10 \times -14{\cdot}5 \\ +\,0{\cdot}20 \times 6{\cdot}5 \end{matrix}\right\} + \frac{0{\cdot}015}{1{\cdot}02} \times 199{\cdot}2$$

i.e.,

$$261{\cdot}4 = H_{\text{air}} + 7{\cdot}10 + 2{\cdot}93 .$$

Hence

$$H_{\text{air}} = 251{\cdot}4 .$$

From Table 1 the required temperature is 1,006°K.

It is obvious that the correct result will be obtained by the second trial taking 1,006°K as an approximation for the temperature. Use of the value of the property as if it applied to air provides a useful first approximation to the temperature. In this example the temperature would be 1,042°K, and since the total heat of products of combustion is greater than that of air a lower value, say 1,020°K, could well have been assumed for the calculation of the θ functions. With experience it will generally be found that a second calculation is unnecessary.

4.3.2. *Determination of combustion temperature rise.*—Use of equation (18) permits a simple determination of combustion temperature rise given the initial conditions and fuel/air ratio, as shown in example (*l*).

Example (l)

Fuel ($\bar{C} = 0{\cdot}8008$, $\bar{H} = 0{\cdot}0992$, $\bar{O} = 0{\cdot}10$) at 15°C and $h_p = 8{,}000$ C.H.U./lb at 15°C is burned in dry air at 300°K, with fuel/air ratio 0·03. What is the temperature of the products?

Heat release C.H.U./lb air at 15°C = 0·03 × 8,000	= 240·0 C.H.U.
Sensible heat of materials above 15°C	= 2·83 C.H.U.
Sensible heat of products above 15°C = 242·83/1·03	= 235·76 C.H.U./lb.

Assume the total heat of the products to be equal to that of air.

Then T_2	= 1,198°K.
Therefore assume T_2	= 1,180°K.

Then

$$235{\cdot}76 = \Big[H_{\text{air}}\Big]_{288\cdot16}^{T_2} + \left\{\begin{matrix} 0{\cdot}0992 \times 2055{\cdot}3 \\ 0{\cdot}8008 \times 55{\cdot}6 \\ 0{\cdot}1000 \times -11{\cdot}6 \end{matrix}\right\}\frac{0{\cdot}03}{1{\cdot}03}$$

$$= \Big[H_{\text{air}}\Big]_{288\cdot16}^{T_2} + 7{\cdot}20 .$$

Therefore

$$\Big[H_{\text{air}}\Big]_{288\cdot16}^{T_2} = 228{\cdot}56 \text{ and } T_2 = 1{,}172{\cdot}3°\text{K}.$$

Repetition with θ functions calculated for 1,172·3°K gives $T_2 = 1{,}172{\cdot}2°$K.

It has been found impossible to develop methods for a general fuel whereby dissociation loss may be calculated exactly. This loss arises in weak mixtures and at moderately low temperatures mainly through the formation of nitric oxide, which depends upon the oxygen and nitrogen content of the products. Accordingly the loss for products of the standard fuel having fuel/air ratio $q(a_0/a)$ may be used. No special allowance is necessary for the effect of the dissociation products on the properties of the combustion products, nor under normal circumstances, for the effect of combustion loss on product composition. If assumptions can be made concerning the nature of the loss, *e.g.*, if it can be attributed to the proportion of the carbon of the fuel burning to carbon monoxide, then the method given in Section 3.5 may be applied in order to compute the fuel/medium ratio and hence the properties of the products.

5. *The Calculation of Gas Flow.*—Fundamental methods of calculating gas flow tend to be laborious, especially when the data do not include the temperatures concerned. Charts correlating the flow relations are frequently used in order to eliminate trial and error computations, but in general, these have been plotted for fixed values of an expansion exponent (*e.g.*, W. R. Thomson, C.P.158, September, 1952) and their use should, in general, be confined to this, so their application is limited.

The present objective is to set out correlations of as wide application and as high accuracy as is compatible with convenient use. Investigations showed that it was possible to present accurate data for one-dimensional gas flow for all possible perfect gas properties for velocities not exceeding sonic velocity in this manner, but that it was impractical to attempt also an accurate treatment for higher velocities, or to include consideration of friction.

The use of a non-dimensional velocity parameter, *e.g.*, Mach number or critical/velocity ratio is strictly irrelevant to the computation of velocities and introduces some difficulties when a reasonably simple treatment of gases of varying specific heat is considered. Relations involving Mach number are considered, however, as aerodynamic characteristics are conveniently generalized by its use, and a definition negligibly different from physical reality permits convenient use of the data.

In that the correct calculation of the flow of gases of variable specific heat requires a continual check that the correct value of this function is being used, it is desirable that all relations include the determining factors total and static temperature, and the fundamental equations are combined and re-arranged for this purpose.

The data are applicable to gases of any molecular weight and specific heat and at any temperature. They are arranged, however, so that their use for air and for the products of combustion of standard fuel is simplified.

5.1. *The Equations for One-Dimensional Gas Flow.*—5.1.1. *Dimensional Basis.*—The units used are the English Engineering Units, save that °K is preferred to °R, and consequently the C.H.U. to the B.Th.U. Force is defined as:

$$F = \alpha Ma$$

where

F = force

M = mass

a = acceleration

α = proportionality constant, arbitrarily unity in the C.G.S., English Absolute, and English Gravitational systems.

In the English Engineering System the value of α is $1/g_0$, where g_0 is the arbitrarily chosen, so-called standard value of the earth's attraction, assumed constant at sea level and 45° latitude.

Thus

$$F \text{ (lb force)} = \frac{1}{g_0} M\text{(lb mass) } a\text{(ft/sec}^2\text{)}$$

or neglecting differences in gravitational attraction ($g = g_0$),

$$g = \frac{\text{lb (force)}}{\text{lb (mass)}} \times \frac{\text{sec}^2}{\text{ft}}$$

and is dimensionless.

Temperature is regarded as a separate dimension. Accordingly the equations involving it other than as a ratio are strictly dimensional, although its substitution by length²/time² would render them non-dimensional. Though this substitution would be in accord with kinetic theory, no practical advantage would be obtained by making it as unfamiliar conversion factors would be introduced.

5.1.2. *Definitions and Assumptions.*—The flow is assumed to be one-dimensional and frictionless, and the fluid is assumed to behave as a perfect gas, with variable specific heat. Accordingly considerations of the conservation of mass, energy and momentum permit the following relations to be developed:

$$G = AV\rho_s \quad \ldots \quad (35)$$

$$V^2 = 2gJ(H - H_s) \quad \ldots \quad (36)$$

$$\log_{10} p/p_s = \psi - \psi_s \quad \ldots \quad (37)$$

where

G = mass flow (lb (mass)/sec)

A = area of cross-section of flow (ft²)

ρ = density (lb (mass)/ft³)

J = ft lb (force)/C.H.U.

V = velocity (ft/sec)

p = pressure lb (force)/ft²

H = Total heat (C.H.U./lb) above 0°K

ψ = Entropy function

and suffix $_s$ denotes static conditions, defined as those conditions (temperature, pressure, density, etc.), which would be recorded by an observer moving with the velocity of the fluid, while quantities without suffix are those which would obtain if the fluid were brought isentropically to rest.

To these equations is added the equation of state of a perfect gas

$$p_s/\rho_s = (RJ/M)T_s \quad \ldots \quad (38)$$

where

R = universal gas constant (C.H.U./lb mol°)

M = molecular weight.

Equations (36) and (38) may be substituted numerically to give working equations:

$$V = 300 \cdot 22 \sqrt{(H - H_s)} \quad \ldots \quad (36a)$$

$$p_s/\rho_s = 2781 \cdot 6T_s/M \quad \ldots \quad (38a)$$

More general working equations are obtained, however, by combining the unsubstituted equations.

5.1.3. *Flow at subsonic velocities.*—When the flow velocity V is less than the velocity of sound, p/p_s does not exceed $2\cdot0$ for $6\cdot0 < MC_p < 14\cdot0$.

Equations (36) and (37) may then be replaced respectively by

$$V^2 = 2gJC_{pm}(T - T_s) \quad \ldots \quad (39)$$

$$p/p_s = (T/T_s)^{\{\gamma/(\gamma-1)\}_m} \quad \ldots \quad (40)$$

where C_{pm} = true specific heat at $(T + T_s)/2$

$$\{\gamma/(\gamma - 1)\}_m = MC_{pm}/R \quad \ldots \quad (41)$$

without introducing systematic error significant in comparison with the normal random error associated with calculation to 4 significant figures.

Equation (40) being in non-dimensional form and involving three parameters only is already in a convenient form.

Elimination of velocity and density between equations (35), (38) and (39) gives

$$\frac{G\sqrt{T_s}}{Ap_s} = \frac{M}{RJ}\sqrt{\left\{\frac{2gJC_{pm}(T - T_s)}{T_s}\right\}} \quad \ldots \quad (42)$$

or on multiplication by $\sqrt{(M_0/M)}$, where M_0 is the molecular weight of air

$$\frac{G\sqrt{T_s}}{Ap_s}\sqrt{\left(\frac{M_0}{M}\right)} = \sqrt{\left\{\frac{2gM_0MC_{pm}}{R^2J}\left(\frac{T - T_s}{T_s}\right)\right\}} \quad \ldots \quad (43)$$

or

$$\frac{G\sqrt{T}}{Ap}\sqrt{\left(\frac{M_0}{M}\right)} = \sqrt{\left\{\frac{2gM_0MC_{pm}}{R^2J}\left(\frac{T}{T_s}\right)^{-\left(\frac{\gamma+1}{\gamma-1}\right)_m}\left(\frac{T}{T_s} - 1\right)\right\}}. \quad \ldots \quad (43a)$$

Substitution of equation (40) in equation (43) and rearranging gives

$$\frac{G\sqrt{T}}{Ap}\sqrt{\left(\frac{M_0}{M}\right)} = \sqrt{\left(\frac{2gM_0MC_{pm}}{R^2J}\right)}\sqrt{\left\{\left(\frac{p_s}{p}\right)^{(2/\gamma)_m} - \left(\frac{p_s}{p}\right)^{\{(\gamma+1)/\gamma\}_m}\right\}}. \quad \ldots \quad (44)$$

Since $\{\gamma/(\gamma - 1)\}_m = MC_{pm}/R$, γ_m is a function of MC_{pm} and $(G\sqrt{T}/Ap)\sqrt{(M_0/M)}$ may be presented as a function of either p/p_s or T/T_s and MC_{pm} alone.

Differentiation of equation (44) with respect to p/p_s shows that

$$\left\{\frac{G\sqrt{T}}{Ap}\sqrt{\left(\frac{M_0}{M}\right)}\right\}_{\max} = \sqrt{\left(\frac{g\gamma_m M_0}{RJ}\right)}\sqrt{\left\{\left(\frac{2}{\gamma + 1}\right)^{(\gamma+1)/(\gamma-1)_m}\right\}} \quad \ldots \quad (45)$$

when

$$p/p_s = \{(\gamma + 1)/2\}^{(\gamma/\gamma-1)_m} \quad \ldots \quad (46)$$

or on substitution of equation (40), when

$$T/T_s = \{(\gamma + 1)/2\}_m. \quad \ldots \quad (47)$$

Substitution of this value of T/T_s in equation (39) gives the velocity V^* at the maximum value of the flow parameter, $\{(G\sqrt{T}/Ap)\sqrt{(M_0/M)}\}_{\max}$,

$$(V^*)^2 = 2gJC_{pm}T_s\{(\gamma_m - 1)/2\} = \frac{gRJ}{M}\gamma_m T_s. \quad \ldots \quad (48)$$

The last expression of equation (48) would be equal to the velocity of sound in the gas, were C_p constant. For gases of varying specific heat the relative difference in velocity is proportional to the square root of the ratio of γ_m and γ at T_s, i.e., it is generally very small. Accordingly a non-dimensional velocity (Mach number) which is the ratio velocity/sonic velocity is given with sufficient accuracy for subsonic velocities by the ratio V/V^*. Thus

$$\text{Mach number} = \sqrt{\left\{\frac{2gJC_{pm}(T - T_s)}{2gJC_{pm}T_s\{(\gamma - 1)/2\}_m}\right\}} = \sqrt{\left\{\frac{2}{(\gamma - 1)_m}\left(\frac{T}{T_s} - 1\right)\right\}}$$

I II III

$$= \sqrt{\left(\frac{RJ}{M_0 g\gamma_m}\right)}\frac{G\sqrt{T_s}}{Ap_s}\sqrt{\left(\frac{M_0}{M}\right)}. \qquad (49)$$

IV

Mach number may thus be expressed as a function of MC_{pm} and T/T_s alone (I = III), and for constant MC_{pm} is proportional to $(G\sqrt{T_s}/Ap_s)\sqrt{(M_0/M)}$, (I = IV), the constant of proportionality being $\sqrt{(RJ/M_0 g\gamma_m)}$. This may be expressed as a function of MC_{pm}.

5.1.4. *Flow at supersonic velocities.*—Supersonic flow involves greater temperature difference $(T - T_s)$ than subsonic flow, and accordingly only a lower standard of accuracy is often necessary. In these circumstances the systematic error involved in the extrapolation of equations (40) to (49) is generally tolerable.

When greatest possible accuracy is desired, however, it is necessary to use the basic equations (35), (36*a*), (37) and (38*a*):

$$G = AV\rho_s \qquad (35)$$

$$V = 300\cdot 22\sqrt{(H - H)} \qquad (36a)$$

$$\log_{10} p/p_s = \psi - \psi_s \qquad (37)$$

$$p_s/\rho_s = 2781\cdot 6T_s/M \qquad (38a)$$

Elimination of ρ_s and V between equations (35), (36*a*) and (38*a*) gives the following

$$\frac{GT_s}{AMp_s} = 0\cdot 10793\sqrt{(H - H_s)} = \frac{V}{2781\cdot 6} \qquad (50)$$

so that if specific mass flow G/AM, static temperature and static pressure are given, total conditions are directly calculable.

However, given total conditions and specific mass flow a simple trial and error process using equations (37) and (50) is necessary, but one involving no serious difficulties. Use of plotted functions can shorten it through providing a good first approximation.

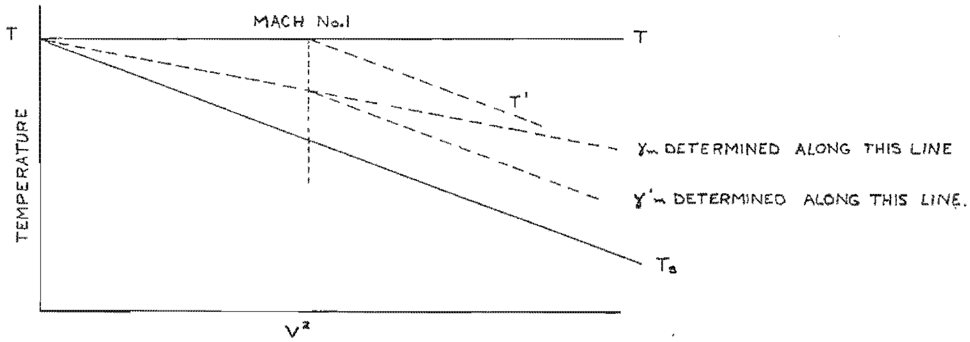
If Mach number is to be used in accurate calculations for supersonic velocities a definition which is reasonably close to reality, and still consistent with that for subsonic flow, is needed. In the latter respect it is essential that the new definition gives Mach number = 1 under the same conditions as does the definition for subsonic velocities.

Such a Mach number must still remain a relation between true velocity and an arbitrary sonic velocity, and consistency with the definition for subsonic velocities indicates that selection of a suitable value of γ, say γ', is the only adjustment possible.

Hence at Mach number $= 1$, γ'_m must equal γ_m. From the following sketch it is apparent that the divergence of γ_m from physical reality is increasing with velocity. It is therefore possible to prevent further increase in error for Mach number > 1 by defining a temperature T' such that

$$V_s = \sqrt{\left(g\gamma'_m \frac{RJ}{M} T_s\right)} = \sqrt{\{2gJC'(T' - T_s)\}}, \quad \ldots \quad \ldots \quad \ldots \quad (51)$$

where γ'_m corresponds to $C_p{}'_m$ and is determined at $(T_s + T')/2$. With this definition of Mach number, equation (49) (I = IV) is still valid with γ_m replaced by γ'_m, i.e., Table 11 read at $MC_p{}'_m$.



Continuity is obviously achieved since $T' = T$ when Mach number $= 1\cdot0$, though the continuity of γ'_m at Mach number $= 1\cdot0$ is not uniform.

It should be noted that this definition of Mach number does not affect the calculation of true velocity by the above methods for, as pointed out earlier, the use of any non-dimensional velocity parameter is optional.

5.2. *Presentation of Data.*—Calculation of the flow of gases of varying specific heat requires the ability to check that the correct mean value of specific heat is being used. This value depends upon T and T_s, and it would be desirable to be able to relate changes of velocity and pressure directly with changes of temperature. The flow parameter may be expressed as $G\sqrt{T_s}/Ap_s \sqrt{(M_0/M)}$, equation (43), or $G\sqrt{T}/A_p\sqrt{(M_0/M)}$, equation (43*a*). The latter form is preferred, as total temperatures and pressures are more easily measured than the static value.

Unfortunately equation (43*a*) gives intersecting curves which would be difficult to read. Equation (44) relating the flow parameter with pressure ratio is satisfactory in this respect. The relation can have direct application in cycle analysis, and since temperature ratio is readily determined from pressure ratio, it is considered to be the most useful form in which to present a flow parameter. It is plotted in Figs. (27) to (35) for pressure ratios up to 45/1, and values of C_{pm} from $6\cdot0$ to $14\cdot0$. Since the equations are less accurate for hypersonic velocities a reduced scale is used at the higher pressure ratios.

Tables 11 and 12 present functions of MC_p and C_p for general fuels and the standard fuel respectively, so that calculation of other flow parameters is simplified.

T/T_s is determined from pressure ratio using the exponent $\gamma/(\gamma - 1)$ or $(\gamma - 1)/\gamma$, and Mach number may be determined simply from the relation

$$\text{Mach number} = \sqrt{\left\{\frac{2}{(\gamma - 1)_m}\left(\frac{T}{T_s} - 1\right)\right\}}, \qquad \text{Equation (49) (I = III)}$$

using tabulated data for $2/(\gamma - 1)$.

Since also

$$\text{Mach number} = \sqrt{\left(\frac{RJ}{M_0 g \gamma_m}\right)} \frac{G\sqrt{T_s}}{Ap_s} \sqrt{\left(\frac{M_0}{M}\right)}, \qquad \text{Equation (49) (I = IV)}$$

tabulated data for $\sqrt{(RJ/M_0 g\gamma)}$ permits the development of relations between the static flow parameter $G\sqrt{T_s}/Ap_s \sqrt{(M_0/M)}$ and temperature ratio.

The principles underlying the use of the relations developed and the range of their application are best understood by study of actual examples. A selection is accordingly presented, starting with different given conditions. Air is considered as the fluid in all instances, since it may be presumed that suitable data sheets would have been prepared for other purposes before detailed flow calculations are made, and the determination of M and C_p by direct calculation would add only unnecessary complexity.

It will be seen that a trial and error calculation is frequently needed to determine the temperature for which specific heat data are used. Experience will enable this temperature to be estimated fairly closely, and the number of trial and error calculations reduced.

The methods are also applicable to dissociated gases if the change in molecular weight is small, as discussed under the calculation of gas turbine performance.

Example (m)

50 lb/sec air, $T = 1{,}115°K$ and $p_s = 15$ lb/in.² is flowing with Mach number $= 0{\cdot}60$. Determine its velocity, sonic velocity and density, and the flow area needed.

$$M_0/M = 1{\cdot}0 \qquad M = 28{\cdot}969$$

First T_s is determined by a trial and error process as follows:

	C_{pm}	MC_{pm} (Table 12)	$\frac{2}{\gamma - 1}$ (Table 12)	T/T_s (Eqn. 49) $I = III$	T_s	$(T + T_s)/2$	C_{pm}†	
Trial I	0·2750	7·97	6·027	1·0597	1052	1083·5	0·2762	Incorrect
Trial II	0·2762	8·00	6·057	1·0594	1052·5	1083·8	0·2762	Correct

Velocity $= 300{\cdot}22\sqrt{\{0{\cdot}2762 \times (T - T_s)\}} = 1{,}247$ ft/sec

Velocity of sound $= \dfrac{1{,}247}{\text{Mach number}} = 2{,}078$ ft/sec

$$\frac{T}{T_s} = 1{\cdot}0594,\ MC_{pm} = 8{\cdot}0,\ \frac{\gamma}{\gamma - 1} = 4{\cdot}028;\ \text{therefore } p/p_s = 1{\cdot}262 \qquad \text{Equation (40).}$$

$$p/p_s = 1{\cdot}262,\ MC_{pm} = 8{\cdot}00;\ \text{therefore } \frac{G\sqrt{T}}{Ap}\sqrt{\left(\frac{M_0}{M}\right)} = 0{\cdot}3268 \qquad \text{(Fig. 30).}$$

Therefore area $= 50\sqrt{1{,}115}/0{\cdot}3268 \times 1{\cdot}262 \times 15{\cdot}0$ sq in. $= 269{\cdot}9$ sq in.

$$\frac{p_s}{\rho_s} = \frac{2781{\cdot}6T_s}{M}. \qquad \text{Equation (38a)}$$

Therefore density $= \rho_s = \dfrac{28{\cdot}969 \times 15 \times 144}{2781{\cdot}6 \times 1052{\cdot}5} = 0{\cdot}2137$ lb/ft³.

Note:

(1) The initial trial and error determination of static temperature permits the direct determination of other parameters

(2) The rapid convergence about the mean specific heat

(3) The substitution of pressure (lb/in.) in equation (44) (Figs. 27 to 35) to calculate area (sq in.)

(4) The calculation is typical of the determination of flow area, for specified Mach number. The earlier stages of the calculation, including the trial and error process would be identical if p were specified instead of p_s.

† These values of C_{pm} correspond to the values of $(T + T_s)/2$ given in the 6th column.

Example (n)

60 lb/sec air, $T = 288\cdot0°K$ and $p = 14\cdot50$ lb/in.² is flowing with a velocity of 450 ft/sec. Determine the flow area needed.

$$M_0/M = 1\,, \qquad M = 28\cdot969\,,$$

$$V = 300\cdot22\sqrt{\{C_p(T - T_s)\}} = 450\,;\ \text{hence}\ C_p(T - T_s) = 2\cdot2467\,.$$

	Estimated C_{pm}	$T - T_s = \frac{2\cdot2467}{C_p}$	T_s	$(T + T_s)/2$	C_{pm} (Fig. 1)	
Trial I	0·2396	9·4	278·6	283·3	0·2396	Correct

$$MC_p = 6\cdot94,\ T/T_s = 1\cdot0337,\ \frac{\gamma}{\gamma - 1} = 3\cdot495\,;$$

therefore $p/p_s = 1\cdot123$ Equation (40)

Therefore $p_s = 12\cdot91$ lb/sq in.

$$\frac{GT_s}{AMp_s} = \frac{V}{2781\cdot6} = 0\cdot1618\,. \qquad \text{Equation (50)}$$

$$\text{Therefore area} = \frac{60\cdot0 \times 278\cdot6}{28\cdot969 \times 12\cdot91 \times 0\cdot1618} = 276\cdot2\ \text{sq in.}$$

Alternatively

$$p/p_s = 1{,}123\,,\ \frac{G\sqrt{T}}{Ap}\sqrt{\left(\frac{M_0}{M}\right)} = 0\cdot2544 \qquad \text{Fig. 30}$$

$$\text{Therefore area} = \frac{60\cdot0\sqrt{288\cdot0}}{14\cdot50 \times 0\cdot2544} = 276\cdot0\ \text{sq in.}$$

Note:

This calculation is typical of the calculation of the area of compressor delivery volutes, etc.

Example (o)

47·3 lb/sec air, $p_s = 15$ lb/in.² is flowing through 120 in.² with a Mach number of 0·739. Determine its velocity, density and total head pressure.

$$M_0/M = 1\cdot0\,, \qquad M = 28\cdot969\,.$$

	Estimated C_{pm}	MC_{pm}	$\sqrt{\left(\frac{RJ}{M_0 g\gamma}\right)}$ (Table 12)	$\frac{G\sqrt{T_s}}{Ap_s}\sqrt{\left(\frac{M_0}{M}\right)}$ (Eqn. 49) $I = IV$	T_s°K	$\frac{2}{\gamma - 1}$ (Table 12)	T/T_s (Eqn. 49) $I = III$	T °K	$\frac{T+T_s}{2}$	C_{pm} (Fig. 1)	
Trial I	0·2485	7·20	1·470	0·5027	366·0	5·251	1·1040	404·1	385	0·2415	Incorrect
Trial II	0·2415	6·996	1·462	0·5055	370·0	5·046	1·1082	410·0	390	0·2416	Correct

$$\text{Velocity} = 300\cdot22\sqrt{\{0\cdot2416(T - T_s)\}} = 933\ \text{ft/sec.}$$

$$T/T_s = 1\cdot1082,\ MC_{pm} = 6\cdot996,\ \frac{\gamma}{\gamma - 1} = 3\cdot523\,;$$

therefore $p/p_s = 1\cdot436.$ Equation (40)

Total head pressure $= 1{\cdot}436 \times 15{\cdot}0 = 21{\cdot}56$ lb/sq in.

$$\frac{p_s}{\rho_s} = \frac{2781{\cdot}6T_s}{M}. \qquad \text{Equation (4a)}$$

Density $$\rho_s = \frac{28{\cdot}969 \times 15{\cdot}0 \times 144}{2781{\cdot}6 \times 370{\cdot}0} = 0{\cdot}06080 \text{ lb/ft}^3.$$

Note:

This calculation illustrates the use of the proportionality factor (equation 49 and Table 12) and the procedure for calculating gas flow without initial knowledge of a temperature.

Example (p)

Air, $T_s = 1{,}000{\cdot}9°$K and $p_s = 20$ lb/in.^{2}, is flowing with $A/G = 1{\cdot}1848$ in.^{2}/sec/lb. Determine its total temperature and pressure, velocity and Mach number.

$$M_0/M = 1, \qquad M = 28{\cdot}969.$$

(i) *Accurate calculation.*

From equation (50) $$\frac{GT_s}{AMp_s} = \frac{V}{2781{\cdot}6}.$$

Therefore velocity $$= \frac{2781{\cdot}6 \times 1000{\cdot}9}{1{\cdot}1848 \times 28{\cdot}969 \times 20{\cdot}0} = 4{,}056 \text{ ft/sec.}$$

$$H - H_s = \left(\frac{V}{300{\cdot}22}\right)^2 = 182{\cdot}52 \qquad \text{Equation (36a)}$$

$H_s = 250{\cdot}08$. Therefore $H = 432{\cdot}60$ C.H.U./lb.

Therefore $T = 1643{\cdot}9°$K.

$\psi_s = 12{\cdot}0582$

$\psi = 12{\cdot}9479$

$\log p/p_s = 0{\cdot}8897$. Therefore $p/p_s = 7{\cdot}757$.

Therefore $p = 155{\cdot}14$ lb/sq in.

To determine T' and hence Mach number.

	Estimated C_{pm}	MC_{pm}	Mach number	$\frac{2}{\gamma - 1}$ (Table 12)	T'/T_s	T'	$\frac{T' + T_s}{2}$	C_{pm} (Fig. 1)	
Trial I	0·2693	7·80	1·0	5·856	1·1708	1171·9	1086·4	0·2763	Incorrect
Trial II	0·2763	8·00	1·0	6·057	1·1651	1166·1	1083·5	0·2762	Correct

$$V_{sonic} = 300{\cdot}22\sqrt{\{0{\cdot}2762(T' - T_s)\}} = 2028 \text{ ft/sec.}$$

Therefore Mach number $= 2{\cdot}0$.

(ii) *Approximate calculation.*

V is determined as in accurate calculation as 4056 ft/sec.

Therefore $C_p(T - T_s) = \left(\frac{V}{300 \cdot 22}\right)^2 = 182 \cdot 52.$

C_{pm} and T are determined by trial and error as follows:

	Estimated C_{pm}	$T - T_s$	T	$(T+T_s)/2$	C_{pm}	
Trial I ..	0·2800	651·8	1652·7	1313·3	0·2942	Incorrect
Trial II ..	0·2842	642·3	1643·2	1322·1	0·2845	Incorrect
Trial III ..	0·2845	641·2	1642·1	1321·5	0·2845	Correct

Therefore $T = 1642 \cdot 1$. Therefore $T/T_s = 1 \cdot 641$.

Therefore $C_{pm} = 0 \cdot 2845$.

Therefore $MC_{pm} = 8 \cdot 24,\ \frac{\gamma}{\gamma - 1} = 4 \cdot 149,\ \frac{2}{\gamma - 1} = 6 \cdot 298.$ Table 12

Therefore $p/p_s = 7 \cdot 81$. Equation (40)

Therefore $p = 156 \cdot 2$ lb/sq in. and

Mach number $= 2 \cdot 01$. Equation (49)

Note:

(1) The results of the approximate calculation are within 1 per cent of the correct values

(2) In this example the accurate calculation is relatively easy. No trial and error is avoided by making the approximate calculation first.

(3) The ratio of the velocity to the true velocity of sound could be determined directly equally well, but it is considered best in the interests of consistency to use the arbitrary definition of Mach number, as this is generally more easily deduced.

Example (q)

Air, $p = 155 \cdot 14$ lb/in. and $p_s = 20$ lb/in.^{2} is flowing with $A/G = 1 \cdot 1848$ in.^{2}/sec/lb. Determine accurately its total and static temperature, and its velocity and Mach number.

$$M_0/M = 1,\ M = 28 \cdot 969,\ p/p_s = 7 \cdot 757.$$

Therefore $\frac{G}{Ap}\sqrt{\left(\frac{M_0}{M}\right)} = 0 \cdot 00544.$

Approximate values of T and T_s are determined as follows:

	Estimated C_{pm}	MC_p (Table 12)	$\frac{\gamma - 1}{\gamma}$ (Table 12)	T/T_s (Eqn. (40))	$\frac{G\sqrt{T}}{Ap}\sqrt{\left(\frac{M_0}{M}\right)}$ (Fig. 34)	T °K	T_s °K	$(T+T_s)/2$	C_{pm}	
Trial I	0·2850	8·25	0·2407	1·637	0·2200	1635	999	1317	0·2843	Incorrect
Trial II	0·2843	8·24	0·2410	1·638	0·2201	1637	999	1318	0·2843	Correct

The accurate calculation is now made substituting the approximate value of T_s found above in equation (50), with $G/AMp_s = 0\cdot0014568$, so that $H - H_s$, H, and T may be determined. $\psi - \psi_s$ are then checked against $p/p_s = 7\cdot757$.

	T_s	H_s (Table 1)	$\frac{G\sqrt{T_s}}{AMp_s}$	$H - H_s$ (Eqn. (50))	H	T °K (Table 1)	ψ (Table 1)	ψ_s (Table 1)	$\psi - \psi_s$	p/p_s
Trial I	999·0	249·57	1·4553	181·81	431·38	163·97	12·9432	12·0549	0·8883	7·732
Trial II	1000·0	249·84	1·4568	182·19	432·03	1641·9	12·9457	12·0566	0·8891	7·746
Trial III	1000·8*	250·06	1·4580	182·48	432·54	1643·7	12·9477	12·0580	0·8897	7·757

Thus $T_s = 1000\cdot8$°K, $T = 1643\cdot7$°K. V and Mach number are then calculated as in Example (p) giving:

$$V = 4056 \text{ ft/sec}$$

$$\text{Mach number} = 2\cdot00.$$

Notes:

(1) This calculation is the converse of Example (p).

(2) The accurate trial and error calculation is tedious, and not rapidly convergent. Hence the approximate determination of T and T_s reduces the work considerably.

Example (r)

Air, $T = 1{,}000$°K is flowing with $p = 75\cdot0$ lb/in.^{2} and $p_s = 15$ lb/in.^{2} Determine the velocity and mass flow per unit area.

$$M_0/M = 1\cdot0, \qquad M = 28\cdot969, \qquad p/p_s = 5\cdot00$$

$$\psi = 12\cdot0566 \text{ (Table 1)}, \log\frac{p}{p_s} = 0\cdot6990\,.$$

Therefore $\psi_s = 11\cdot3576$ and $T_s = 657\cdot4$°K (Table 1).

$H = 249\cdot84$ C.H.U./lb, $H_s = 159\cdot48$ C.H.U./lb. (Table 1).

Therefore $V = 300\cdot22\sqrt{90\cdot36} = 2854$ ft/sec Equation (36a)

Using equation 50: $= \frac{GT_s}{AMp_s} = \frac{V}{2781\cdot6} = 1\cdot026\,.$

Therefore $G/A = \frac{28\cdot969 \times 1\cdot026 \times 15}{657\cdot4} = 0\cdot6782$ lb/sec^{-1} in.$^{-2}$.

Note :

This calculation is typical of the accurate calculation of flow in a supersonic nozzle, which with the given data requires no trial and error.

Acknowledgement.—The authors gratefully acknowledge the advice and encouragement received from Mr. H. Farrington of Metropolitan-Vickers Electrical Co., Ltd., and Mr. W. R. Thomson of the National Gas Turbine Establishment, and the permission of the Directors of Metropolitan-Vickers Electrical Co., Ltd., and of the Director, National Gas Turbine Establishment to publish this work.

* By extrapolation from trials 1 and 2.

APPENDIX I

Constants and Notations

1. *Constants.*—1.1. *Energy.*—The unit of energy used in this work is the C.H.U. defined as

$$1 \text{ C.H.U./lb} = 4\cdot1868 \text{ abs. Joules/gm.}$$

The gravitational constant used assumes equal gravitational forces over the Earth's surface and defines the relation between force, mass and acceleration as follows:

$$g = \text{lb (force)} \times \text{sec}^2/\text{lb (mass)} \times \text{ft}$$

or

$$g = 32\cdot174 \text{ lb (force) sec}^2/\text{lb (mass)} \times \text{ft}$$

and is dimensionless.

Accordingly,

$$J = \text{ft lb (force)/C.H.U., } i.e., \text{ is dimensionless}$$

$$1 \text{ C.H.U.} = 1400\cdot71 \text{ ft lb (force)}$$

$$1 \text{ h.p.} = 550 \text{ ft lb (force)/sec}$$

$$= 0\cdot745565 \text{ kW}$$

$$1 \text{ C.H.U./sec} = 1\cdot89876 \text{ kW} = 2\cdot54674 \text{ h.p.}$$

All temperatures are quoted in °K, the relation between °K and °C being

$$°\text{K} = °\text{C} + 273\cdot16\,.$$

1.2. *Gas Constant and Molecular Weight.*—The universal gas constant is taken as

$$R = 1\cdot98586 \text{ C.H.U./lb Mol °K.}$$

Molecular weights of principal elements:

Oxygen	32·000	Carbon	12·010
Nitrogen	28·016	Argon	39·950
Hydrogen	2·016	Sulphur	32·070

Dry Air

	Nitrogen	*Oxygen*	*Argon*
Composition (v/v)	78·030%	20·990%	0·980%
Composition (w/w)	75·463%	23·186%	1·351%

Molecular weight = 28·969

RJ/M = 96·0204 ft lb (force)/lb (mass) °K.

2. *Notation.*—As all symbols are defined in the text the system only is given here.

2.1. *Quantities.*

C	Specific heat (C.H.U./lb °K)
H	Total heat above 0°K (C.H.U./lb)
$\bar{\text{H}}$	Hydrogen content of reactant (lb/lb)
$\bar{\text{O}}$	Oxygen content of reactant (lb/lb)
$\bar{\text{S}}$	Sulphur content of reactant (lb/lb)
$\bar{\text{W}}$	Water vapour content of reactant (lb/lb)

$\bar{C}$	Carbon content of reactant (lb/lb)
$\bar{N}$	Nitrogen content of reactant (lb/lb)
$\bar{u}$	u content of reactant (lb/lb)
$\bar{j}$	j content of reactant(lb/lb)

where u and j are general combustible and inert components respectively.

M	Molecular weight
M_0	Molecular weight of air
p	Total-head pressure (lb force per unit area abs.)
A	Area (ft²)
G	Mass flow (lb/sec)
V	Velocity (ft/sec)
T	Total head temperature °K
ρ	Density (lb/ft³)
f	General function of gases, *e.g.*, total heat
h_p	Net calorific value at constant pressure
E.C.V.	Effective calorific value
R	Universal gas constant
ψ	Entropy function $= \dfrac{\log_{10} e}{R} \displaystyle\int_0^T \dfrac{MC_p\,dT}{T}$
Ω	Temperature functions of total heat, specific heat, etc. (reactants)
θ	Temperature functions of total heat, specific heat, etc. (products of combustion)
k	Molecular weight functions of components $\begin{Bmatrix} k_u \text{ for burned component} \\ k_j \text{ for unburned component} \end{Bmatrix}$

2.2. *Ratios, etc.*

J	Mechanical equivalent of heat
γ	Ratio of specific heats C_p/C_v
q	Fuel/air ratio
a	Stoiciometric air/fuel ratio
M'	Ratio of molecular weights M_0/M

2.3. *General Subscripts and Modifying Signs.*

0	Refers to 0°K
$_0$	Refers to air
$_m$	Refers to true value at mean temperature, e.g., C_{pm} or γ_m, or a property of the 'medium' reactant, e.g., H_m
$_{(s)}$	Refers to standard fuel
$_s$	Refers to static condition
$_p$	Refers to constant pressure
$\Big[\ \Big]_1^2$	Refers to a difference in the enclosed quantity between states 2 and 1

APPENDIX II

The Effects of Random Error in Thermodynamic Data

The Summation of Random Errors.

The efficiency of a power cycle is defined as the ratio of the work output to the heat input. The accuracy of the calculation depends upon the random error in determining the total heat of the working fluid at various conditions. If in an internal combustion cycle unit quantity of air enters at T_1, is compressed to T_2, heated by combustion to T_3, expanded to T_4 and rejected at this temperature,

$$\eta = \frac{(H_3 - H_4) - (H_2 - H_1)}{(H_3 - H_2)} \quad \ldots \quad (52)$$

There are thus in a simple cycle four total heats to determine. If heat exchange is used no more need be considered in so far as accuracy is concerned, as errors in intermediate values are mutually cancelled.

The number of random errors therefore depends upon the number of readings required for the determination of these four total heats. Typical cases are as follows:

(*a*) The isentropic changes $T_1 \rightarrow T_2$ and $T_3 \rightarrow T_4$ may be determined by an entropy method and total heats are determined at these temperatures, with fuel consumption calculated from H_{T2} and H_{T3} by means of effective calorific value.

(*b*) As (*a*) but using combustion temperature rise charts to determine fuel consumption.

(*c*) The heat changes in compression and expansion may be determined by means of single specific heat readings and combustion temperature rise from specific heat and effective calorific value.

The effect of these random errors may be assessed approximately, if it is assumed that they are of equal magnitude.

Case (i).—From equation (52)

$$\eta \pm \delta\eta = \frac{(H_3 \pm \delta H) - (H_4 \pm \delta H) - (H_2 \pm \delta H) + (H_1 \pm \delta H)}{(H_3 \pm \delta H) - (H_2 \pm \delta H)} \quad \ldots \quad (53)$$

Therefore $\eta(H_3 - H_2) \pm 2\eta\delta H \pm \delta n(H_3 - H_2)$

$$= H_3 - H_4 - (H_2 - H_1) \pm 4\delta H .$$

Therefore

$$\delta\eta = \frac{\pm 4\delta H \pm 2\eta\, \delta H}{(H_3 - H_2)} \quad \ldots \quad (54)$$

The error in each value of total heat is partly a function of the error in the temperature–total-heat conversion and partly of the error involved in the reading of entropy. Four entropy-temperature conversions are involved. Presuming all errors to have equivalent effect and expressing as error in the reading of total heat,

$$\delta\eta = \frac{2(\pm 4\delta H \pm 2\eta\, \delta H)}{H_3 - H_2} \quad \ldots \quad (55)$$

Errors in total heat at T_2 and T_3 are partly compensated through their effect on the determination of heat input. Accordingly for $\eta = 0 \cdot 25$,

$$\delta\eta \simeq \frac{\pm 7\delta H}{H_3 - H_2} = \frac{\pm 7\delta H}{Q}, \quad \ldots \quad (56)$$

where Q is the heat released per unit mass of fluid.

Case (ii).—Equation (52) gives

$$\eta \pm \delta\eta = \frac{H_3 \pm \delta H - H_4 \pm \delta H - H_2 \pm \delta H + H_1 \pm \delta H}{Q \pm \delta Q}, \quad \ldots \quad (57)$$

where Q is the heat quantity added.

Accordingly $$\delta\eta = \frac{\pm 4\delta H}{Q} \pm \frac{\eta\, \delta Q}{Q}. \quad \ldots \quad (58)$$

Presuming equal errors in temperature-entropy conversions, and expressing as before in terms of the error in an individual reading

$$\delta\eta = \pm \frac{8\delta H}{Q} \pm \frac{\eta\, \delta Q}{Q}. \quad \ldots \quad (59)$$

A somewhat greater tolerance appears permissible in combustion temperature rise curves than in total heat or entropy functions as the effect of the error $\eta\, \delta Q/Q$ is equivalent to that of the sum of the other errors, but negligible error can be permitted, however, without the tolerance in the reading of H being reduced, so relative reduction of scale of combustion temperature rise curves is not justified. Given precise charts, however, there need be no increase in random error as compared with calculation according to (i).

Case (iii).—When a specific heat is used for determination of isentropic change, the random error in the determination of temperature change is partially compensated in the determination of the heat change. The random error in the determination of the heat changes is accordingly less than $\delta C_p\,(T_3 - T_4) + \delta C_p\,(T_1 - T_2)$. The total error will not therefore exceed

$$\pm \frac{2\delta C_p\,(T_3 - T_4)}{Q} \pm \frac{\eta\, \delta Q}{Q}.$$

If combustion temperature rise is also determined by means of C_p, the sum becomes

$$\not> \pm \frac{3\delta C_p\,(T_3 - T_4)}{Q},$$

and is probably no greater than $\pm \dfrac{2\delta C_p(T_3 - T_4)}{Q}$. The random error in the result for a given random error in C_p will be least when the pressure ratio is low, *i.e.*, for the conditions when calculation by this method is recommended. Some systematic error is introduced, but it is also slight for these low pressure ratios.

Accuracy Requirements

Negligible error will accrue from effective calorific value in the determination of combustion temperature rise, and if all other errors are presumed to be equal or equivalent, there is a limiting random error for a given probability that $\delta\eta$ does not exceed a stipulated value. When the error in determining total heat from temperature does not exceed 1/800 of the heat input (and the error in determining temperature from entropy is equivalent), then for 7 errors the probability that $\delta\eta \leqslant \pm 0{\cdot}0025$ is estimated as being of the order of 80 per cent.

The conditions necessary for this order of accuracy, when the combustion temperature rise is 200°K are therefore :

(*a*) The reading of total heat to the nearest 0·1 C.H.U./lb

(*b*) The reading of temperature to the nearest 0·5°K.

(*c*) The reading of ψ to permit the determination of temperature to the nearest 0·5°K

(*d*) The reading of fuel/air ratio to nearest 0·00001.

In other words the greatest error that can be tolerated is ± 0·05 C.H.U./lb, or ± 0·25°K.

When specific heat is used for all stages of the calculation of a cycle involving temperature changes not exceeding 200°K, $\delta C_p/C_p$ should not exceed about 1/1200, i.e., C_p should be read to 0·0004 C.H.U./lb for the calculation of fuel consumption with an accuracy of ± 1 per cent. A more precise estimate is needed for better accuracy, or if the heat changes in compression and expansion are significantly greater than the combustion heat release.

TABLE 1

Properties of Dry Air

H = Total heat above 0°K C.H.U./lb.; ψ = Entropy function,

C_p = Specific heat at constant pressure C.H.U./lb °K; H_{15} = Total heat above 288·16°K (15°C) C.H.U./lb.

Air composition by weight: N_2 0·75463, O_2 0·23186, A 0·01351

T°K	H	C_p	ψ	H_{15}	T°K	H	C_p	ψ	H_{15}
200	47·76	0·2393	9·5264	−21·11					
201	48·00	0·2393	9·5340	−20·87	241	57·57	0·2393	9·8091	−11·30
202	48·24	0·2393	9·5415	−20·63	242	57·81	0·2394	9·8154	−11·06
203	48·47	0·2393	9·5490	−20·40	243	58·05	0·2394	9·8217	−10·82
204	48·71	0·2393	9·5564	−20·16	244	58·29	0·2394	9·8279	−10·58
205	48·95	0·2393	9·5638	−19·92	245	58·53	0·2394	9·8341	−10·34
206	49·19	0·2393	9·5712	−19·68	246	58·77	0·2394	9·8403	−10·10
207	49·43	0·2393	9·5785	−19·44	247	59·01	0·2394	9·8464	− 9·86
208	49·67	0·2393	9·5858	−19·20	248	59·24	0·2394	9·8525	− 9·63
209	49·91	0·2393	9·5931	−18·96	249	59·48	0·2394	9·8586	− 9·39
210	50·15	0·2393	9·6003	−18·72	250	59·72	0·2394	9·8647	− 9·15
211	50·39	0·2393	9·6075	−18·48	251	59·96	0·2394	9·8707	− 8·91
212	50·63	0·2393	9·6147	−18·24	252	60·20	0·2394	9·8767	− 8·67
213	50·86	0·2393	9·6218	−18·01	253	60·44	0·2394	9·8827	− 8·43
214	51·10	0·2393	9·6289	−17·77	254	60·68	0·2394	9·8887	− 8·19
215	51·34	0·2393	9·6360	−17·53	255	60·92	0·2394	9·8947	− 7·95
216	51·58	0·2393	9·6430	−17·29	256	61·16	0·2394	9·9006	− 7·71
217	51·82	0·2393	9·6500	−17·05	257	61·40	0·2394	9·9065	− 7·47
218	52·06	0·2393	9·6570	−16·81	258	61·64	0·2394	9·9124	− 7·23
219	52·30	0·2393	9·6639	−16·57	259	61·88	0·2394	9·9183	− 6·99
220	52·54	0·2393	9·6708	−16·33	260	62·12	0·2394	9·9242	− 6·75
221	52·78	0·2393	9·6777	−16·09	261	62·36	0·2394	9·9300	− 6·51
222	53·02	0·2393	9·6845	−15·85	262	62·60	0·2395	9·9358	− 6·27
223	53·26	0·2393	9·6913	−15·61	263	62·84	0·2395	9·9416	− 6·03
224	53·50	0·2393	9·6981	−15·37	264	63·08	0·2395	9·9474	− 5·79
225	53·74	0·2393	9·7048	−15·13	265	63·32	0·2395	9·9531	− 5·55
226	53·98	0·2393	9·7115	−14·89	266	63·56	0·2395	9·9588	− 5·31
227	54·22	0·2393	9·7182	−14·65	267	63·80	0·2395	9·9645	− 5·07
228	54·46	0·2393	9·7249	−14·41	268	64·04	0·2395	9·9702	− 4·83
229	54·70	0·2393	9·7315	−14·17	269	64·28	0·2395	9·9759	− 4·59
230	54·94	0·2393	9·7381	−13·93	270	64·52	0·2395	9·9815	− 4·35
231	55·18	0·2393	9·7447	−13·69	271	64·76	0·2395	9·9871	− 4·11
232	55·42	0·2393	9·7513	−13·45	272	65·00	0·2395	9·9927	− 3·87
233	55·65	0·2393	9·7578	−13·22	273	65·23	0·2395	9·9983	− 3·64
234	55·89	0·2393	9·7643	−12·98	274	65·47	0·2395	10·0038	− 3·40
235	56·13	0·2393	9·7708	−12·74	275	65·71	0·2395	10·0093	− 3·16
236	56·37	0·2393	9·7773	−12·50	276	65·95	0·2395	10·0148	− 2·92
237	56·61	0·2393	9·7837	−12·26	277	66·19	0·2395	10·0203	− 2·68
238	56·85	0·2393	9·7901	−12·02	278	66·43	0·2396	10·0258	− 2·44
239	57·09	0·2393	9·7965	−11·78	279	66·67	0·2396	10·0312	− 2·20
240	57·33	0·2393	9·8028	−11·54	280	66·91	0·2396	10·0366	− 1·96

TABLE 1—*continued*

T°K	H	C_p	ψ	H_{15}	T°K	H	C_p	ψ	H_{15}
281	67·15	0·2396	10·0420	− 1·72	331	79·14	0·2403	10·2910	10·27
282	67·39	0·2396	10·0474	− 1·48	332	79·38	0·2403	10·2956	10·51
283	67·63	0·2396	10·0528	− 1·24	333	79·63	0·2403	10·3002	10·76
284	67·87	0·2396	10·0582	− 1·00	334	79·87	0·2403	10·3048	11·00
285	68·11	0·2396	10·0635	− 0·76	335	80·11	0·2404	10·3093	11·24
286	68·35	0·2396	10·0688	− 0·52	336	80·35	0·2404	10·3139	11·48
287	68·59	0·2396	10·0741	− 0·28	337	80·59	0·2404	10·3184	11·72
288	68·83	0·2396	10·0794	− 0·04	338	80·83	0·2404	10·3229	11·96
288·16	68·87	0·2396	10·0802	− 0·0	339	81·07	0·2404	10·3274	12·20
289	69·07	0·2397	10·0847	+ 0·20	340	81·31	0·2405	10·3319	12·44
290	69·31	0·2397	10·0899	0·44					
291	69·55	0·2397	10·0951	0·68	341	81·55	0·2405	10·3364	12·68
292	69·79	0·2397	10·1003	0·92	342	81·79	0·2405	10·3409	12·92
293	70·02	0·2397	10·1055	1·15	343	82·03	0·2405	10·3454	13·16
294	70·26	0·2397	10·1107	1·39	344	82·27	0·2405	10·3498	13·40
295	70·50	0·2397	10·1159	1·63	345	82·51	0·2406	10·3542	13·64
296	70·74	0·2398	10·1211	1·87	346	82·75	0·2406	10·3586	13·88
297	70·98	0·2398	10·1262	2·11	347	82·99	0·2406	10·3630	14·12
298	71·22	0·2398	10·1313	2·35	348	83·23	0·2406	10·3674	14·36
299	71·46	0·2398	10·1364	2·59	349	83·47	0·2406	10·3718	14·60
300	71·70	0·2398	10·1415	2·83	350	83·71	0·2407	10·3761	14·84
301	71·94	0·2398	10·1466	3·07	351	83·95	0·2407	10·3805	15·08
302	72·18	0·2398	10·1516	3·31	352	84·19	0·2407	10·3848	15·32
303	72·42	0·2399	10·1566	3·55	353	84·44	0·2407	10·3981	15·57
304	72·66	0·2399	10·1616	3·79	354	84·68	0·2407	10·3934	15·81
305	72·90	0·2399	10·1666	4·03	355	84·92	0·2408	10·3977	16·05
306	73·14	0·2399	10·1716	4·27	356	85·16	0·2408	10·4020	16·29
307	73·38	0·2399	10·1766	4·51	357	85·40	0·2408	10·4063	16·53
308	73·62	0·2399	10·1815	4·75	358	85·64	0·2408	10·4106	16·77
309	73·86	0·2399	10·1864	4·99	359	85·88	0·2408	10·4148	17·01
310	74·10	0·2400	10·1913	5·23	360	86·12	0·2409	10·4190	17·25
311	74·34	0·2400	10·1962	5·47	361	86·36	0·2409	10·4232	17·49
312	74·58	0·2400	10·2011	5·71	362	86·60	0·2409	10·4274	17·73
313	74·82	0·2400	10·2060	5·95	363	86·85	0·2409	10·4316	17·98
314	75·06	0·2400	10·2108	6·19	364	87·09	0·2410	10·4358	18·22
315	75·30	0·2400	10·2156	6·43	365	87·33	0·2410	10·4400	18·46
316	75·54	0·2400	10·2204	6·67	366	87·57	0·2410	10·4442	18·70
317	75·78	0·2401	10·2252	6·91	367	87·81	0·2410	10·4484	18·94
318	76·02	0·2401	10·2300	7·15	368	88·05	0·2411	10·4526	19·18
319	76·26	0·2401	10·2348	7·39	369	88·29	0·2411	10·4567	19·42
320	76·50	0·2401	10·2396	7·63	370	88·53	0·2411	10·4608	19·66
321	76·74	0·2401	10·2444	7·87	371	88·77	0·2411	10·4649	19·90
322	76·98	0·2401	10·2491	8·11	372	89·01	0·2412	10·4690	20·14
323	77·22	0·2402	10·2538	8·35	373	89·26	0·2412	10·4731	20·39
324	77·46	0·2402	10·2585	8·59	374	89·50	0·2412	10·4772	20·63
325	77·70	0·2402	10·2632	8·83	375	89·74	0·2412	10·4813	20·87
326	77·94	0·2402	10·2679	9·07	376	89·98	0·2413	10·4854	21·11
327	78·18	0·2402	10·2726	9·31	377	90·22	0·2413	10·4895	21·35
328	78·42	0·2402	10·2772	9·55	378	90·46	0·2413	10·4936	21·59
329	78·66	0·2403	10·2818	9·79	379	90·70	0·2413	10·4976	21·83
330	78·90	0·2403	10·2864	+10·03	380	90·94	0·2414	10·5016	22·07

TABLE 1—*continued*

T°K	H	C_p	ψ	H_{15}	T°K	H	C_p	ψ	H_{15}
381	91·18	0·2414	10·5056	22·31	431	103·28	0·2429	10·6947	34·41
382	91·42	0·2414	10·5096	22·55	432	103·53	0·2430	10·6983	34·66
383	91·67	0·2414	10·5136	22·80	433	103·77	0·2430	10·7019	34·90
384	91·91	0·2415	10·5176	23·04	434	104·02	0·2430	10·7054	35·15
385	92·15	0·2415	10·5216	23·28	435	104·26	0·2431	10·7089	35·39
386	92·39	0·2415	10·5256	23·52	436	104·50	0·2431	10·7125	35·63
387	92·63	0·2415	10·5296	23·76	437	104·75	0·2431	10·7160	35·88
388	92·88	0·2416	10·5335	24·01	438	104·99	0·2432	10·7195	36·12
389	93·12	0·2416	10·5374	24·25	439	105·24	0·2432	10·7230	36·37
390	93·36	0·2416	10·5413	24·49	440	105·48	0·2432	10·7265	36·61
391	93·60	0·2416	10·5452	24·73	441	105·72	0·2433	10·7300	36·85
392	93·84	0·2417	10·5491	24·97	442	105·97	0·2433	10·7335	37·10
393	94·09	0·2417	10·5530	25·22	443	106·21	0·2433	10·7370	37·34
394	94·33	0·2417	10·5569	25·46	444	106·46	0·2434	10·7405	37·59
395	94·57	0·2417	10·5608	25·70	445	106·70	0·2434	10·7439	37·83
396	94·81	0·2418	10·5647	25·94	446	106·94	0·2435	10·7474	38·07
397	95·05	0·2418	10·5686	26·18	447	107·19	0·2435	10·7509	38·32
398	95·29	0·2418	10·5725	26·42	448	107·43	0·2435	10·7544	38·56
399	95·53	0·2419	10·5763	26·66	449	107·68	0·2436	10·7578	38·81
400	95·77	0·2419	10·5801	26·90	450	107·92	0·2436	10·7612	39·05
401	96·01	0·2419	10·5839	27·14	451	108·16	0·2436	10·7647	39·29
402	96·25	0·2420	10·5877	27·38	452	108·41	0·2437	10·7681	39·54
403	96·50	0·2420	10·5915	27·63	453	108·65	0·2437	10·7715	39·78
404	96·74	0·2420	10·5953	27·87	454	108·90	0·2438	10·7749	40·03
405	96·98	0·2421	10·5991	28·11	455	109·14	0·2438	10·7783	40·27
406	97·22	0·2421	10·6029	28·35	456	109·38	0·2438	10·7817	40·51
407	97·46	0·2421	10·6067	28·59	457	109·63	0·2439	10·7851	40·76
408	97·71	0·2422	10·6105	28·84	458	109·87	0·2439	10·7885	41·00
409	97·95	0·2422	10·6142	29·08	459	110·12	0·2440	10·7919	41·25
410	98·19	0·2422	10·6179	29·32	460	110·36	0·2440	10·7952	41·49
411	98·43	0·2423	10·6217	29·56	461	110·60	0·2440	10·7986	41·73
412	98·68	0·2423	10·6254	29·81	462	110·85	0·2441	10·8020	41·98
413	98·92	0·2423	10·6291	30·05	463	111·09	0·2441	10·8053	42·22
414	99·17	0·2424	10·6328	30·30	464	111·34	0·2442	10·8086	42·47
415	99·41	0·2424	10·6365	30·54	465	111·58	0·2442	10·8119	42·71
416	99·65	0·2424	10·6402	30·78	466	111·82	0·2442	10·8152	42·95
417	99·89	0·2425	10·6439	31·02	467	112·07	0·2443	10·8185	43·20
418	100·14	0·2425	10·6476	31·27	468	112·31	0·2443	10·8218	43·44
419	100·38	0·2425	10·6513	31·51	469	112·56	0·2444	10·8251	43·69
420	100·62	0·2426	10·6549	31·75	470	112·80	0·2444	10·8284	43·93
421	100·86	0·2426	10·6586	31·99	471	113·04	0·2444	10·8317	44·17
422	101·10	0·2426	10·6623	32·23	472	113·29	0·2445	10·8350	44·42
423	101·35	0·2427	10·6659	32·48	473	113·53	0·2445	10·8383	44·66
424	101·59	0·2427	10·6695	32·72	474	113·78	0·2446	10·8416	44·91
425	101·83	0·2427	10·6731	32·96	475	114·02	0·2446	10·8448	45·15
426	102·07	0·2428	10·6767	33·20	476	114·26	0·2446	10·8481	45·39
427	102·31	0·2428	10·6803	33·44	477	114·51	0·2447	10·8514	45·64
428	102·56	0·2428	10·6839	33·69	478	114·75	0·2447	10·8547	45·88
429	102·80	0·2429	10·6875	33·93	479	115·00	0·2448	10·8579	46·13
430	103·04	0·2429	10·6911	34·17	480	115·24	0·2448	10·8611	46·37

TABLE 1—*continued*

T°K	H	C_p	ψ	H_{15}	T°K	H	C_p	ψ	H_{15}
481	115·48	0·2449	10·8644	46·61	531	127·79	0·2473	11·0186	58·92
482	115·73	0·2449	10·8676	46·86	532	128·04	0·2474	11·0216	59·17
483	115·97	0·2450	10·8708	47·10	533	128·28	0·2474	11·0245	59·41
484	116·22	0·2450	10·8740	47·35	534	128·53	0·2475	11·0274	59·66
485	116·46	0·2451	10·8772	47·59	535	128·78	0·2475	11·0303	59·91
486	116·71	0·2451	10·8804	47·84	536	129·03	0·2476	11·0333	60·16
487	116·95	0·2451	10·8836	48·08	537	129·28	0·2476	11·0362	60·41
488	117·20	0·2452	10·8868	48·33	538	129·52	0·2477	11·0391	60·65
489	117·44	0·2452	10·8900	48·57	539	129·77	0·2477	11·0420	60·90
490	117·69	0·2453	10·8931	48·82	540	130·02	0·2478	11·0449	61·15
491	117·94	0·2453	10·8963	49·07	541	130·27	0·2479	11·0478	61·40
492	118·18	0·2454	10·8995	49·31	542	130·52	0·2479	11·0507	61·65
493	118·43	0·2454	10·9027	49·56	543	130·76	0·2480	11·0536	61·89
494	118·67	0·2455	10·9058	49·80	544	131·01	0·2480	11·0565	62·14
495	118·92	0·2455	10·9089	50·05	545	131·26	0·2481	11·0594	62·39
496	119·16	0·2456	10·9121	50·29	546	131·51	0·2481	11·0623	62·64
497	119·41	0·2456	10·9152	50·54	547	131·76	0·2482	11·0652	62·89
498	119·65	0·2457	10·9183	50·78	548	132·00	0·2482	11·0681	63·13
499	119·90	0·2457	10·9214	51·03	549	132·25	0·2483	11·0710	63·38
500	120·14	0·2458	10·9245	51·27	550	132·50	0·2483	11·0738	63·63
501	120·39	0·2458	10·9276	51·52	551	132·75	0·2484	11·0767	63·88
502	120·63	0·2459	10·9307	51·76	552	133·00	0·2484	11·0796	64·13
503	120·88	0·2459	10·9338	52·01	553	133·24	0·2485	11·0824	64·37
504	121·12	0·2460	10·9369	52·25	554	133·49	0·2485	11·0852	64·62
505	121·37	0·2460	10·9400	52·50	555	133·74	0·2486	11·0880	64·87
506	121·62	0·2461	10·9431	52·75	556	133·99	0·2486	11·0909	65·12
507	121·86	0·2461	10·9462	52·99	557	134·24	0·2487	11·0937	65·37
508	122·11	0·2462	10·9493	53·24	558	134·49	0·2487	11·0965	65·62
509	122·35	0·2462	10·9524	53·48	559	134·74	0·2488	11·0993	65·87
510	122·60	0·2463	10·9554	53·73	560	134·99	0·2488	11·1021	66·12
511	122·85	0·2463	10·9585	53·98	561	135·24	0·2489	11·1049	66·37
512	123·09	0·2464	10·9616	54·22	562	135·49	0·2490	11·1077	66·62
513	123·34	0·2464	10·9646	54·47	563	135·73	0·2490	11·1105	66·86
514	123·58	0·2465	10·9676	54·71	564	135·98	0·2491	11·1133	67·11
515	123·83	0·2465	10·9706	54·96	565	136·23	0·2491	11·1161	67·36
516	124·08	0·2466	10·9737	55·21	566	136·48	0·2492	11·1189	67·61
517	124·33	0·2466	10·9767	55·46	567	136·73	0·2492	11·1217	67·86
518	124·57	0·2467	10·9797	55·70	568	136·97	0·2493	11·1245	68·10
519	124·82	0·2467	10·9827	55·95	569	137·22	0·2493	11·1273	68·35
520	125·07	0·2468	10·9857	56·20	570	137·47	0·2494	11·1300	68·60
521	125·32	0·2468	10·9887	56·45	571	137·72	0·2495	11·1328	68·85
522	125·57	0·2469	10·9917	56·70	572	137·97	0·2495	11·1356	69·10
523	125·81	0·2469	10·9947	56·94	573	138·22	0·2496	11·1384	69·35
524	126·06	0·2470	10·9977	57·19	574	138·47	0·2496	11·1411	69·60
525	126·31	0·2470	11·0007	57·44	575	138·72	0·2497	11·1438	69·85
526	126·56	0·2471	11·0037	57·69	576	138·97	0·2497	11·1466	70·10
527	126·80	0·2471	11·0067	57·93	577	139·22	0·2498	11·1494	70·35
528	127·05	0·2472	11·0097	58·18	578	139·47	0·2498	11·1521	70·60
529	127·29	0·2472	11·0127	58·42	579	139·72	0·2499	11·1548	70·85
530	127·54	0·2473	11·0156	58·67	580	139·97	0·2499	11·1575	71·10

TABLE 1—*continued*

T°K	H	C_p	ψ	H_{15}	T°K	H	C_p	ψ	H_{15}
581	140·22	0·2500	11·1603	71·35	631	152·78	0·2527	11·2917	83·91
582	140·47	0·2500	11·1630	71·60	632	153·03	0·2528	11·2943	84·16
583	140·72	0·2501	11·1657	71·85	633	153·29	0·2528	11·2968	84·42
584	140·97	0·2501	11·1684	72·10	634	153·54	0·2529	11·2993	84·67
585	141·22	0·2502	11·1711	72·35	635	153·79	0·2529	11·3018	84·92
586	141·47	0·2502	11·1738	72·60	636	154·04	0·2530	11·3044	85·17
587	141·72	0·2503	11·1765	72·85	637	154·30	0·2531	11·3069	85·43
588	141·98	0·2504	11·1792	73·11	638	154·55	0·2531	11·3094	85·68
589	142·23	0·2504	11·1819	73·36	639	154·81	0·2532	11·3119	85·94
590	142·48	0·2505	11·1846	73·61	640	155·06	0·2532	11·3144	86·19
591	142·73	0·2505	11·1873	73·86	641	155·31	0·2533	11·3169	86·44
592	142·98	0·2506	11·1900	74·11	642	155·57	0·2534	11·3194	86·70
593	143·23	0·2506	11·1927	74·36	643	155·82	0·2534	11·3219	86·95
594	143·48	0·2507	11·1954	74·61	644	156·08	0·2535	11·3244	87·21
595	143·73	0·2507	11·1980	74·86	645	156·33	0·2535	11·3269	87·46
596	143·98	0·2508	11·2007	75·11	646	156·58	0·2536	11·3294	87·71
597	144·23	0·2508	11·2034	75·36	647	156·84	0·2536	11·3319	87·97
598	144·48	0·2509	11·2061	75·61	648	157·09	0·2537	11·3344	88·22
599	144·73	0·2510	11·2087	75·86	649	157·35	0·2537	11·3369	88·48
600	144·98	0·2510	11·2113	76·11	650	157·60	0·2538	11·3393	88·73
601	145·23	0·2511	11·2140	76·36	651	157·85	0·2539	11·3418	88·98
602	145·48	0·2511	11·2167	76·61	652	158·11	0·2539	11·3443	89·24
603	145·74	0·2512	11·2193	76·87	653	158·36	0·2540	11·3468	89·49
604	145·99	0·2512	11·2219	77·12	654	158·62	0·2540	11·3492	89·75
605	146·24	0·2513	11·2245	77·37	655	158·87	0·2541	11·3516	90·00
606	146·49	0·2513	11·2272	77·62	656	159·12	0·2541	11·3541	90·25
607	146·74	0·2514	11·2298	77·87	657	159·38	0·2542	11·3566	90·51
608	147·00	0·2514	11·2324	78·13	658	159·63	0·2542	11·3590	90·76
609	147·25	0·2515	11·2350	78·38	659	159·89	0·2543	11·3614	91·02
610	147·50	0·2515	11·2376	78·63	660	160·14	0·2544	11·3638	91·27
611	147·75	0·2516	11·2402	78·88	661	160·39	0·2544	11·3663	91·52
612	148·00	0·2517	11·2428	79·13	662	160·65	0·2545	11·3688	91·78
613	148·26	0·2517	11·2454	79·39	663	160·90	0·2545	11·3712	92·03
614	148·51	0·2518	11·2480	79·64	664	161·16	0·2546	11·3736	92·29
615	148·76	0·2518	11·2506	79·89	665	161·41	0·2546	11·3760	92·54
616	149·01	0·2519	11·2532	80·14	666	161·67	0·2547	11·3785	92·80
617	149·26	0·2519	11·2558	80·39	667	161·92	0·2547	11·3809	93·05
618	149·51	0·2520	11·2584	80·64	668	162·18	0·2548	11·3833	93·31
619	149·76	0·2520	11·2610	80·89	669	162·43	0·2549	11·3857	93·56
620	150·01	0·2521	11·2635	81·14	670	162·69	0·2549	11·3881	93·82
621	150·26	0·2522	11·2661	81·39	671	162·95	0·2550	11·3905	94·08
622	150·51	0·2522	11·2687	81·64	672	163·20	0·2550	11·3929	94·33
623	150·77	0·2523	11·2713	81·90	673	163·46	0·2551	11·3953	94·59
624	151·02	0·2523	11·2738	82·15	674	163·71	0·2552	11·3977	94·84
625	151·27	0·2524	11·2763	82·40	675	163·97	0·2552	11·4001	95·10
626	151·52	0·2524	11·2789	82·65	676	164·22	0·2553	11·4025	95·35
627	151·77	0·2525	11·2815	82·90	677	164·48	0·2553	11·4049	95·61
628	152·03	0·2526	11·2841	83·16	678	164·73	0·2554	11·4073	95·86
629	152·28	0·2526	11·2866	83·41	679	164·99	0·2554	11·4097	96·12
630	152·53	0·2527	11·2891	83·66	680	165·24	0·2555	11·4120	96·37

TABLE 1—*continued*

T°K	H	C_p	ψ	H_{15}	T°K	H	C_p	ψ	H_{15}
681	165·50	0·2556	11·4144	96·63	731	178·35	0·2585	11·5298	109·48
682	165·75	0·2556	11·4168	96·88	732	178·61	0·2585	11·5321	109·74
683	166·01	0·2557	11·4192	97·14	733	178·86	0·2586	11·5343	109·99
684	166·26	0·2558	11·4216	97·39	734	179·12	0·2586	11·5365	110·25
685	166·52	0·2558	11·4239	97·65	735	179·38	0·2587	11·5387	110·51
686	166·78	0·2559	11·4263	97·91	736	179·64	0·2587	11·5410	110·77
687	167·03	0·2559	11·4287	98·16	737	179·90	0·2588	11·5433	111·03
688	167·29	0·2560	11·4311	98·42	738	180·15	0·2589	11·5455	111·28
689	167·54	0·2560	11·4334	98·67	739	180·41	0·2589	11·5477	111·54
690	167·80	0·2561	11·4357	98·93	740	180·67	0·2590	11·5499	111·80
691	168·06	0·2562	11·4381	99·19	741	180·93	0·2590	11·5522	112·06
692	168·31	0·2562	11·4405	99·44	742	181·19	0·2591	11·5544	112·32
693	168·57	0·2563	11·4428	99·70	743	181·45	0·2591	11·5566	112·58
694	168·82	0·2563	11·4451	99·95	744	181·71	0·2592	11·5588	112·84
695	169·08	0·2564	11·4474	100·21	745	181·97	0·2592	11·5610	113·10
696	169·34	0·2564	11·4498	100·47	746	182·23	0·2593	11·5632	113·36
697	169·59	0·2565	11·4522	100·72	747	182·49	0·2594	11·5654	113·62
698	169·85	0·2565	11·4545	100·98	748	182·75	0·2594	11·5676	113·88
699	170·10	0·2566	11·4568	101·23	749	183·01	0·2595	11·5698	114·14
700	170·36	0·2567	11·4591	101·49	750	183·27	0·2595	11·5720	114·40
701	170·62	0·2567	11·4615	101·75	751	183·53	0·2596	11·5742	114·66
702	170·88	0·2568	11·4638	102·01	752	183·79	0·2597	11·5764	114·92
703	171·13	0·2568	11·4661	102·26	753	184·05	0·2597	11·5786	115·18
704	171·39	0·2569	11·4684	102·52	754	184·31	0·2598	11·5808	115·44
705	171·65	0·2570	11·4707	102·78	755	184·57	0·2598	11·5829	115·70
706	171·91	0·2570	11·4730	103·04	756	184·83	0·2599	11·5851	115·96
707	172·16	0·2571	11·4753	103·29	757	185·09	0·2599	11·5873	116·22
708	172·42	0·2571	11·4776	103·55	758	185·35	0·2600	11·5895	116·48
709	172·67	0·2572	11·4799	103·80	759	185·61	0·2600	11·5916	116·74
710	172·93	0·2572	11·4822	104·06	760	185·87	0·2601	11·5937	117·00
711	173·19	0·2573	11·4855	104·32	761	186·13	0·2602	11·5959	117·26
712	173·45	0·2574	11·4878	104·58	762	186·39	0·2602	11·5981	117·52
713	173·70	0·2574	11·4901	104·83	763	186·65	0·2603	11·6003	117·78
714	173·96	0·2575	11·4924	105·09	764	186·91	0·2603	11·6024	118·04
715	174·22	0·2575	11·4936	105·35	765	187·17	0·2604	11·6045	118·30
716	174·48	0·2576	11·4959	105·61	766	187·43	0·2605	11·6067	118·56
717	174·74	0·2576	11·4982	105·87	767	187·69	0·2605	11·6089	118·82
718	174·99	0·2577	11·5005	106·12	768	187·95	0·2606	11·6111	119·08
719	175·25	0·2578	11·5028	106·38	769	188·21	0·2606	11·6132	119·34
720	175·51	0·2578	11·5050	106·64	770	188·47	0·2607	11·6153	119·60
721	175·77	0·2579	11·5073	106·90	771	188·73	0·2607	11·6175	119·86
722	176·03	0·2580	11·5096	107·16	772	188·99	0·2608	11·6197	120·12
723	176·28	0·2580	11·5119	107·41	773	189·26	0·2609	11·6218	120·39
724	176·54	0·2581	11·5141	107·67	774	189·52	0·2609	11·6239	120·65
725	176·80	0·2581	11·5163	107·93	775	189·78	0·2610	11·6260	120·91
726	177·06	0·2582	11·5186	108·19	776	190·04	0·2610	11·6282	121·17
727	177·32	0·2582	11·5209	108·45	777	190·30	0·2611	11·6304	121·43
728	177·57	0·2583	11·5231	108·70	778	190·56	0·2611	11·6325	121·69
729	177·83	0·2583	11·5253	108·96	779	190·82	0·2612	11·6346	121·95
730	178·09	0·2584	11·5275	109·22	780	191·08	0·2612	11·6367	122·21

TABLE 1—*continued*

T°K	H	C_p	ψ	H_{15}	T°K	H	C_p	ψ	H_{15}
781	191·34	0·2613	11·6389	122·47	831	204·48	0·2641	11·7421	135·61
782	191·60	0·2614	11·6410	122·73	832	204·75	0·2641	11·7441	135·88
783	191·87	0·2614	11·6431	123·00	833	205·01	0·2642	11·7461	136·14
784	192·13	0·2615	11·6452	123·26	834	205·28	0·2642	11·7481	136·41
785	192·39	0·2615	11·6473	123·52	835	205·54	0·2643	11·7501	136·67
786	192·65	0·2616	11·6494	123·78	836	205·80	0·2643	11·7521	136·93
787	192·91	0·2616	11·6515	124·04	837	206·07	0·2644	11·7541	137·20
788	193·18	0·2617	11·6536	124·31	838	206·33	0·2645	11·7561	137·46
789	193·44	0·2617	11·6557	124·57	839	206·60	0·2645	11·7581	137·73
790	193·70	0·2618	11·6578	124·83	840	206·86	0·2646	11·7601	137·99
791	193·96	0·2619	11·6599	125·09	841	207·12	0·2646	11·7621	138·25
792	194·22	0·2619	11·6620	125·35	842	207·39	0·2647	11·7641	138·52
793	194·49	0·2620	11·6641	125·62	843	207·65	0·2647	11·7661	138·78
794	194·75	0·2620	11·6662	125·88	844	207·92	0·2648	11·7681	139·05
795	195·01	0·2621	11·6682	126·14	845	208·18	0·2648	11·7700	139·31
796	195·27	0·2622	11·6703	126·40	846	208·45	0·2649	11·7720	139·58
797	195·53	0·2622	11·6724	126·66	847	208·71	0·2649	11·7740	139·84
798	195·80	0·2623	11·6745	126·93	848	208·98	0·2650	11·7760	140·11
799	196·06	0·2623	11·6766	127·19	849	209·24	0·2650	11·7780	140·37
800	196·32	0·2624	11·6786	127·45	850	209·51	0·2651	11·7799	140·64
801	196·58	0·2624	11·6807	127·71	851	209·77	0·2651	11·7819	140·90
802	196·84	0·2625	11·6828	127·97	852	210·04	0·2652	11·7839	141·17
803	197·11	0·2625	11·6849	128·24	853	210·30	0·2652	11·7859	141·43
804	197·37	0·2626	11·6870	128·50	854	210·57	0·2653	11·7879	141·70
805	197·63	0·2626	11·6890	128·76	855	210·83	0·2653	11·7898	141·96
806	197·89	0·2627	11·6911	129·02	856	211·10	0·2654	11·7918	142·23
807	198·16	0·2628	11·6932	129·29	857	211·36	0·2654	11·7938	142·49
808	198·42	0·2628	11·6953	129·55	858	211·63	0·2655	11·7958	142·76
809	198·69	0·2629	11·6973	129·82	859	211·89	0·2655	11·7977	142·92
810	198·95	0·2629	11·6993	130·08	860	212·16	0·2656	11·7996	143·29
811	199·21	0·2630	11·7014	130·34	861	212·43	0·2656	11·8016	143·56
812	199·48	0·2630	11·7035	130·61	862	212·69	0·2657	11·8036	143·82
813	199·74	0·2631	11·7056	130·87	863	212·96	0·2658	11·8056	144·09
814	200·01	0·2631	11·7076	131·14	864	213·22	0·2658	11·8075	144·35
815	200·27	0·2632	11·7096	131·40	865	213·49	0·2659	11·8094	144·62
816	200·53	0·2632	11·7117	131·66	866	213·76	0·2659	11·8114	144·89
817	200·79	0·2633	11·7138	131·92	867	214·02	0·2660	11·8134	145·15
818	201·06	0·2634	11·7158	132·19	868	214·29	0·2660	11·8153	145·42
819	201·32	0·2634	11·7178	132·45	869	214·55	0·2661	11·8172	145·68
820	201·58	0·2635	11·7198	132·71	870	214·82	0·2661	11·8191	145·95
821	201·84	0·2635	11·7219	132·97	871	215·09	0·2662	11·8211	146·22
822	202·11	0·2636	11·7239	133·24	872	215·35	0·2662	11·8230	146·48
823	202·37	0·2636	11·7259	133·50	873	215·62	0·2663	11·8249	146·75
824	202·64	0·2637	11·7279	133·77	874	215·88	0·2663	11·8268	147·01
825	202·90	0·2638	11·7299	134·03	875	216·15	0·2664	11·8287	147·28
826	203·16	0·2638	11·7320	134·29	876	216·42	0·2664	11·8307	147·55
827	203·43	0·2639	11·7340	134·56	877	216·68	0·2665	11·8326	147·81
828	203·69	0·2639	11·7360	134·82	878	216·95	0·2665	11·8345	148·08
829	203·96	0·2640	11·7380	135·09	879	217·21	0·2666	11·8364	148·34
830	204·22	0·2640	11·7400	135·35	880	217·48	0·2666	11·8383	148·61

TABLE 1—*continued*

T°K	H	C_p	ψ	H_{15}	T°K	H	C_p	ψ	H_{15}
881	217·75	0·2667	11·8403	148·88	931	231·15	0·2692	11·9340	162·28
882	218·02	0·2668	11·8422	149·15	932	231·42	0·2693	11·9359	162·55
883	218·28	0·2668	11·8441	149·41	933	231·69	0·2693	11·9377	162·82
884	218·55	0·2669	11·8460	149·68	934	231·96	0·2694	11·9395	163·09
885	218·82	0·2669	11·8479	149·95	935	232·23	0·2694	11·9413	163·36
886	219·09	0·2670	11·8498	150·22	936	232·50	0·2695	11·9432	163·63
887	219·36	0·2670	11·8517	150·49	937	232·77	0·2695	11·9450	163·90
888	219·62	0·2671	11·8536	150·75	938	233·03	0·2696	11·9468	164·16
889	219·89	0·2671	11·8555	151·02	939	233·30	0·2696	11·9486	164·43
890	220·16	0·2672	11·8574	151·29	940	233·57	0·2697	11·9504	164·70
891	220·43	0·2672	11·8593	151·56	941	233·84	0·2697	11·9523	164·97
892	220·69	0·2673	11·8612	151·82	942	234·11	0·2698	11·9541	165·24
893	220·96	0·2673	11·8631	152·09	943	234·38	0·2698	11·9559	165·51
894	221·22	0·2674	11·8650	152·35	944	234·65	0·2699	11·9577	165·78
895	221·49	0·2674	11·8669	152·62	945	234·92	0·2699	11·9595	166·05
896	221·76	0·2675	11·8688	152·89	946	235·19	0·2700	11·9613	166·32
897	222·03	0·2675	11·8707	153·16	947	235·46	0·2700	11·9631	166·59
898	222·29	0·2676	11·8726	153·42	948	235·73	0·2700	11·9649	166·86
899	222·56	0·2676	11·8745	153·69	949	236·00	0·2701	11·9667	167·13
900	222·83	0·2677	11·8764	153·96	950	236·27	0·2701	11·9685	167·40
901	223·10	0·2677	11·8783	154·23	951	236·54	0·2702	11·9703	167·67
902	223·37	0·2678	11·8802	154·50	952	236·81	0·2702	11·9721	167·94
903	223·63	0·2678	11·8821	154·76	953	237·08	0·2703	11·9739	168·21
904	223·90	0·2679	11·8840	155·03	954	237·35	0·2703	11·9757	168·48
905	224·17	0·2679	11·8858	155·30	955	237·62	0·2704	11·9775	168·75
906	224·44	0·2680	11·8877	155·57	956	237·89	0·2704	11·9793	169·02
907	224·71	0·2680	11·8896	155·84	957	238·16	0·2705	11·9811	169·29
908	224·97	0·2681	11·8915	156·10	958	238·43	0·2705	11·9829	169·56
909	225·24	0·2681	11·8934	156·37	959	238·70	0·2706	11·9847	169·83
910	225·51	0·2682	11·8952	156·64	960	238·97	0·2706	11·9864	170·10
911	225·78	0·2682	11·8971	156·91	961	239·24	0·2707	11·9882	170·37
912	226·05	0·2683	11·8990	157·18	962	239·51	0·2707	11·9900	170·64
913	226·31	0·2683	11·9009	157·44	963	239·79	0·2708	11·9918	170·92
914	226·58	0·2684	11·9027	157·71	964	240·06	0·2708	11·9936	171·19
915	226·85	0·2684	11·9045	157·98	965	240·33	0·2709	11·9953	171·46
916	227·12	0·2685	11·9064	158·25	966	240·60	0·2709	11·9971	171·73
917	227·39	0·2685	11·9083	158·52	967	240·87	0·2710	11·9989	172·00
918	227·65	0·2686	11·9101	158·78	968	241·14	0·2710	12·0007	172·27
919	227·92	0·2686	11·9119	159·05	969	241·41	0·2710	12·0025	172·54
920	228·19	0·2687	11·9137	159·32	970	241·68	0·2711	12·0042	172·81
921	228·46	0·2687	11·9156	159·59	971	241·95	0·2711	12·0060	173·08
922	228·73	0·2688	11·9175	159·86	972	242·22	0·2712	12·0078	173·35
923	228·99	0·2688	11·9193	160·12	973	242·50	0·2712	12·0096	173·63
924	229·26	0·2689	11·9211	160·39	974	242·77	0·2713	12·0113	173·90
925	229·53	0·2689	11·9229	160·66	975	243·04	0·2713	12·0130	174·17
926	229·80	0·2690	11·9248	160·93	976	243·31	0·2714	12·0148	174·44
927	230·07	0·2690	11·9267	161·20	977	243·58	0·2714	12·0166	174·71
928	230·34	0·2691	11·9285	161·47	978	243·86	0·2715	12·0184	174·99
929	230·61	0·2691	11·9303	161·74	979	244·13	0·2715	12·0201	175·26
930	230·88	0·2692	11·9321	162·01	980	244·40	0·2716	12·0218	175·53

TABLE 1—*continued*

T°K	H	C_p	ψ	H_{15}	T°K	H	C_p	ψ	H_{15}
981	244·67	0·2716	12·0236	175·80	1031	258·31	0·2739	12·1095	189·44
982	244·94	0·2717	12·0254	176·07	1032	258·59	0·2740	12·1112	189·72
983	245·22	0·2717	12·0271	176·35	1033	258·86	0·2740	12·1129	189·99
984	245·49	0·2718	12·0288	176·62	1034	259·14	0·2740	12·1146	190·27
985	245·76	0·2718	12·0305	176·89	1035	259·41	0·2741	12·1162	190·54
986	246·03	0·2719	12·0323	177·16	1036	259·68	0·2741	12·1179	190·81
987	246·30	0·2719	12·0341	177·43	1037	259·96	0·2742	12·1196	191·09
988	246·58	0·2720	12·0358	177·71	1038	260·23	0·2742	12·1213	191·36
989	246·85	0·2720	12·0375	177·98	1039	260·51	0·2743	12·1230	191·64
990	247·12	0·2720	12·0392	178·25	1040	260·78	0·2743	12·1246	191·91
991	247·39	0·2721	12·0410	178·52	1041	261·05	0·2744	12·1263	192·18
992	247·66	0·2721	12·0428	178·79	1042	261·33	0·2744	12·1280	192·46
993	247·94	0·2722	12·0445	179·07	1043	261·60	0·2745	12·1297	192·73
994	248·21	0·2722	12·0462	179·34	1044	261·88	0·2745	12·1313	193·01
995	248·48	0·2723	12·0479	179·61	1045	262·15	0·2745	12·1329	193·28
996	248·75	0·2723	12·0497	179·88	1046	262·43	0·2746	12·1346	193·56
997	249·02	0·2724	12·0515	180·15	1047	262·70	0·2746	12·1363	193·83
998	249·30	0·2724	12·0532	180·43	1048	262·98	0·2747	12·1380	194·11
999	249·57	0·2725	12·0549	180·70	1049	263·25	0·2747	12·1396	194·38
1000	249·84	0·2725	12·0566	180·97	1050	263·53	0·2748	12·1412	194·66
1001	250·11	0·2725	12·0584	181·24	1051	263·80	0·2478	12·1429	194·93
1002	250·39	0·2726	12·0601	181·52	1052	264·08	0·2748	12·1446	195·21
1003	250·66	0·2726	12·0618	181·79	1053	264·35	0·2749	12·1463	195·48
1004	250·94	0·2727	12·0635	182·07	1054	264·63	0·2749	12·1479	195·76
1005	251·21	0·2727	12·0652	182·34	1055	264·90	0·2750	12·1495	196·03
1006	251·48	0·2728	12·0670	182·61	1056	265·18	0·2750	12·1512	196·31
1007	251·75	0·2728	12·0687	182·88	1057	265·45	0·2751	12·1529	196·58
1008	252·03	0·2729	12·0704	183·16	1058	265·73	0·2751	12·1545	196·86
1009	252·30	0·2729	12·0721	183·43	1059	266·00	0·2751	12·1561	197·13
1010	252·57	0·2730	12·0738	183·70	1060	266·28	0·2752	12·1577	197·41
1011	252·84	0·2730	12·0756	183·97	1061	266·55	0·2752	12·1594	197·68
1012	253·11	0·2730	12·0773	184·24	1062	266·83	0·2753	12·1611	197·96
1013	253·39	0·2731	12·0790	184·52	1063	267·10	0·2753	12·1627	198·23
1014	253·66	0·2731	12·0807	184·79	1064	267·38	0·2754	12·1643	198·51
1015	253·93	0·2732	12·0824	185·06	1065	267·65	0·2754	12·1659	198·78
1016	254·20	0·2732	12·0841	185·33	1066	267·93	0·2755	12·1676	199·06
1017	254·48	0·2733	12·0858	185·61	1067	268·20	0·2755	12·1693	199·33
1018	254·75	0·2733	12·0875	185·88	1068	268·48	0·2755	12·1709	199·61
1019	255·03	0·2734	12·0892	186·16	1069	268·75	0·2756	12·1725	199·88
1020	255·30	0·2734	12·0909	186·43	1070	269·03	0·2756	12·1741	200·16
1021	255·57	0·2735	12·0926	186·70	1071	269·31	0·2757	12·1758	200·44
1022	255·85	0·2735	12·0943	186·98	1072	269·58	0·2757	12·1775	200·71
1023	256·12	0·2735	12·0960	187·25	1073	269·86	0·2757	12·1791	200·99
1024	256·40	0·2736	12·0977	187·53	1074	270·13	0·2758	12·1807	201·26
1025	256·67	0·2736	12·0994	187·80	1075	270·41	0·2758	12·1823	201·54
1026	256·94	0·2737	12·1011	188·07	1076	270·69	0·2759	12·1840	201·82
1027	257·22	0·2737	12·1028	188·35	1077	270·96	0·2759	12·1856	202·09
1028	257·49	0·2738	12·1045	188·62	1078	271·24	0·2760	12·1872	202·37
1029	257·77	0·2738	12·1062	188·90	1079	271·51	0·2760	12·1888	202·64
1030	258·04	0·2739	12·1078	189·17	1080	271·79	0·2760	12·1904	202·92

TABLE 1—*continued*

T °K	H	C_p	ψ	H_{15}	T °K	H	C_p	ψ	H_{15}
1081	272·07	0·2761	12·1921	203·20	1131	285·92	0·2781	12·2714	217·05
1082	272·34	0·2761	12·1937	203·47	1132	286·20	0·2781	12·2730	217·35
1083	272·62	0·2762	12·1953	203·75	1133	286·47	0·2782	12·2746	217·60
1084	272·89	0·2762	12·1969	204·02	1134	286·75	0·2782	12·2761	217·88
1085	273·17	0·2763	12·1985	204·30	1135	287·03	0·2782	12·2776	218·16
1086	273·45	0·2763	12·2001	204·58	1136	287·31	0·2783	12·2792	218·44
1087	273·72	0·2763	12·2017	204·85	1137	287·59	0·2783	12·2808	218·72
1088	274·00	0·2764	12·2033	205·13	1138	287·86	0·2783	12·2823	218·99
1089	274·27	0·2764	12·2049	205·40	1139	288·14	0·2784	12·2838	219·27
1090	274·55	0·2765	12·2065	205·68	1140	288·42	0·2784	12·2853	219·55
1091	274·83	0·2765	12·2081	205·96	1141	288·70	0·2785	12·2869	219·83
1092	275·10	0·2765	12·2097	206·23	1142	288·98	0·2785	12·2885	220·11
1093	275·38	0·2766	12·2113	206·51	1143	289·26	0·2785	12·2900	220·39
1094	275·65	0·2766	12·2129	206·78	1144	289·54	0·2786	12·2915	220·67
1095	275·93	0·2767	12·2145	207·06	1145	289·82	0·2786	12·2930	220·95
1096	276·21	0·2767	12·2161	207·34	1146	290·10	0·2787	12·2946	221·23
1097	276·49	0·2768	12·2177	207·62	1147	290·38	0·2287	12·2962	221·51
1098	276·76	0·2768	12·2193	207·89	1148	290·65	0·2787	12·2977	221·78
1099	277·04	0·2668	12·2209	208·17	1149	290·93	0·2788	12·2992	222·06
1100	277·32	0·2769	12·2225	208·45	1150	291·21	0·2788	12·3007	222·34
1101	277·60	0·2769	12·2241	208·73	1151	291·49	0·2789	12·3023	222·62
1102	277·87	0·2770	12·2257	209·00	1152	291·77	0·2789	12·3039	222·90
1103	278·15	0·2770	12·2273	209·28	1153	292·05	0·2789	12·3054	223·18
1104	278·42	0·2770	12·2289	209·55	1154	292·33	0·2790	12·3069	223·46
1105	278·70	0·2771	12·2305	209·83	1155	292·61	0·2790	12·3084	223·74
1106	278·98	0·2771	12·2321	210·11	1156	292·89	0·2790	12·3100	224·02
1107	279·26	0·2772	12·2337	210·39	1157	293·17	0·2791	12·3116	224·30
1108	279·53	0·2772	12·2353	210·66	1158	293·44	0·2791	12·3131	224·57
1109	279·81	0·2772	12·2369	210·94	1159	293·72	0·2791	12·3146	224·85
1110	280·09	0·2773	12·2384	211·22	1160	294·00	0·2792	12·3161	225·13
1111	280·37	0·2773	12·2400	211·50	1161	294·28	0·2792	12·3177	225·41
1112	280·65	0·2774	12·2416	211·78	1162	294·56	0·2793	12·3192	225·69
1113	280·92	0·2774	12·2432	212·05	1163	294·83	0·2793	12·3207	225·96
1114	281·20	0·2774	12·2448	212·33	1164	295·11	0·2793	12·3222	226·24
1115	281·48	0·2775	12·2463	212·61	1165	295·39	0·2794	12·3237	226·52
1116	281·76	0·2775	12·2479	212·89	1166	295·67	0·2794	12·3253	226·70
1117	282·03	0·2776	12·2495	213·16	1167	295·95	0·2794	12·3268	227·08
1118	282·31	0·2776	12·2511	213·44	1168	296·23	0·2795	12·3283	227·36
1119	282·58	0·2776	12·2527	213·71	1169	296·51	0·2795	12·3298	227·64
1120	282·86	0·2777	12·2542	213·99	1170	296·79	0·2795	12·3313	227·92
1121	283·14	0·2777	12·2558	214·27	1171	297·07	0·2796	12·3329	228·20
1122	283·42	0·2778	12·2574	214·55	1172	297·35	0·2796	12·3344	228·48
1123	283·69	0·2778	12·2590	214·82	1173	297·63	0·2797	12·3359	228·76
1124	283·97	0·2778	12·2605	215·10	1174	297·91	0·2797	12·3374	229·04
1125	284·25	0·2779	12·2620	215·38	1175	298·19	0.2797	12·3389	229·32
1126	284·53	0·2779	12·2636	215·66	1176	298·47	0·2798	12·3404	229·60
1127	284·81	0·2779	12·2652	215·94	1177	298·75	0·2798	12·3419	229·88
1128	285·08	0·2780	12·2668	216·21	1178	299·03	0·2798	12·3434	230·16
1129	285·36	0·2780	12·2683	216·49	1179	299·31	0·2799	12·3449	230·44
1130	285·64	0·2780	12·2698	216·77	1180	299·59	0·2799	12·3464	230·72

TABLE 1—*continued*

T°K	H	C_p	ψ	H_{15}	T°K	H	C_p	ψ	H_{15}
1181	299·87	0·2799	12·3479	231·00	1231	313·91	0·2816	12·4217	245·04
1182	300·15	0·2800	12·3494	231·28	1232	314·19	0·2817	12·4232	245·32
1183	300·43	0·2800	12·3509	231·56	1233	314·48	0·2817	12·4247	245·61
1184	300·71	0·2800	12·3524	231·84	1234	314·76	0·2817	12·4261	245·89
1185	300·99	0·2801	12·3539	232·12	1235	315·04	0·2818	12·4275	246·17
1186	301·27	0·2801	12·3554	232·40	1236	315·32	0·2818	12·4290	246·45
1187	301·55	0·2801	12·3569	232·68	1237	315·60	0·2818	12·4305	246·73
1188	301·83	0·2802	12·3584	232·96	1238	315·89	0·2819	12·4319	247·02
1189	302·11	0·2802	12·3599	233·24	1239	316·17	0·2819	12·4333	247·30
1190	302·39	0·2802	12·3614	233·52	1240	316·45	0·2819	12·4347	247·58
1191	302·67	0·2803	12·3629	233·80	1241	316·73	0·2820	12·4362	247·86
1192	302·95	0·2803	12·3644	234·08	1242	317·01	0·2820	12·4377	248·14
1193	303·23	0·2804	12·3659	234·36	1243	317·30	0·2820	12·4391	248·43
1194	303·51	0·2804	12·3674	234·64	1244	317·58	0·2820	12·4405	248·71
1195	303·79	0·2804	12·3688	234·92	1245	317·86	0·2821	12·4419	248·99
1196	304·07	0·2805	12·3703	235·20	1246	318·14	0·2821	12·4434	249·27
1197	304·35	0·2805	12·3718	235·48	1247	318·42	0·2821	12·4448	249·55
1198	304·63	0·2805	12·3733	235·76	1248	318·71	0·2822	12·4462	249·84
1199	304·91	0·2806	12·3748	236·04	1249	318·99	0·2822	12·4476	250·12
1200	305·19	0·2806	12·3762	236·32	1250	319·27	0·2822	12·4490	250·40
1201	305·47	0·2806	12·3777	236·60	1251	319·55	0·2823	12·4505	250·68
1202	305·75	0·2807	12·3792	236·88	1252	319·83	0·2823	12·4519	250·96
1203	306·04	0·2807	12·3807	237·17	1253	320·12	0·2823	12·4533	251·25
1204	306·32	0·2807	12·3822	237·45	1254	320·40	0·2824	12·4547	251·53
1205	306·60	0·2808	12·3836	237·73	1255	320·68	0·2824	12·4561	251·81
1206	306·88	0·2808	12·3851	238·01	1256	320·96	0·2824	12·4576	252·07
1207	307·16	0·2808	12·3866	238·29	1257	321·24	0·2825	12·4590	252·37
1208	307·44	0·2809	12·3881	238·57	1258	321·53	0·2825	12·4604	252·66
1209	307·72	0·2809	12·3896	238·85	1259	321·81	0·2825	12·4618	252·94
1210	308·00	0·2809	12·3910	239·13	1260	322·09	0·2825	12·4632	253·22
1211	308·28	0·2810	12·3925	239·41	1261	322·37	0·2826	12·4647	253·50
1212	308·56	0·2810	12·3940	239·69	1262	322·66	0·2826	12·4661	253·79
1213	308·85	0·2810	12·3955	239·98	1263	322·94	0·2826	12·4675	254·07
1214	309·13	0·2811	12·3969	240·26	1264	323·23	0·2827	12·4689	254·36
1215	309·41	0·2811	12·3983	240·54	1265	323·51	0·2827	12·4703	254·64
1216	309·69	0·2811	12·3998	240·82	1266	323·79	0·2827	12·4718	254·92
1217	309·97	0·2812	12·4013	241·10	1267	324·07	0·2828	12·4732	255·20
1218	310·26	0·2812	12·4028	241·39	1268	324·36	0·2828	12·4746	255·49
1219	310·54	0·2812	12·4042	241·67	1269	324·64	0·2828	12·4760	255·77
1220	310·82	0·2813	12·4056	241·95	1270	324·92	0·2829	12·4774	256·05
1221	311·10	0·2813	12·4071	242·23	1271	325·20	0·2829	12·4789	256·33
1222	311·38	0·2813	12·4086	242·51	1272	325·49	0·2829	12·4803	256·62
1223	311·66	0·2814	12·4101	242·79	1273	325·77	0·2830	12·4817	256·90
1224	311·94	0·2814	12·4115	243·07	1274	326·06	0·2830	12·4831	257·19
1225	312·22	0·2814	12·4129	243·35	1275	326·34	0·2830	12·4845	257·47
1226	312·50	0·2815	12·4144	243·63	1276	326·62	0·2830	12·4859	257·75
1227	312·78	0·2815	12·4159	243·91	1277	326·91	0·2831	12·5873	258·04
1228	313·07	0·2815	12·4174	244·20	1278	327·19	0·2831	12·4887	258·32
1229	313·35	0·2816	12·4188	244·48	1279	327·48	0·2831	12·4901	258·61
1230	313·63	0·2816	12·4202	244·76	1280	327·76	0·2832	12·4915	258·89

TABLE 1—*continued*

T°K	H	C_p	ψ	H_{15}	T°K	H	C_p	ψ	H_{15}
1281	328·04	0·2832	12·4929	259·17	1331	342·23	0·2847	12·5618	273·36
1282	328·32	0·2832	12·4943	259·45	1332	342·52	0·2847	12·5632	273·65
1283	328·61	0·2833	12·4957	259·74	1333	342·80	0·2848	12·5646	273·93
1284	328·89	0·2833	12·4971	260·02	1334	343·09	0·2848	12·5659	274·22
1285	329·17	0·2833	12·4985	260·30	1335	343·37	0·2848	12·5672	274·50
1286	329·45	0·2834	12·4999	260·58	1336	343·66	0·2849	12·5686	274·79
1287	329·74	0·2834	12·5013	260·87	1337	343·94	0·2849	12·5700	275·07
1288	330·02	0·2834	12·5027	261·15	1338	344·23	0·2849	12·5713	275·40
1289	330·31	0·2835	12·5041	261·44	1339	344·51	0·2850	12·5726	275·64
1290	330·59	0·2835	12·5055	261·72	1340	344·80	0·2850	12·5739	275·93
1291	330·87	0·2835	12·5069	262·00	1341	345·09	0·2850	12·5753	276·22
1292	331·16	0·2835	12·5083	262·29	1342	345·37	0·2850	12·5767	276·50
1293	331·44	0·2836	12·5097	262·57	1343	345·66	0·2851	12·5780	276·79
1294	331·73	0·2836	12·5111	262·86	1344	345·94	0·2851	12·5793	277·07
1295	332·01	0·2836	12·5134	263·14	1345	346·23	0·2851	12·5806	277·36
1296	332·29	0·2837	12·5138	263·42	1346	346·51	0·2851	12·5820	277·64
1297	332·57	0·2837	12·5152	263·60	1347	346·80	0·2852	12·5834	277·93
1298	332·86	0·2837	12·5166	263·99	1348	347·08	0·2852	12·5847	278·21
1299	333·14	0·2838	12·5180	264·27	1349	347·37	0·2852	12·5860	278·50
1300	333·42	0·2838	12·5193	264·55	1350	347·65	0·2853	12·5873	278·78
1301	333·70	0·2838	12·5207	264·83	1351	347·94	0·2853	12·5887	279·07
1302	333·99	0·2839	12·5221	265·12	1352	348·22	0·2853	12·5901	279·35
1303	334·27	0·2839	12·5235	265·40	1353	348·51	0·2853	12·5914	279·64
1304	334·56	0·2839	12·5249	265·69	1354	348·79	0·2854	12·5927	279·92
1305	334·84	0·2839	12·5262	265·97	1355	349·08	0·2854	12·5940	280·21
1306	335·12	0·2840	12·5276	266·25	1356	349·37	0·2854	12·5954	280·50
1307	335·41	0·2840	12·5290	266·54	1357	349·65	0·2855	12·5968	280·78
1308	335·69	0·2840	12·5304	266·82	1358	349·94	0·2855	12·5981	281·07
1309	335·98	0·2840	12·5318	267·11	1359	350·22	0·2855	12·5994	281·35
1310	336·26	0·2841	12·5331	267·39	1360	350·51	0·2855	12·6007	281·64
1311	336·54	0·2841	12·5345	267·67	1361	350·80	0·2856	12·6021	281·93
1312	336·83	0·2841	12·5359	267·96	1362	351·08	0·2856	12·6034	282·21
1313	337·11	0·2842	12·5373	268·24	1363	351·37	0·2856	12·6047	282·50
1314	337·40	0·2842	12·5387	268·53	1364	351·65	0·2857	12·6060	282·78
1315	337·68	0·2842	12·5400	268·81	1365	351·94	0·2857	12·6073	283·07
1316	337·96	0·2843	12·5414	269·09	1366	352·23	0·2857	12·6087	283·36
1317	338·25	0·2843	12·5428	269·38	1367	352·51	0·2857	12·6100	283·64
1318	338·53	0·2843	12·5442	269·66	1368	352·80	0·2858	12·6113	283·93
1319	338·82	0·2844	12·5455	269·95	1369	353·08	0·2858	12·6126	284·21
1320	339·10	0·2844	12·5468	270·23	1370	353·37	0·2858	12·6139	284·50
1321	339·38	0·2844	12·5482	270·51	1371	353·66	0·2859	12·6153	284·79
1322	339·67	0·2845	12·5496	270·80	1372	353·94	0·2859	12·6166	285·07
1323	339·95	0·2845	12·5510	271·08	1373	354·23	0·2859	12·6179	285·36
1324	340·24	0·2845	12·5523	271·37	1374	354·51	0·2859	12·6192	285·64
1325	340·52	0·2845	12·5536	271·65	1375	354·80	0·2860	12·6205	285·93
1326	340·81	0·2846	12·5550	271·94	1376	355·09	0·2860	12·6219	286·22
1327	341·09	0·2946	12·5564	272·22	1377	355·37	0·2860	12·6232	286·50
1328	341·38	0·2846	12·5578	272·51	1378	355·66	0·2860	12·6245	286·79
1329	341·64	0·2847	12·5591	272·77	1379	355·94	0·2861	12·6258	287·07
1330	341·95	0·2847	12·5604	273·08	1380	356·23	0·2861	12·6271	287·36

TABLE 1—*continued*

T°K	H	C_p	ψ	H_{15}	T°K	H	C_p	ψ	H_{15}
1381	356·52	0·2861	12·6285	287·65	1431	370·85	0·2875	12·6931	301·98
1382	356·80	0·2862	12·6298	287·93	1432	371·14	0·2875	12·6944	302·27
1383	357·09	0·2862	12·6311	288·22	1433	371·42	0·2875	12·6957	302·55
1384	357·37	0·2862	12·6324	288·50	1434	371·71	0·2875	12·6970	302·84
1385	357·66	0·2862	12·6337	288·79	1435	372·00	0·2876	12·6982	303·13
1386	357·95	0·2863	12·6350	289·08	1436	372·29	0·2876	12·6995	303·42
1387	358·23	0·2863	12·6363	289·36	1437	372·58	0·2876	12·7008	303·71
1388	358·52	0·2863	12·6376	289·65	1438	372·86	0·2876	12·7021	303·99
1389	358·80	0·2864	12·6389	289·93	1439	373·15	0·2877	12·7033	304·28
1390	359·09	0·2864	12·6402	290·22	1440	373·44	0·2877	12·7045	304·57
1391	359·38	0·2864	12·6415	290·51	1441	373·73	0·2877	12·7058	304·86
1392	359·66	0·2864	12·6428	290·79	1442	374·02	0·2877	12·7071	305·15
1393	359·95	0·2865	12·6441	291·08	1443	374·30	0·2878	12·7084	305·43
1394	360·23	0·2865	12·6454	281·36	1444	374·59	0·2878	12·7096	305·72
1395	360·52	0·2865	12·6467	291·65	1445	374·88	0·2878	12·7108	306·01
1396	360·81	0·2865	12·6480	291·94	1446	375·17	0·2878	12·7121	306·30
1397	361·09	0·2866	12·6493	292·22	1447	375·46	0·2879	12·7134	306·59
1398	361·38	0·2866	12·6506	292·51	1448	375·74	0·2879	12·7147	306·87
1399	361·66	0·2866	12·6519	292·79	1449	376·03	0·2879	12·7159	307·16
1400	361·95	0·2867	12·6532	293·08	1450	376·32	0·2880	12·7171	307·45
1401	362·24	0·2867	12·6545	293·37	1451	376·61	0·2880	12·7184	307·74
1402	362·52	0·2867	12·6558	293·65	1452	376·90	0·2880	12·7197	308·03
1403	362·81	0·2867	12·6571	293·94	1453	377·18	0·2880	12·7210	308·31
1404	363·09	0·2868	12·6584	294·22	1454	377·47	0·2881	12·7222	308·60
1405	363·38	0·2868	12·6597	294·51	1455	377·76	0·2881	12·7234	308·89
1406	363·67	0·2868	12·6610	294·80	1456	378·05	0·2881	12·7247	309·18
1407	363·96	0·2868	12·6623	295·09	1457	378·34	0·2881	12·7260	309·47
1408	364·24	0·2869	12·6636	295·37	1458	378·62	0·2882	12·7273	309·75
1409	364·53	0·2869	12·6649	295·66	1459	378·91	0·2882	12·7285	310·04
1410	364·82	0·2869	12·6662	295·95	1460	379·20	0·2882	12·7297	310·33
1411	365·11	0·2869	12·6675	296·24	1461	379·49	0·2882	12·7310	310·62
1412	365·40	0·2870	12·6688	296·53	1462	379·78	0·2883	12·7323	310·91
1413	365·68	0·2870	12·6701	296·81	1463	380·06	0·2883	12·7335	311·19
1414	365·97	0·2870	12·6714	297·10	1464	380·35	0·2883	12·7347	311·48
1415	366·26	0·2870	12·6726	297·39	1465	380·64	0·2883	12·7359	311·77
1416	366·55	0·2871	12·6739	297·68	1466	380·93	0·2884	12·7372	312·06
1417	366·83	0·2871	12·6752	297·96	1467	381·22	0·2884	12·7385	312·35
1418	367·12	0·2871	12·6765	298·25	1468	381·50	0·2884	12·7397	312·63
1419	367·40	0·2871	12·6778	298·53	1469	381·79	0·2884	12·7409	312·92
1420	367·69	0·2872	12·6790	298·82	1470	382·08	0·2885	12·7421	313·21
1421	367·98	0·2872	12·6803	299·11	1471	382·37	0·2885	12·7434	313·50
1422	368·26	0·2872	12·6816	299·39	1472	382·66	0·2885	12·7447	313·79
1423	368·55	0·2872	12·6829	299·68	1473	382·95	0·2885	12·7459	314·08
1424	368·83	0·2873	12·6842	299·96	1474	383·24	0·2886	12·7471	314·37
1425	369·12	0·2873	12·6854	300·25	1475	383·53	0·2886	12·7483	314·66
1426	369·41	0·2873	12·6867	300·54	1476	383·82	0·2886	12·7496	314·95
1427	369·70	0·2874	12·6880	300·83	1477	384·11	0·2886	12·7509	315·24
1428	369·98	0·2874	12·6893	301·11	1478	384·39	0·2887	12·7521	315·52
1429	370·27	0·2874	12·6906	301·40	1479	384·68	0·2887	12·7533	315·81
1430	370·56	0·2874	12·6918	301·69	1480	384·97	0·2887	12·7545	316·10

TABLE 1—*continued*

T°K	H	C_p	ψ	H_{15}	T°K	H	C_p	ψ	H_{15}
1481	385·26	0·2887	12·7558	316·39	1531	399·73	0·2899	12·8166	330·86
1482	385·55	0·2888	12·7571	316·68	1532	400·02	0·2900	12·8178	331·15
1483	385·84	0·2888	12·7583	316·97	1533	400·31	0·2900	12·8190	331·44
1484	386·13	0·2888	12·7595	317·26	1534	400·60	0·2900	12·8202	331·73
1485	386·42	0·2888	12·7607	317·55	1535	400·89	0·2900	12·8214	332·02
1486	386·71	0·2889	12·7620	317·84	1536	401·18	0·2901	12·8226	332·31
1487	387·00	0·2889	12·7633	318·13	1537	401·47	0·2901	12·8238	332·60
1488	387·28	0·2889	12·7645	318·41	1538	401·76	0·2901	12·8250	332·89
1489	387·57	0·2889	12·7657	318·70	1539	402·05	0·2901	12·8262	333·18
1490	387·86	0·2890	12·7669	318·99	1540	402·34	0·2901	12·8274	333·47
1491	388·15	0·2890	12·7682	319·28	1541	402·63	0·2902	12·8286	333·76
1492	388·44	0·2890	12·7694	319·57	1542	402·92	0·2902	12·8298	334·05
1493	388·72	0·2890	12·7706	319·85	1543	403·21	0·2902	12·8310	334·34
1494	389·01	0·2891	12·7718	320·14	1544	403·50	0·2902	12·8322	334·63
1495	389·30	0·2891	12·7730	320·43	1545	403·79	0·2903	12·8334	334·92
1496	389·59	0·2891	12·7743	320·72	1546	404·08	0·2903	12·8346	335·21
1497	389·88	0·2891	12·7755	321·01	1547	404·37	0·2903	12·8358	335·50
1498	390·17	0·2892	12·7767	321·30	1548	404·66	0·2903	12·8370	335·79
1499	390·46	0·2892	12·7779	321·59	1549	404·95	0·2904	12·8382	336·08
1500	390·75	0·2892	12·7791	321·88	1550	405·24	0·2904	12·8394	336·37
1501	391·04	0·2892	12·7804	322·17	1551	405·53	0·2904	12·8406	336·66
1502	391·33	0·2893	12·7816	322·46	1552	405·82	0·2904	12·8418	336·95
1503	391·61	0·2893	12·7828	322·74	1553	406·11	0·2905	12·8430	337·24
1504	391·90	0·2883	12·7840	323·03	1554	406·40	0·2905	12·8442	337·53
1505	392·19	0·2893	12·7852	323·32	1555	406·69	0·2905	12·8453	337·82
1506	392·48	0·2894	12·7865	323·61	1556	406·98	0·2905	12·8465	338·11
1507	392·77	0·2894	12·7877	323·90	1557	407·27	0·2905	12·8477	338·40
1508	393·06	0·2894	12·7889	324·19	1558	407·56	0·2906	12·8489	338·69
1509	393·35	0·2894	12·7901	324·48	1559	407·85	0·2906	12·8501	338·98
1510	393·64	0·2895	12·7913	324·77	1560	408·14	0·2906	12·8512	339·27
1511	393·93	0·2895	12·7926	325·06	1561	408·43	0·2906	12·8524	339·56
1512	394·22	0·2895	12·7938	325·35	1562	408·72	0·2907	12·8536	339·85
1513	394·51	0·2895	12·7950	325·64	1563	409·02	0·2907	12·8548	340·15
1514	394·80	0·2895	12·7962	325·93	1564	409·31	0·2907	12·8560	340·44
1515	395·09	0·2896	12·7974	326·22	1565	409·60	0·2907	12·8571	340·73
1516	395·38	0·2896	12·7986	326·51	1566	409·89	0·2907	12·8583	341·02
1517	395·67	0·2896	12·7998	326·80	1567	410·18	0·2908	12·8595	341·31
1518	395·96	0·2896	12·8010	327·09	1568	410·47	0·2908	12·8607	341·60
1519	396·25	0·2897	12·8022	327·38	1569	410·76	0·2908	12·8619	341·89
1520	396·54	0·2897	12·8034	327·67	1570	411·05	0·2908	12·8630	342·18
1521	396·83	0·2897	12·8046	327·96	1571	411·34	0·2909	12·8642	342·47
1522	397·12	0·2897	12·8058	328·25	1572	411·63	0·2909	12·8654	342·76
1523	397·41	0·2898	12·8070	328·54	1573	411·93	0·2909	12·8666	343·06
1524	397·70	0·2898	12·8082	328·83	1574	412·22	0·2909	12·8677	343·35
1525	397·99	0·2898	12·8094	329·12	1575	412·51	0·2910	12·8688	343·64
1526	398·28	0·2898	12·8106	329·41	1576	412·80	0·2910	12·8700	343·93
1527	398·57	0·2899	12·8118	329·70	1577	413·09	0·2910	12·8712	344·22
1528	398·86	0·2899	12·8130	329·99	1578	413·38	0·2910	12·8724	344·51
1529	399·15	0·2899	12·8142	330·28	1579	413·67	0·2910	12·8735	344·80
1530	399·44	0·2899	12·8154	330·57	1580	413·96	0·2911	12·8746	345·09

TABLE 1—*continued*

T°K	H	C_p	ψ	H_{15}	T°K	H	C_p	ψ	H_{15}
1581	414·25	0·2911	12·8758	345·38	1631	428·84	0·2922	12·9334	359·97
1582	414·54	0·2911	12·8770	345·67	1632	429·13	0·2922	12·9346	360·26
1583	414·84	0·2911	12·8782	345·97	1633	429·43	0·2922	12·9357	360·56
1584	415·13	0·2912	12·8793	346·26	1634	429·72	0·2922	12·9368	360·85
1585	415·42	0·2912	12·8804	346·55	1635	430·01	0·2922	12·9379	361·14
1586	415·71	0·2912	12·8816	346·84	1636	430·30	0·2923	12·9391	361·43
1587	416·00	0·2912	12·8828	347·13	1637	430·59	0·2923	12·9402	361·72
1588	416·29	0·2912	12·8840	347·42	1638	430·89	0·2923	12·9413	362·02
1589	416·58	0·2913	12·8851	347·71	1639	431·18	0·2923	12·9424	362·31
1590	416·87	0·2913	12·8862	348·00	1640	431·47	0·2923	12·9435	362·60
1591	417·16	0·2913	12·8874	348·29	1641	431·76	0·2924	12·9447	362·89
1592	417·45	0·2913	12·8886	348·58	1642	432·05	0·2924	12·9458	363·18
1593	417·75	0·2914	12·8898	348·88	1643	432·35	0·2924	12·9469	363·48
1594	418·04	0·2914	12·8909	349·17	1644	432·64	0·2924	12·9480	363·77
1595	418·33	0·2914	12·8920	349·46	1645	432·93	0·2925	12·9491	364·06
1596	418·62	0·2914	12·8932	349·75	1646	433·22	0·2925	12·9503	364·35
1597	418·91	0·2914	12·8944	350·04	1647	433·51	0·2925	12·9514	364·64
1598	419·21	0·2915	12·8956	350·34	1648	433·81	0·2925	12·9525	364·94
1599	419·50	0·2915	12·8967	350·63	1649	434·10	0·2925	12·9536	365·23
1600	419·79	0·2915	12·8978	350·92	1650	434·39	0·2926	12·9547	365·52
1601	420·08	0·2915	12·8990	351·21	1651	434·68	0·2926	12·9559	365·81
1602	420·37	0·2916	12·9002	351·50	1652	434·98	0·2926	12·9570	366·11
1603	420·67	0·2916	12·9014	351·80	1653	435·27	0·2926	12·9581	366·40
1604	420·96	0·2916	12·9025	352·09	1654	435·57	0·2926	12·9592	366·70
1605	421·25	0·2916	12·9036	352·38	1655	435·86	0·2927	12·9603	366·99
1606	421·54	0·2916	12·9048	352·67	1656	436·15	0·2927	12·9615	367·28
1607	421·83	0·2917	12·9060	352·96	1657	436·44	0·2927	12·9626	367·57
1608	422·13	0·2917	12·9072	353·26	1658	436·74	0·2927	12·9637	367·87
1609	422·42	0·2917	12·9083	353·55	1659	437·03	0·2927	12·9648	368·16
1610	422·71	0·2917	12·9094	353·84	1660	437·32	0·2928	12·9659	368·45
1611	423·00	0·2918	12·9106	354·13	1661	437·61	0·2928	12·9671	368·74
1612	423·29	0·2918	12·9118	354·42	1662	437·90	0·2928	12·9682	369·03
1613	423·59	0·2918	12·9129	354·72	1663	438·20	0·2928	12·9693	369·33
1614	423·88	0·2918	12·9140	355·01	1664	438·49	0·2928	12·9704	369·62
1615	424·17	0·2918	12·9151	355·30	1665	438·78	0·2929	12·9715	369·91
1616	424·46	0·2919	12·9163	355·59	1666	439·07	0·2929	12·9727	370·20
1617	424·75	0·2919	12·9175	355·88	1667	439·36	0·2929	12·9738	370·49
1618	425·05	0·2919	12·9186	356·18	1668	439·66	0·2929	12·9749	370·79
1619	425·34	0·2919	12·9197	356·47	1669	439·95	0·2929	12·9760	371·08
1620	425·63	0·2919	12·9208	356·76	1670	440·24	0·2930	12·9771	371·37
1621	425·92	0·2920	12·9220	357·05	1671	440·53	0·2930	12·9783	371·66
1622	426·21	0·2920	12·9232	357·34	1672	440·83	0·2930	12·9794	371·96
1623	426·51	0·2920	12·9243	357·64	1673	441·12	0·2930	12·9805	372·25
1624	426·80	0·2920	12·9254	357·93	1674	441·42	0·2930	12·9816	372·55
1625	427·09	0·2920	12·9265	358·22	1675	441·71	0·2931	12·9827	372·84
1626	427·38	0·2921	12·9277	358·51	1676	442·00	0·2931	12·9839	373·13
1627	427·67	0·2921	12·9289	358·80	1677	442·29	0·2931	12·9850	373·42
1628	427·97	0·2921	12·9300	359·10	1678	442·59	0·2931	12·9861	373·72
1629	428·26	0·2921	12·9311	359·39	1679	442·88	0·2931	12·9872	374·01
1630	428·55	0·2921	12·9322	359·68	1680	443·17	0·2932	12·9883	374·30

TABLE 1—*continued*

$T°K$	H	C_p	ψ	H_{15}	$T°K$	H	C_p	ψ	H_{15}
1681	443·46	0·2932	12·9894	374·59	1731	458·15	0·2941	13·0439	389·28
1682	443·76	0·2932	12·9905	374·89	1732	458·45	0·2942	13·0450	389·58
1683	444·05	0·2932	12·9916	375·18	1733	458·74	0·2942	13·0461	389·87
1684	444·34	0·2932	12·9927	375·47	1734	459·04	0·2942	13·0472	390·17
1685	444·64	0·2933	12·9938	375·77	1735	459·33	0·2942	13·0482	390·46
1686	444·93	0·2933	12·9949	376·06	1736	459·62	0·2942	13·0493	390·75
1687	445·23	0·2933	12·9960	376·36	1737	459·92	0·2942	13·0504	391·05
1688	445·52	0·2933	12·9971	376·65	1738	460·21	0·2943	13·0515	391·34
1689	445·82	0·2933	12·9982	376·95	1739	460·51	0·2943	13·0526	391·64
1690	446·11	0·2934	12·9993	377·24	1740	460·80	0·2943	13·0536	391·93
1691	446·40	0·2934	13·0004	377·53	1741	461·09	0·2943	13·0547	392·22
1692	446·69	0·2934	13·0015	377·82	1742	461·39	0·2943	13·0558	392·52
1693	446·99	0·2934	13·0026	378·12	1743	461·68	0·2944	13·0569	392·81
1694	447·28	0·2934	13·0037	378·41	1744	461·98	0·2944	13·0579	393·11
1695	447·57	0·2935	13·0048	378·70	1745	462·27	0·2944	13·0589	393·40
1696	447·86	0·2935	13·0059	378·99	1746	462·57	0·2944	13·0600	393·70
1697	448·16	0·2935	13·0070	379·29	1747	462·86	0·2944	13·0611	393·99
1698	448·45	0·2935	13·0081	379·58	1748	463·16	0·2945	13·0622	394·29
1699	448·75	0·2935	13·0092	379·88	1749	463·45	0·2945	13·0632	394·58
1700	449·04	0·2936	13·0103	380·17	1750	463·75	0·2945	13·0642	394·88
1701	449·33	0·2936	13·0114	380·46	1751	464·04	0·2945	13·0653	395·17
1702	449·63	0·2936	13·0125	380·76	1752	464·34	0·2945	13·0664	395·47
1703	449·92	0·2936	13·0136	381·05	1753	464·63	0·2945	13·0675	395·76
1704	450·22	0·2936	13·0147	381·35	1754	464·93	0·2946	13·0685	396·06
1705	450·51	0·2937	13·0158	381·64	1755	465·22	0·2946	13·0695	396·35
1706	450·80	0·2937	13·0169	381·93	1756	465·51	0·2946	13·0706	396·64
1707	451·10	0·2937	13·0180	382·23	1757	465·81	0·2946	13·0717	396·94
1708	451·39	0·2937	13·0191	382·52	1758	466·10	0·2946	13·0728	397·23
1709	451·69	0·2937	13·0202	382·82	1759	466·40	0·2946	13·0738	397·53
1710	451·98	0·2938	13·0212	383·11	1760	466·69	0·2947	13·0748	397·82
1711	452·27	0·2938	13·0223	383·40	1761	466·99	0·2947	13·0759	398·12
1712	452·59	0·2938	13·0234	383·70	1762	467·28	0·2947	13·0770	398·41
1713	452·86	0·2938	13·0245	383·99	1763	467·58	0·2947	13·0781	398·71
1714	453·16	0·2938	13·0256	384·29	1764	467·87	0·2947	13·0791	399·00
1715	453·45	0·2938	13·0266	384·58	1765	468·17	0·2948	13·0801	399·30
1716	453·74	0·2939	13·0277	384·87	1766	468·46	0·2948	13·0812	399·59
1717	454·04	0·2939	13·0288	385·17	1767	468·76	0·2948	13·0823	399·89
1718	454·33	0·2939	13·0299	385·46	1768	469·05	0·2948	13·0834	400·18
1719	454·63	0·2939	13·0310	385·76	1769	469·35	0·2948	13·0844	400·48
1720	454·92	0·2939	13·0320	386·05	1770	469·64	0·2948	13·0854	400·77
1721	455·21	0·2940	12·0331	386·34	1771	469·93	0·2949	13·0865	401·06
1722	455·51	0·2940	13·0342	386·64	1772	470·23	0·2949	13·0876	401·36
1723	455·80	0·2940	13·0353	386·93	1773	470·52	0·2949	13·0887	401·65
1724	456·10	0·2940	13·0364	387·23	1774	470·82	0·2949	13·0897	401·95
1725	456·39	0·2940	13·0374	387·52	1775	471·11	0·2949	13·0907	402·24
1726	456·68	0·2940	13·0385	387·81	1776	471·41	0·2949	13·0918	402·54
1727	456·98	0·2941	13·0396	388·11	1777	471·70	0·2950	13·0929	402·83
1728	457·27	0·2941	13·0407	388·40	1778	472·00	0·2950	13·0940	403·13
1729	457·57	0·2941	13·0418	388·70	1779	472·29	0·2950	13·0950	403·42
1730	457·86	0·2941	13·0428	388·99	1780	472·59	0·2950	13·0960	403·72

TABLE 1—*continued*

T°K	H	C_p	ψ	H_{15}	T°K	H	C_p	ψ	H_{15}
1781	472·88	0·2950	13·0971	404·01	1831	487·65	0·2959	13·1488	418·78
1782	473·18	0·2950	13·0982	404·31	1832	487·95	0·2960	13·1498	419·08
1783	473·47	0·2951	13·0993	404·60	1833	488·24	0·2960	13·1509	419·37
1784	473·77	0·2951	13·1003	404·90	1834	488·54	0·2960	13·1519	419·67
1785	474·06	0·2951	13·1013	405·19	1835	488·84	0·2960	13·1529	419·97
1786	474·36	0·2951	13·1024	405·49	1836	489·13	0·2960	13·1539	420·26
1787	474·65	0·2951	13·1035	405·78	1837	489·43	0·2960	13·1550	420·56
1788	474·95	0·2951	13·1045	406·08	1838	489·72	0·2961	13·1560	420·85
1789	475·24	0·2952	13·1055	406·37	1839	490·02	0·2961	13·1570	421·15
1790	475·54	0·2952	13·1065	406·67	1840	490·32	0·2961	13·1580	421·45
1791	475·83	0·2952	13·1076	406·96	1841	490·61	0·2961	13·1590	421·74
1792	476·13	0·2952	13·1087	407·26	1842	490·91	0·2961	13·1601	422·04
1793	476·42	0·2952	13·1097	407·55	1843	491·21	0·2931	13·1611	422·34
1794	476·72	0·2952	13·1107	407·85	1844	491·50	0·2962	13·1621	422·63
1795	477·01	0·2953	13·1117	408·14	1845	491·80	0·2962	13·1631	422·93
1796	477·31	0·2953	13·1128	408·44	1846	492·10	0·2962	13·1641	423·23
1797	477·60	0·2953	13·1139	408·73	1847	492·39	0·2962	13·1652	423·52
1798	477·90	0·2953	13·1149	409·03	1848	492·69	0·2962	13·1662	423·82
1799	478·19	0·2953	13·1159	409·32	1849	492·98	0·2962	13·1672	424·11
1800	478·49	0·2954	13·1169	409·62	1850	493·28	0·2963	13·1682	424·41
1801	478·78	0·2954	13·1180	409·91	1851	493·58	0·2963	13·1692	424·71
1802	479·08	0·2954	13·1190	410·21	1852	493·87	0·2963	13·1702	425·00
1803	479·37	0·2954	13·1200	410·50	1853	494·17	0·2963	13·1712	425·30
1804	479·67	0·2954	13·1210	410·80	1854	494·47	0·2963	13·1723	425·60
1805	479·96	0·2955	13·1221	411·09	1855	494·76	0·2963	13·1733	425·89
1806	480·26	0·2955	13·1231	411·39	1856	495·06	0·2964	13·1743	426·19
1807	480·55	0·2955	13·1241	411·68	1857	495·36	0·2964	13·1753	426·49
1808	480·85	0·2955	13·1252	411·98	1858	495·65	0·2964	13·1763	426·78
1809	481·15	0·2955	13·1262	412·28	1859	495·95	0·2964	13·1773	427·08
1810	481·44	0·2956	13·1272	412·57	1860	496·25	0·2964	13·1783	427·38
1811	481·74	0·2956	13·1283	412·87	1861	496·54	0·2964	13·1793	427·67
1812	482·03	0·2956	13·1293	413·16	1862	496·84	0·2965	13·1803	427·97
1813	482·33	0·2956	13·1303	413·46	1863	497·14	0·2965	13·1813	428·27
1814	482·62	0·2956	13·1313	413·75	1864	497·43	0·2965	13·1823	428·56
1815	482·92	0·2957	13·1324	414·05	1865	497·73	0·2965	13·1834	428·86
1816	483·21	0·2957	13·1334	414·34	1866	498·02	0·2965	13·1844	429·15
1817	483·51	0·2957	13·1344	414·64	1867	498·32	0·2965	13·1854	429·45
1818	483·81	0·2957	13·1355	414·94	1868	498·62	0·2966	13·1864	429·75
1819	484·10	0·2957	13·1365	415·23	1869	498·91	0·2966	13·1874	430·04
1820	484·40	0·2958	13·1375	415·53	1870	499·21	0·2966	13·1884	430·34
1821	484·69	0·2958	13·1386	415·82	1871	499·51	0·2966	13·1894	430·64
1822	484·99	0·2958	13·1396	416·12	1872	499·80	0·2966	13·1904	430·93
1823	485·28	0·2958	13·1406	416·41	1873	500·10	0·2966	13·1914	431·23
1824	485·58	0·2958	13·1416	416·71	1874	500·40	0·2967	13·1924	431·53
1825	485·87	0·2958	13·1427	417·00	1875	500·69	0·2967	13·1934	431·82
1826	486·17	0·2959	13·1437	417·30	1876	500·99	0·2967	13·1944	432·12
1827	486·47	0·2959	13·1447	417·60	1877	501·29	0·2967	13·1954	432·42
1828	486·76	0·2959	13·1457	417·89	1878	501·58	0·2967	13·1964	432·71
1829	487·06	0·2959	13·1468	418·19	1879	501·88	0·2967	13·1974	433·01
1830	487·36	0·2959	13·1478	418·49	1880	502·18	0·2968	13·1984	433·31

TABLE 1—*continued*

T°K	H	C_p	ψ	H_{15}	T°K	H	C_p	ψ	H_{15}
1881	502·47	0·2968	13·1994	433·60	1931	517·33	0·2976	13·2488	448·46
1882	502·77	0·2968	13·2004	433·90	1932	517·63	0·2976	13·2498	448·76
1883	503·07	0·2968	13·2014	434·20	1933	517·93	0·2976	13·2508	449·06
1884	503·36	0·2968	13·2024	434·49	1934	518·23	0·2976	13·2517	449·36
1885	503·66	0·2968	13·2034	434·79	1935	518·52	0·2976	13·2527	449·65
1886	503·96	0·2969	13·2044	435·09	1936	518·82	0·2976	13·2537	449·95
1887	504·25	0·2969	13·2054	435·38	1937	519·12	0·2977	13·2547	450·25
1888	504·55	0·2969	13·2064	435·68	1938	519·42	0·2977	13·2556	450·55
1889	504·85	0·2969	13·2074	435·98	1939	519·71	0·2977	13·2566	450·84
1890	505·15	0·2969	13·2084	436·28	1940	520·01	0·2977	13·2576	451·14
1891	505·44	0·2969	13·2094	436·57	1941	520·31	0·2977	13·2585	451·44
1892	505·74	0·2970	13·2104	436·87	1942	520·61	0·2977	13·2595	451·74
1893	506·04	0·2970	13·2114	437·17	1943	520·90	0·2978	13·2605	452·03
1894	506·33	0·2970	13·2124	437·46	1944	521·20	0·2978	13·2615	452·33
1895	506·63	0·2970	13·2134	437·76	1945	521·50	0·2978	13·2624	452·63
1896	506·93	0·2970	13·2144	438·06	1946	521·80	0·2978	13·2634	452·93
1897	507·22	0·2970	13·2154	438·35	1947	522·09	0·2978	13·2644	453·22
1898	507·52	0·2970	13·2164	438·65	1948	522·39	0·2978	13·2653	453·52
1899	507·82	0·2971	13·2174	438·95	1949	522·69	0·2978	13·2663	453·82
1900	508·12	0·2971	13·2183	439·25	1950	522·99	0·2979	13·2673	454·12
1901	508·41	0·2971	13·2193	439·54	1951	523·28	0·2979	13·2682	454·41
1902	508·71	0·2971	13·2203	439·84	1952	523·58	0·2979	13·2692	454·71
1903	509·01	0·2971	13·2213	440·14	1953	523·88	0·2979	13·2702	455·01
1904	509·30	0·2971	13·2223	440·43	1954	524·18	0·2979	13·2711	455·31
1905	509·60	0·2972	13·2233	440·73	1955	524·48	0·2979	13·2721	455·61
1906	509·90	0·2972	13·2243	441·03	1956	524·77	0·2980	13·2730	455·90
1907	510·20	0·2972	13·2253	441·33	1957	525·07	0·2980	13·2740	456·20
1908	510·49	0·2972	13·2263	441·62	1958	525·37	0·2980	13·2750	456·50
1909	510·79	0·2972	13·2272	441·92	1959	525·67	0·2980	13·2759	456·80
1910	511·09	0·2972	13·2282	442·22	1960	525·97	0·2980	13·2769	457·10
1911	511·39	0·2973	13·2292	442·52	1961	526·26	0·2980	13·2778	457·39
1912	511·68	0·2973	13·2302	442·81	1962	526·56	0·2980	13·2788	457·69
1913	511·98	0·2973	13·2312	443·11	1963	526·86	0·2981	13·2798	457·99
1914	512·28	0·2973	13·2322	443·41	1964	527·16	0·2981	13·2807	458·29
1915	512·58	0·2973	13·2332	443·71	1965	527·46	0·2981	13·2817	458·59
1916	512·87	0·2973	13·2341	444·00	1966	527·75	0·2981	13·2826	458·88
1917	513·17	0·2974	13·2351	444·30	1967	528·05	0·2981	13·2836	459·18
1918	513·47	0·2974	13·2361	444·60	1968	528·35	0·2981	13·2846	459·48
1919	513·77	0·2974	13·2371	444·90	1969	528·65	0·2981	13·2855	459·78
1920	514·06	0·2974	13·2381	445·19	1970	528·95	0·2982	13·2865	460·08
1921	514·36	0·2974	13·2390	445·49	1971	529·24	0·2982	13·2874	460·37
1922	514·66	0·2974	13·2400	445·79	1972	529·54	0·2982	13·2884	460·67
1923	514·95	0·2974	13·2410	446·08	1973	529·84	0·2982	13·2894	460·97
1924	515·25	0·2975	13·2420	446·38	1974	530·14	0·2982	13·2903	461·27
1925	515·55	0·2975	13·2430	446·68	1975	530·44	0·2982	13·2913	461·57
1926	515·85	0·2975	13·2439	446·98	1976	530·73	0·2982	13·2922	461·86
1927	516·14	0·2975	13·2449	447·27	1977	531·03	0·2983	13·2932	462·16
1928	516·44	0·2975	13·2459	447·57	1978	531·33	0·2983	13·2941	462·46
1929	516·74	0·2975	13·2469	447·87	1979	531·63	0·2983	13·2951	462·76
1930	517·04	0·2975	13·2478	448·17	1980	531·93	0·2983	13·2960	463·06

TABLE 1—*continued*

T°K	H	C_p	ψ	H_{15}	T°K	H	C_p	ψ	H_{15}
1981	532·22	0·2983	13·2970	463·35	1991	535·21	0·2985	13·3065	466·34
1982	532·52	0·2983	13·2980	463·65	1992	535·50	0·2985	13·3075	466·63
1983	532·82	0·2984	13·2989	463·95	1993	535·80	0·2985	13·3084	466·93
1984	533·12	0·2984	13·2999	464·25	1994	536·10	0·2985	13·3094	467·23
1985	533·42	0·2984	13·3008	464·55	1995	536·40	0·2985	13·3103	467·53
1986	533·72	0·2984	13·3018	464·85	1996	536·70	0·2985	13·3113	467·83
1987	534·01	0·2984	13·3027	465·14	1997	537·00	0·2986	13·3122	468·13
1988	534·31	0·2984	13·3037	465·44	1998	537·29	0·2986	13·3132	468·42
1989	534·61	0·2984	13·3046	465·74	1999	537·59	0·2986	13·3141	468·72
1990	534·91	0·2985	13·3056	466·04	2000	537·89	0·2986	13·3151	469·02

TABLE 2

Total Heat Ω Functions†*

$$H_F = H_{air} + \Sigma \bar{j}_F \Omega_j ; \quad H_m = H_{air} + \Sigma \bar{j}_m \Omega_j ,$$

where H_{air} = total heat of dry air at temperature T°K

$\bar{j}_F$ = CH_4, C_2H_6, etc., content of fuel by weight

$\bar{j}_m$ = CH_4, C_2H_6, etc., content of medium by weight

T°K	Methane $\Omega(CH_4)$	Ethane $\Omega(C_2H_6)$	Propane $\Omega(C_3H_8)$	n-Butane $\Omega(C_4H_{10})$	n-Pentane $\Omega(C_5H_{12})$	Hydrogen $\Omega(H_2)$	Carbon Monoxide $\Omega(CO)$	T°K
200	51·6	9·0	− 0·8	− 3·6	− 2·4	626·5	1·8	200
220	57·0	11·8	+ 0·1	− 1·5	− 1·8	687·1	2·0	220
240	62·3	14·6	1·5	+ 0·7	− 0·4	748·6	2·1	240
260	67·6	17·5	3·4	3·1	+ 1·7	810·9	2·3	260
280	73·0	20·6	5·8	5·8	4·4	873·8	2·5	280
300	78·6	24·0	8·7	8·9	7·6	937·2	2·7	300
320	84·5	27·8	12·1	12·5	11·2	1000·9	2·8	320
340	90·7	32·0	15·9	16·5	15·2	1064·8	3·0	340
360	97·2	36·6	20·2	20·9	19·6	1128·8	3·2	360
380	104·1	41·6	25·0	25·7	24·4	1192·9	3·3	380
400	111·3	47·0	30·2	30·9	29·6	1257·1	3·5	400
420	118·8	52·8	35·8	36·5	35·1	1321·4	3·7	420
440	126·6	59·0	41·8	42·5	41·1	1385·7	3·8	440
460	134·7	65·5	48·2	48·9	47·5	1450·1	4·0	460
480	143·1	72·4	55·0	55·6	54·2	1514·5	4·2	480
500	151·8	79·6	62·1	62·7	61·2	1578·9	4·4	500
520	160·8	87·2	69·5	70·1	68·5	1643·3	4·5	520
540	170·2	95·2	77·3	77·9	76·2	1707·7	4·7	540
560	180·0	103·6	85·4	86·1	84·3	1772·1	4·8	560
580	190·2	112·3	93·9	94·6	92·7	1836·5	5·0	580
600	200·7	121·4	102·7	103·3	101·3	1901·0	5·2	600
620	211·5	130·8	111·8	112·3	110·2	1965·5	5·4	620
640	222·6	140·5	121·2	121·6	119·4	2030·0	5·5	640
660	234·0	150·5	130·9	131·2	128·9	2094·5	5·7	660
680	245·7	160·8	140·9	141·1	138·6	2159·0	5·9	680
700	257·7	171·3	151·2	151·2	148·6	2223·6	6·1	700
720	270·0	182·1	161·7	161·5	158·8	2288·2	6·2	720
740	282·6	193·2	172·5	172·0	169·2	2352·9	6·4	740
760	295·5	204·5	183·5	182·8	179·8	2417·7	6·6	760
780	308·6	216·0	194·7	193·8	190·7	2482·5	6·8	780
800	322·0	227·8	206·2	205·0	201·8	2547·4	7·0	800
820	335·6	239·9	217·9	216·4	213·1	2612·4	7·2	820
840	349·5	252·2	229·8	228·0	224·6	2677·5	7·4	840
860	363·7	264·7	241·9	239·8	236·2	2742·6	7·6	860
880	378·2	277·4	254·2	251·8	248·0	2807·9	7·8	880
900	393·1	290·3	266·7	264·0	260·0	2873·3	8·0	900
920	408·2	303·4	279·4	276·4	272·2	2938·8	8·2	920
940	423·5	316·7	292·3	289·0	284·6	3004·4	8·4	940
960	438·9	330·2	305·3	301·7	297·2	3070·2	8·6	960
980	454·5	343·9	+318·5	+314·6	+309·9	3136·1	8·8	980

* This Table is to be used for mixtures of gases only. Use Table 5 for total heat of combustion products.
† Use θ functions (Table 5) for incombustible gases (CO_2, N_2, etc.).

TABLE 2—*continued*

T°K	Methane $\Omega(CH_4)$	Ethane $\Omega(C_2H_6)$	Propane $\Omega(C_3H_8)$	n-Butane $\Omega(C_4H_{10})$	n-Pentane $\Omega(C_5H_{12})$	Hydrogen $\Omega(H_2)$	Carbon Monoxide $\Omega(CO)$	T°K
1000	470·3	357·8	331·9	327·6	322·8	3202·2	9·1	1000
1020	486·3	371·9	345·5	340·8	335·8	3268·4	9·3	1020
1040	502·5	386·2	359·3	354·2	349·0	3334·8	9·5	1040
1060	518·9	400·7	373·2	367·8	362·4	3401·4	9·7	1060
1080	535·6	415·4	387·3	381·5	375·9	3468·1	9·9	1080
1100	552·5	430·2	401·5	395·3	389·5	3534·9	10·1	1100
1120	569·6	445·1	415·9	409·3	403·3	3601·9	10·4	1120
1140	586·8	460·2	430·5	423·4	417·2	3669·1	10·6	1140
1160	604·2	475·4	445·2	437·6	431·2	3736·5	10·8	1160
1180	621·9	490·8	460·0	452·0	445·3	3804·1	11·0	1180
1200	639·8	506·4	474·9	466·5	459·6	3871·9	11·2	1200
1220	657·9	522·2	489·9	481·2	474·0	3939·8	11·4	1220
1240	676·2	538·1	505·0	496·0	488·5	4007·9	11·6	1240
1260	694·6	554·1	520·3	510·9	503·1	4076·2	11·9	1260
1280	713·1	570·3	535·7	525·9	517·8	4144·7	12·1	1280
1300	731·8	586·6	551·2	541·0	532·6	4213·4	12·3	1300
1320	750·6	603·0	566·8	556·2	547·5	4282·3	12·5	1320
1340	769·6	619·5	582·5	571·5	562·6	4351·4	12·8	1340
1360	788·7	636·1	598·3	586·9	577·8	4420·7	13·0	1360
1380	807·9	652·8	614·2	602·4	593·1	4490·1	13·2	1380
1400	827·3	669·7	630·3	618·0	608·5	4559·7	13·4	1400
1420	846·8	686·8	646·5	633·7	624·0	4629·5	13·6	1420
1440	866·4	704·0	662·8	649·5	639·6	4699·5	13·9	1440
1460	886·1	721·3	679·2	665·3	665·2	4769·7	14·1	1460
1480	905·8	738·6	695·6	681·2	670·8	4840·1	14·3	1480
1500	925·6	755·9	711·9	697·1	686·4	4910·7	14·5	1500
1520						4981·5	14·8	1520
1540						5052·5	15·0	1540
1560						5123·7	15·2	1560
1580						5195·1	15·4	1580
1600						5266·7	15·7	1600
1620						5338·5	15·9	1620
1640						5410·5	16·1	1640
1660						5482·7	16·3	1660
1680						5555·1	16·5	1680
1700						5627·6	16·8	1700
1720						5700·3	17·0	1720
1740						5773·1	17·2	1740
1760						5846·1	17·4	1760
1780						5919·4	17·6	1780
1800						5993·1	17·8	1800
1820						6066·8	18·0	1820
1840						6140·6	18·2	1840
1860						6214·5	18·5	1860
1880						6288·6	18·7	1880
1900						6362·9	18·9	1900
1920						6437·4	19·1	1920
1940						6512·1	19·3	1940
1960						6586·9	19·5	1960
1980						6661·8	19·8	1980
2000						6736·8	20·0	2000

TABLE 3

*Specific Heat Ω Functions**†

$$C_{pF} = C_{p\,\mathrm{air}} + \Sigma \bar{j}_F \Omega_j ; \quad C_{pm} = C_{p\,\mathrm{air}} + \Sigma \bar{j}_m \Omega_j ,$$

where $C_{p\,\mathrm{air}}$ = true specific heat of air at temperature °K

$\bar{j}_F$ = CH_4, C_2H_6, etc., content of fuel by weight

$\bar{j}_m$ = CH_4, C_2H_6, etc., content of medium by weight

T°K	Methane $\Omega(CH_4)$	Ethane $\Omega(C_2H_6)$	Propane $\Omega(C_3H_8)$	n-Butane $\Omega(C_4H_{10})$	n-Pentane $\Omega(C_5H_{12})$	Hydrogen $\Omega(H_2)$	Carbon Monoxide $\Omega(CO)$	T°K
200	0·2439	0·0866	0·0470	0·0689	0·0725	2·9907	0·0088	200
220	0·2517	0·1046	0·0701	0·0887	0·0910	3·0508	0·0088	220
240	0·2605	0·1231	0·0930	0·1086	0·1100	3·0975	0·0088	240
260	0·2703	0·1420	0·1157	0·1286	0·1294	3·1327	0·0087	260
280	0·2811	0·1612	0·1382	0·1487	0·1491	3·1584	0·0086	280
300	0·2929	0·1806	0·1605	0·1689	0·1690	3·1765	0·0085	300
320	0·3057	0·2001	0·1826	0·1892	0·1890	3·1889	0·0084	320
340	0·3194	0·2197	0·2045	0·2096	0·2091	3·1972	0·0083	340
360	0·3338	0·2395	0·2262	0·2300	0·2294	3·2030	0·0083	360
380	0·3489	0·2594	0·2477	0·2503	0·2495	3·2075	0·0082	380
400	0·3646	0·2792	0·2689	0·2704	0·2694	3·2112	0·0082	400
420	0·3808	0·2989	0·2897	0·2903	0·2891	3·2141	0·0082	420
440	0·3974	0·3184	0·3100	0·3099	0·3085	3·2162	0·0082	440
460	0·4141	0·3375	0·3297	0·3290	0·3274	3·2176	0·0082	460
480	0·4309	0·3562	0·3487	0·3475	0·3456	3·2185	0·0083	480
500	0·4477	0·3744	0·3670	0·3653	0·3631	3·2191	0·0083	500
520	0·4646	0·3922	0·3846	0·3823	0·3798	3·2196	0·0084	520
540	0·4814	0·4095	0·4015	0·3986	0·3957	3·2201	0·0084	540
560	0·4980	0·4263	0·4178	0·4143	0·4109	3·2206	0·0085	560
580	0·5144	0·4427	0·4336	0·4294	0·4256	3·2212	0·0086	580
600	0·5306	0·4586	0·4489	0·4440	0·4399	3·2220	0·0087	600
620	0·5466	0·4740	0·4637	0·4582	0·4538	3·2230	0·0088	620
640	0·5624	0·4890	0·4781	0·4719	0·4673	3·2243	0·0089	640
660	0·5779	0·5036	0·4920	0·4851	0·4803	3·2259	0·0090	660
680	0·5931	0·5178	0·5054	0·4979	0·4928	3·2278	0·0092	680
700	0·6080	0·5317	0·5184	0·5103	0·5049	3·2300	0·0093	700
720	0·6226	0·5453	0·5310	0·5223	0·5166	3·2325	0·0094	720
740	0·6369	0·5585	0·5433	0·5339	0·5279	3·2353	0·0095	740
760	0·6510	0·5714	0·5522	0·5452	0·5389	3·2384	0·0096	760
780	0·6648	0·5839	0·5668	0·5562	0·5496	3·2418	0·0097	780
800	0·6783	0·5961	0·5780	0·5669	0·5600	3·2455	0·0098	800
820	0·6916	0·6080	0·5889	0·5773	0·5701	3·2497	0·0099	820
840	0·7046	0·6196	0·5996	0·5875	0·5799	3·2545	0·0099	840
860	0·7174	0·6309	0·6100	0·5974	0·5895	3·2598	0·0100	860
880	0·7299	0·6419	0·6201	0·6070	0·5988	3·2655	0·0101	880
900	0·7421	0·6526	0·6300	0·6164	0·6079	3·2716	0·0102	900
920	0·7541	0·6631	0·6396	0·6255	0·6167	3·2780	0·0103	920
940	0·7658	0·6733	0·6489	0·6343	0·6253	3·2847	0·0103	940
960	0·7773	0·6832	0·6580	0·6429	0·6337	3·2917	0·0104	960
980	0·7886	0·6929	0·6669	0·6513	0·6418	3·2990	0·0105	980

* This Table is to be used for mixtures of gases only. Use Table 6 for total heat of combustion products.
† Use θ functions (Table 6) for incombustible gases (CO_2, N_2, etc.).

TABLE 3—*continued*

T°K	Methane $\Omega(CH_4)$	Ethane $\Omega(C_2H_6)$	Propane $\Omega(C_3H_8)$	n-Butane $\Omega(C_4H_{10})$	n-Pentane $\Omega(C_5H_{12})$	Hydrogen $\Omega(H_2)$	Carbon Monoxide $\Omega(CO)$	T°K
1000	0·7996	0·7023	0·6755	0·6594	0·6496	3·3065	0·0105	1000
1020	0·8103	0·7115	0·6838	0·6673	0·6572	3·3142	0·0106	1020
1040	0·8206	0·7204	0·6918	0·6749	0·6645	3·3221	0·0107	1040
1060	0·8306	0·7291	0·6996	0·6822	0·6716	3·3302	0·0107	1060
1080	0·8404	0·7376	0·7072	0·6893	0·6785	3·3385	0·0108	1080
1100	0·8500	0·7458	0·7146	0·6963	0·6852	3·3469	0·0108	1100
1120	0·8595	0·7538	0·7218	0·7032	0·6918	3·3555	0·0109	1120
1140	0·8688	0·7616	0·7288	0·7099	0·6983	3·3642	0·0109	1140
1160	0·8779	0·7690	0·7356	0·7165	0·7047	3·3731	0·0110	1160
1180	0·8868	0·7764	0·7423	0·7229	0·7109	3·3821	0·0110	1180
1200	0·8955	0·7836	0·7488	0·7291	0·7169	3·3911	0·0110	1200
1220	0·9040	0·7906	0·7551	0·7351	0·7227	3·4002	0·0111	1220
1240	0·9122	0·7974	0·7613	0·7409	0·7283	3·4093	0·0111	1240
1260	0·9201	0·8040	0·7673	0·7465	0·7338	3·4185	0·0111	1260
1280	0·9278	0·8104	0·7732	0·7520	0·7391	3·4278	0·0111	1280
1300	0·9353	0·8166	0·7789	0·7573	0·7443	3·4372	0·0112	1300
1320	0·9427	0·8227	0·7844	0·7625	0·7493	3·4466	0·0112	1320
1340	0·9499	0·8287	0·7897	0·7676	0·7542	3·4561	0·0112	1340
1360	0·9570	0·8345	0·7949	0·7725	0·7590	3·4657	0·0112	1360
1380	0·9638	0·8402	0·7999	0·7773	0·7636	3·4753	0·0112	1380
1400	0·9704	0·8457	0·8048	0·7819	0·7680	3·4850	0·0112	1400
1420	0·9768	0·8510	0·8095	0·7863	0·7722	3·4948	0·0112	1420
1440	0·9830	0·8561	0·8141	0·7906	0·7763	3·5046	0·0112	1440
1460	0·9890	0·8610	0·8186	0·7948	0·7803	3·5145	0·0112	1460
1480	0·9950	0·8659	0·8230	0·7989	0·7842	3·5243	0·0112	1480
1500	1·0009	0·8707	0·8272	0·8028	0·7879	3·5341	0·0112	1500
1520						3·5439	0·0112	1520
1540						3·5537	0·0112	1540
1560						3·5635	0·0111	1560
1580						3·5733	0·0111	1580
1600						3·5831	0·0111	1600
1620						3·5928	0·0111	1620
1640						3·6025	0·0110	1640
1660						3·6121	0·0110	1660
1680						3·6216	0·0110	1680
1700						3·6310	0·0109	1700
1720						3·6404	0·0109	1720
1740						3·6497	0·0109	1740
1760						3·6588	0·0108	1760
1780						3·6678	0·0108	1780
1800						3·6767	0·0107	1800
1820						3·6854	0·0107	1820
1840						3·6939	0·0107	1840
1860						3·7022	0·0106	1860
1880						3·7103	0·0106	1880
1900						3·7183	0·0106	1900
1920						3·7262	0·0106	1920
1940						3·7340	0·0105	1940
1960						3·7417	0·0105	1960
1980						3·7494	0·0105	1980
2000						3·7570	0·0105	2000

TABLE 4

*Ω Functions for Ψ (Entropy Function)**†

$$M'\psi_F = \psi_{\text{air}} + \Sigma \bar{j}_F \Omega_j ; \quad M'\psi_m = \psi_{\text{air}} + \Sigma \bar{j}_m \Omega_j ,$$

where ψ_{air} = entropy function of dry air at temperature T°K

$\bar{j}_F$ = CH_4, C_2H_6, etc., content of fuel by weight

$\bar{j}_m$ = CH_4, C_2H_6, etc., content of medium by weight

$$M'_F = 1 + \Sigma \bar{j}_F k_j ; \quad M'_m = 1 + \Sigma \bar{j}_m k_j .$$

k_j T°K	Methane 0·8058 $\Omega(CH_4)$	Ethane −0·0366 $\Omega(C_2H_6)$	Propane −0·3430 $\Omega(C_3H_8)$	n-Butane −0·5016 $\Omega(C_4H_{10})$	n-Pentane −0·5985 $\Omega(C_5H_{12})$	Hydrogen 13·3695 $\Omega(H_2)$	Carbon Monoxide 0·0342 $\Omega(CO)$	T°K
200	6·776	1·085	−1·128	−2·348	−3·114	80·039	0·536	200
220	6·919	1·147	−1·089	−2·301	−3·067	81·868	0·542	220
240	7·056	1·212	−1·042	−2·247	−3·015	83·560	0·547	240
260	7·188	1·280	−0·988	−2·187	−2·953	85·140	0·551	260
280	7·316	1·351	−0·928	−2·122	−2·888	86·619	0·555	280
300	7·441	1·425	−0·863	−2·053	−2·819	88·006	0·559	300
320	7·564	1·502	−0·794	−1·981	−2·747	89·309	0·563	320
340	7·685	1·582	−0·721	−1·905	−2·671	90·536	0·566	340
360	7·804	1·665	−0·643	−1·825	−2·591	91·694	0·569	360
380	7·921	1·751	−0·561	−1·742	−2·508	92·791	0·572	380
400	8·036	1·839	−0·476	−1·657	−2·423	93·833	0·575	400
420	8·150	1·928	−0·389	−1·570	−2·337	94·827	0·578	420
440	8·264	2·018	−0·301	−1·481	−2·249	95·776	0·580	440
460	8·378	2·110	−0·211	−1·391	−2·160	96·684	0·582	460
480	8·491	2·203	−0·120	−1·300	−2·070	97·553	0·584	480
500	8·604	2·297	−0·028	−1·208	−1·979	98·386	0·586	500
520	8·717	2·392	−0·065	−1·115	−1·887	99·186	0·588	520
540	8·830	2·488	+0·158	−1·022	−1·795	99·955	0·590	540
560	8·943	2·584	0·252	−0·929	−1·702	100·697	0·592	560
580	9·056	2·681	0·346	−0·836	−1·609	101·413	0·594	580
600	9·169	2·778	0·441	−0·742	−1·516	102·105	0·596	600
620	9·282	2·876	0·536	−0·648	−1·423	102·774	0·598	620
640	9·394	2·974	0·631	−0·555	−1·331	103·421	0·600	640
660	9·505	3·072	0·726	−0·462	−1·239	104·049	0·601	660
680	9·616	3·169	0·820	−0·369	−1·147	104·660	0·603	680
700	9·726	3·266	0·914	−0·276	−1·055	105·254	0·605	700
720	9·836	3·362	1·008	−0·184	−0·964	105·832	0·607	720
740	9·945	3·458	1·101	−0·092	−0·874	106·395	0·608	740
760	10·034	3·553	1·194	−0·001	−0·784	106·943	0·610	760
780	10·162	3·648	1·287	+0·091	−0·694	107·477	0·611	780
800	10·267	3·743	1·379	0·181	−0·605	107·998	0·613	800
820	10·376	3·837	1·471	0·271	−0·516	108·507	0·615	820
840	10·482	3·931	1·562	0·360	−0·428	109·004	0·616	840
860	10·587	4·024	1·653	0·448	−0·341	109·489	0·618	860
880	10·692	4·116	1·743	0·536	−0·255	109·963	0·619	880
900	10·797	4·208	1·832	0·623	−0·169	110·427	0·620	900
920	10·901	4·300	1·921	0·710	−0·083	110·882	0·622	920
940	11·004	4·391	2·009	0·796	+0·002	111·329	0·623	940
960	11·107	4·481	2·096	0·881	0·086	111·768	0·624	960
980	11·209	4·571	2·183	0·965	0·169	112·199	0·626	980

* This Table is to be used for mixtures of gases only. Use Table 7 for total heat of combustion products.

† Use θ functions (Table 7) for incombustible gases (CO_2, N_2, etc.).

TABLE 4—*continued*

k_j T°K	Methane 0·8058 $\Omega(CH_4)$	Ethane −0·0366 $\Omega(C_2H_6)$	Propane −0·3430 $\Omega(C_3H_8)$	n-Butane −0·5016 $\Omega(C_4H_{10})$	n-Pentane −0·5985 $\Omega(C_5H_{12})$	Hydrogen 13·3695 $\Omega(H_2)$	Carbon Monoxide 0·0342 $\Omega(CO)$	T°K
1000	11·311	4·660	2·269	1·049	0·252	112·623	0·627	1000
1020	11·412	4·749	2·355	1·132	0·334	113·039	0·629	1020
1040	11·512	4·837	2·440	1·215	0·415	113·448	0·630	1040
1060	11·612	4·924	2·524	1·297	0·496	113·850	0·631	1060
1080	11·711	5·010	2·607	1·378	0·576	114·246	0·632	1080
1100	11·809	5·096	2·690	1·458	0·655	114·635	0·634	1100
1120	11·907	5·182	2·773	1·538	0·733	115·017	0·635	1120
1140	12·004	5·267	2·855	1·617	0·811	115·393	0·636	1140
1160	12·100	5·351	2·936	1·693	0·888	115·763	0·638	1160
1180	12·195	5·434	3·016	1·773	0·965	116·128	0·639	1180
1200	12·290	5·517	3·095	1·850	1·401	116·489	0·640	1200
1220	12·385	5·600	3·174	1·926	1·116	116·845	0·641	1220
1240	12·479	5·682	3·252	2·002	1·190	117·195	0·642	1240
1260	12·572	5·763	3·330	2·078	1·264	117·542	0·643	1260
1280	12·664	5·844	3·407	2·153	1·338	117·884	0·644	1280
1300	12·755	5·924	3·484	2·227	1·411	118·222	0·645	1300
1320	12·846	6·004	3·560	2·301	1·484	118·555	0·647	1320
1340	12·936	6·083	3·635	2·374	1·556	118·884	0·648	1340
1360	13·025	6·161	3·709	2·446	1·627	119·209	0·649	1360
1380	13·113	6·238	3·782	2·517	1·697	119·530	0·650	1380
1400	13·201	6·314	3·854	2·587	1·766	119·848	0·651	1400
1420	13·288	6·389	3·925	2·656	1·834	120·162	0·652	1420
1440	13·375	6·464	3·995	2·725	1·901	120·473	0·653	1440
1460	13·463	6·539	4·065	2·794	1·968	120·780	0·654	1460
1480	13·550	6·614	4·135	2·862	2·036	121·083	0·655	1480
1500	13·636	6·689	4·205	2·531	2·104	121·382	0·656	1500
1520						121·678	0·656	1520
1540						121·971	0·657	1540
1560						122·262	0·658	1560
1580						122·251	0·659	1580
1600						122·837	0·660	1600
1620						123·120	0·661	1620
1640						123·400	0·662	1640
1660						123·677	0·662	1660
1680						123·952	0·663	1680
1700						124·224	0·664	1700
1720						124·494	0·665	1720
1740						124·762	0·666	1740
1760						125·027	0·666	1760
1780						125·290	0·667	1780
1800						125·550	0·668	1800
1820						125·807	0·669	1820
1840						126·062	0·670	1840
1860						126·315	0·670	1860
1880						126·566	0·671	1880
1900						126·815	0·672	1900
1920						127·062	0·672	1920
1940						127·307	0·673	1940
1960						127·550	0·674	1960
1980						127·791	0·675	1980
2000						128·029	0·675	2000

TABLE 5

Total Heat θ Functions

$$H = H_{air} + \frac{q}{1+q}(\bar{C}_F\theta_C + \bar{H}_F\theta_H + \bar{O}_F\theta_O + \ldots) + \frac{1}{1+q}(\bar{C}_m\theta_C + \bar{H}_m\theta_H + \bar{O}_m\theta_O + \ldots)$$

where H_{air} = total heat of dry air at temperature T°K

$\bar{C}_F$, $\bar{H}_F$, $\bar{O}_F$, etc. = carbon, hydrogen, oxygen, etc., content of fuel by weight

$\bar{C}_m$, $\bar{H}_m$, $\bar{O}_m$, etc. = carbon, hydrogen, oxygen, etc., content of supporting medium by weight

q = fuel/medium ratio

T°K	θ_C	θ_H	θ_O*	θ_N*	θ_S	θ_W*	θ_{CO_2}*	T°K
200	−44·5	393·1	− 4·5	1·8	− 40·2	40·0	−15·4	200
220	−47·9	432·8	− 5·0	2·0	− 43·7	44·0	−16·7	220
240	−50·8	472·6	− 5·5	2·2	− 47·2	48·1	−17·8	240
260	−53·3	512·4	− 5·9	2·3	− 50·7	52·2	−18·8	260
280	−55·5	552·3	− 6·3	2·5	− 54·2	56·3	−19·7	280
300	−57·4	592·3	− 6·7	2·7	− 57·6	60·4	−20·5	300
320	−58·9	632·3	− 7·1	2·8	− 60·8	64·5	−21·2	320
340	−60·1	672·4	− 7·5	3·0	− 63·8	68·6	−21·8	340
360	−61·1	712·6	− 7·9	3·2	− 66·7	72·8	−22·3	360
380	−61·9	753·0	− 8·3	3·3	− 69·6	77·0	−22·8	380
400	−62·4	793·6	− 8·7	3·5	− 72·5	81·2	−23·2	400
420	−62·7	834·4	− 9·0	3·6	− 75·4	85·4	−23·5	420
440	−62·7	875·4	− 9·3	3·7	− 78·2	89·7	−23·8	440
460	−62·5	916·6	− 9·6	3·9	− 80·9	94·0	−24·0	460
480	−62·2	957·9	− 9·9	4·0	− 83·5	98·4	−24·1	480
500	−61·8	999·4	−10·2	4·1	− 86·1	102·8	−24·2	500
520	−61·3	1041·1	−10·4	4·3	− 88·7	107·3	−24·3	520
540	−60·7	1083·0	−10·6	4·4	− 91·3	111·8	−24·3	540
560	−59·9	1125·2	−10·8	4·5	− 93·9	116·3	−24·3	560
580	−59·0	1167·7	−11·1	4·6	− 96·4	120·8	−24·2	580
600	−58·0	1210·6	−11·4	4·8	− 98·9	125·4	−24·1	600
620	−56·9	1253·8	−11·6	4·9	−101·4	130·0	−24·0	620
640	−55·7	1297·3	−11·8	5·0	−103·9	134·7	−23·8	640
660	−54·5	1341·1	−12·0	5·1	−106·4	139·4	−23·6	660
680	−53·2	1385·2	−12·2	5·2	−108·9	144·2	−23·4	680
700	−51·8	1429·6	−12·4	5·3	−111·4	149·0	−23·2	700
720	−50·3	1474·4	−12·6	5·4	−113·9	153·8	−22·9	720
740	−48·7	1519·6	−12·8	5·5	−116·4	158·7	−22·6	740
760	−47·0	1565·2	−13·0	5·7	−118·9	163·6	−22·3	760
780	−45·3	1611·2	−13·2	5·8	−121·4	168·5	−22·0	780
800	−43·5	1657·6	−13·5	5·9	−123·9	173·5	−21·7	800
820	−41·7	1704·4	−13·7	6·0	−126·4	178·5	−21·4	820
840	−39·8	1751·6	−13·9	6·1	−128·9	183·6	−21·0	840
860	−37·9	1799·2	−14·1	6·2	−131·4	188·8	−20·6	860
880	−35·9	1847·2	−14·3	6·3	−133·9	194·0	−20·2	880
900	−33·9	1895·7	−14·5	6·5	−136·4	199·2	−19·8	900
920	−31·8	1944·6	−14·8	6·6	−138·9	204·5	−19·4	920
940	−29·6	1994·0	−15·0	6·7	−141·5	209·8	−19·0	940
960	−27·4	2043·8	−15·2	6·8	−144·1	215·2	−18·6	960
980	−25·2	2094·1	−15·5	6·9	−146·7	220·6	−18·2	980

* Ω functions also.

TABLE 5—*continued*

T°K	θ_C	θ_H	θ_O*	θ_N*	θ_S	θ_W*	θ_{CO_2}*	T°K
1000	−22·9	2144·9	−15·7	7·1	−149·3	226·1	−17·7	1000
1020	−20·6	2196·2	−15·9	7·2	−151·9	231·6	−17·2	1020
1040	−18·3	2248·0	−16·2	7·3	−154·5	237·2	−16·7	1040
1060	−15·9	2300·2	−16·5	7·5	−157·1	242·8	−16·2	1060
1080	−13·5	2352·9	−16·7	7·6	−159·7	248·5	−15·8	1080
1100	−11·0	2406·1	−17·0	7·7	−162·3	254·2	−15·3	1100
1120	− 8·5	2459·8	−17·3	7·9	−165·0	260·0	−14·8	1120
1140	− 5·9	2514·0	−17·5	8·0	−167·7	265·8	−14·3	1140
1160	− 3·3	2568·7	−17·8	8·1	−170·4	271·6	−13·8	1160
1180	− 0·7	2623·9	−18·1	8·3	−173·1	277·5	−13·3	1180
1200	+ 1·9	2679·5	−18·4	8·5	−175·8	283·5	−12·8	1200
1220	4·5	2735·6	−18·7	8·6	−178·5	289·5	−12·3	1220
1240	7·2	2792·1	−18·9	8·7	−181·2	295·6	−11·8	1240
1260	9·9	2849·1	−19·2	8·9	−183·9	301·7	−11·2	1260
1280	12·6	2906·6	−19·5	9·0	−186·6	307·9	−10·7	1280
1300	15·4	2964·5	−19·8	9·2	−189·3	314·1	−10·2	1300
1320	18·2	3022·9	−20·1	9·3	−192·0	320·4	− 9·7	1320
1340	21·0	3081·8	−20·4	9·5	−194·8	326·7	− 9·2	1340
1360	23·8	3141·1	−20·7	9·6	−197·6	333·1	− 8·6	1360
1380	26·6	3200·8	−21·1	9·8	−200·4	339·5	− 8·1	1380
1400	29·4	3261·0	−21·4	9·9	−203·2	345·9	− 7·6	1400
1420	32·3	3321·6	−21·7	10·1	−206·0	352·4	− 7·0	1420
1440	35·2	3382·6	−22·1	10·2	−208·8	359·0	− 6·4	1440
1460	38·1	3444·0	−22·4	10·4	−211·6	365·6	− 5·8	1460
1480	41·0	3505·8	−22·7	10·6	−214·4	372·2	− 5·2	1480
1500	44·0	3568·0	−23·0	10·7	−217·3	378·9	− 4·7	1500
1520	47·0	3630·6	−23·4	10·9	−220·2	385·6	− 4·1	1520
1540	50·0	3693·7	−23·7	11·0	−223·1	392·3	− 3·5	1540
1560	53·0	3757·2	−24·0	11·2	−226·0	399·1	− 2·9	1560
1580	56·0	3821·0	−24·3	11·4	−228·9	406·0	− 2·4	1580
1600	59·0	3885·1	−24·7	11·5	−231·8	412·9	− 1·8	1600
1620	62·0	3949·6	−25·0	11·7	−234·7	419·8	− 1·2	1620
1640	65·0	4014·5	−25·3	11·9	−237·6	426·8	− 0·6	1640
1660	68·0	4079·7	−25·7	12·0	−240·6	433·8	+ 0·0	1660
1680	71·0	4145·2	−26·0	12·2	−243·6	440·8	0·6	1680
1700	74·1	4211·1	−26·3	12·4	−246·6	447·9	1·1	1700
1720	77·2	4277·3	−26·7	12·5	−249·6	455·0	1·7	1720
1740	80·3	4343·9	−27·0	12·6	−252·6	462·1	2·3	1740
1760	83·4	4410·8	−27·4	12·8	−255·6	469·3	2·9	1760
1780	86·5	4478·0	−27·7	13·0	−258·6	476·5	3·5	1780
1800	89·6	4545·5	−28·0	13·2	−261·6	483·8	4·1	1800
1820	92·7	4613·3	−28·4	13·4	−264·6	491·1	4·7	1820
1840	95·8	4681·4	−28·7	13·6	−267·6	498·4	5·3	1840
1860	98·9	4749·8	−29·0	13·7	−270·6	505·7	5·9	1860
1880	102·0	4818·5	−29·4	13·9	−273·7	513·1	6·5	1880
1900	105·1	4887·5	−29·7	14·0	−276·8	520·5	7·1	1900
1920	108·2	4956·7	−30·1	14·2	−279·9	528·0	7·7	1920
1940	111·4	5026·2	−30·4	14·4	−282·9	535·5	8·3	1940
1960	114·5	5095·9	−30·8	14·5	−285·9	543·0	8·9	1960
1980	117·6	5165·9	−31·1	14·7	−289·0	550·5	9·5	1980
2000	+120·7	5236·2	−31·4	14·9	−292·1	558·1	+10·1	2000

* Ω functions also.

TABLE 6

Specific Heat θ Functions

$$C_p = C_{p\,\mathrm{air}} + \frac{q}{1+q}(\bar{C}_F\theta_C + \bar{H}_F\theta_H + \bar{O}_F\theta_O + \ldots) + \frac{1}{1+q}(\bar{C}_m\theta_C + \bar{H}_m\theta_H + \bar{O}_m\theta_O + \ldots)$$

where $C_{p\,\mathrm{air}}$ = specific heat of dry air at temperature T°K

$\bar{C}_F$, $\bar{H}_F$, $\bar{O}_F$, etc. = carbon, hydrogen, oxygen, etc., content of fuel by weight

$\bar{C}_m$, $\bar{H}_m$, $\bar{O}_m$, etc. = carbon, hydrogen, oxygen, etc., content of supporting medium by weight

q = fuel/medium ratio

T°K	θ_C	θ_H	θ_O*	θ_N*	θ_S	θ_W*	θ_{CO_2}*	T°K
200	−0·1751	1·9840	−0·0220	0·0088	−0·1870	0·2025	−0·0637	200
220	−0·1549	1·9864	−0·0220	0·0088	−0·1811	0·2028	−0·0585	220
240	−0·1356	1·9889	−0·0218	0·0087	−0·1755	0·2032	−0·0532	240
260	−0·1172	1·9916	−0·0215	0·0086	−0·1702	0·2037	−0·0479	260
280	−0·0997	1·9947	−0·0211	0·0085	−0·1653	0·2044	−0·0428	280
300	−0·0832	1·9985	−0·0206	0·0084	−0·1607	0·2052	−0·0379	300
320	−0·0679	2·0033	−0·0201	0·0082	−0·1564	0·2062	−0·0332	320
340	−0·0538	2·0092	−0·0195	0·0080	−0·1524	0·2074	−0·0288	340
360	−0·0409	2·0160	−0·0188	0·0078	−0·1487	0·2088	−0·0248	360
380	−0·0291	2·0236	−0·0180	0·0076	−0·1453	0·2104	−0·0211	380
400	−0·0184	2·0319	−0·0172	0·0074	−0·1422	0·2121	−0·0177	400
420	−0·0087	2·0408	−0·0165	0·0072	−0·1394	0·2138	−0·0145	420
440	+0·0002	2·0503	−0·0158	0·0070	−0·1369	0·2155	−0·0115	440
460	0·0084	2·0605	−0·0151	0·0068	−0·1347	0·2172	−0·0087	460
480	0·0160	2·0714	−0·0144	0·0066	−0·1328	0·2190	−0·0061	480
500	0·0230	2·0830	−0·0137	0·0064	−0·1312	0·2209	−0·0037	500
520	0·0296	2·0953	−0·0131	0·0062	−0·1298	0·2228	−0·0015	520
540	0·0358	2·1082	−0·0126	0·0061	−0·1286	0·2247	+0·0006	540
560	0·0416	2·1218	−0·0122	0·0060	−0·1276	0·2266	0·0025	560
580	0·0471	2·1360	−0·0118	0·0059	−0·1268	0·2286	0·0043	580
600	0·0523	2·1508	−0·0114	0·0058	−0·1261	0·2306	0·0060	600
620	0·0571	2·1662	−0·0111	0·0057	−0·1255	0·2326	0·0075	620
640	0·0616	2·1821	−0·0108	0·0056	−0·1249	0·2346	0·0089	640
660	0·0658	2·1985	−0·0106	0·0056	−0·1244	0·2366	0·0102	660
680	0·0698	2·2154	−0·0105	0·0056	−0·1241	0·2386	0·0114	680
700	0·0736	2·2328	−0·0104	0·0056	−0·1240	0·2406	0·0125	700
720	0·0773	2·2508	−0·0104	0·0056	−0·1241	0·2427	0·0135	720
740	0·0808	2·2694	−0·0104	0·0056	−0·1243	0·2448	0·0145	740
760	0·0842	2·2886	−0·0105	0·0056	−0·1245	0·2469	0·0154	760
780	0·0874	2·3084	−0·0105	0·0057	−0·1247	0·2490	0·0162	780
800	0·0905	2·3288	−0·0106	0·0057	−0·1250	0·2512	0·0170	800
820	0·0934	2·3497	−0·0107	0·0058	−0·1254	0·2534	0·0178	820
840	0·0962	2·3710	−0·0108	0·0058	−0·1258	0·2557	0·0185	840
860	0·0989	2·3927	−0·0109	0·0059	−0·1262	0·2580	0·0191	860
880	0·1015	2·4147	−0·0110	0·0059	−0·1267	0·2603	0·0197	880
900	0·1040	2·4370	−0·0112	0·0060	−0·1272	0·2627	0·0203	900
920	0·1064	2·4597	−0·0113	0·0060	−0·1278	0·2651	0·0208	920
940	0·1087	2·4828	−0·0114	0·0061	−0·1283	0·2676	0·0213	940
960	0·1109	2·5063	−0·0116	0·0062	−0·1289	0·2701	0·0217	960
980	+0·1130	2·5301	−0·0119	0·0063	−0·1294	0·2726	+0·0221	980

* Ω functions also.

TABLE 6—*continued*

T°K	θ_C	θ_H	θ_O*	θ_N*	θ_S	θ_W*	θ_{CO_2}*	T°K
1000	0·1151	2·5542	—0·0121	0·0064	—0·1300	0·2751	0·0225	1000
1020	0·1171	2·5785	—0·0124	0·0065	—0·1305	0·2776	0·0229	1020
1040	0·1190	2·6029	—0·0126	0·0065	—0·1310	0·2801	0·0233	1040
1060	0·1209	2·6273	—0·0128	0·0066	—0·1316	0·2826	0·0237	1060
1080	0·1227	2·6517	—0·0131	0·0067	—0·1321	0·2851	0·0240	1080
1100	0·1245	2·6760	—0·0133	0·0068	—0·1327	0·2876	0·0243	1100
1120	0·1262	2·7002	—0·0136	0·0069	—0·1332	0·2901	0·2460	1120
1140	0·1278	2·7243	—0·0138	0·0070	—0·1337	0·2926	0·0249	1140
1160	0·1293	2·7483	—0·0140	0·0070	—0·1342	0·2951	0·0251	1160
1180	0·1307	2·7722	—0·0142	0·0071	—0·1348	0·2976	0·0254	1180
1200	0·1321	2·7960	—0·0144	0·0072	—0·1353	0·3001	0·0257	1200
1220	0·1334	2·8197	—0·0145	0·0072	—0·1359	0·3026	0·0260	1220
1240	0·1347	2·8432	—0·0146	0·0073	—0·1364	0·3051	0·0262	1240
1260	0·1360	2·8665	—0·0148	0·0073	—0·1369	0·3076	0·0264	1260
1280	0·1373	2·8896	—0·0149	0·0074	—0·1374	0·3101	0·0266	1280
1300	0·1385	2·9125	—0·0151	0·0074	—0·1379	0·3126	0·0268	1300
1320	0·1397	2·9352	—0·0152	0·0075	—0·1384	0·3150	0·0270	1320
1340	0·1408	2·9577	—0·0154	0·0075	—0·1389	0·3174	0·0272	1340
1360	0·1419	2·9800	—0·0155	0·0076	—0·1394	0·3197	0·0274	1360
1380	0·1429	3·0021	—0·0157	0·0076	—0·1399	0·3220	0·0276	1380
1400	0·1439	3·0239	—0·0158	0·0077	—0·1403	0·3243	0·0278	1400
1420	0·1448	3·0454	—0·0159	0·0077	—0·1408	0·3266	0·0279	1420
1440	0·1457	3·0665	—0·0160	0·0078	—0·1413	0·3289	0·0280	1440
1460	0·1466	3·0872	—0·0162	0·0078	—0·1418	0·3311	0·0282	1460
1480	0·1474	3·1075	—0·0163	0·0079	—0·1423	0·3333	0·0284	1480
1500	0·1482	3·1275	—0·0164	0·0079	—0·1429	0·3354	0·0285	1500
1520	0·1489	3·1472	—0·0164	0·0080	—0·1434	0·3375	0·0286	1520
1540	0·1496	3·1666	—0·0165	0·0080	—0·1439	0·3396	0·0288	1540
1560	0·1502	3·1856	—0·0166	0·0080	—0·1444	0·3417	0·0289	1560
1580	0·1508	3·2042	—0·0167	0·0081	—0·1449	0·3437	0·0290	1580
1600	0·1514	3·2225	—0·0168	0·0081	—0·1454	0·3457	0·0291	1600
1620	0·1519	3·2405	—0·0168	0·0081	—0·1459	0·3477	0·0292	1620
1640	0·1524	3·2582	—0·0169	0·0082	—0·1464	0·3496	0·0293	1640
1660	0·1529	3·2756	—0·0169	0·0082	—0·1468	0·3515	0·0294	1660
1680	0·1533	3·2928	—0·0170	0·0082	—0·1473	0·3534	0·0295	1680
1700	0·1537	3·3097	—0·0170	0·0082	—0·1478	0·3553	0·0296	1700
1720	0·1541	3·3263	—0·0170	0·0082	—0·1482	0·3571	0·0296	1720
1740	0·1544	3·3427	—0·0170	0·0083	—0·1486	0·3589	0·0297	1740
1760	0·1547	3·3589	—0·0171	0·0083	—0·1490	0·3607	0·0298	1760
1780	0·1550	3·3748	—0·0171	0·0083	—0·1495	0·3625	0·0299	1780
1800	0·1553	3·3904	—0·0171	0·0083	—0·1499	0·3642	0·0300	1800
1820	0·1555	3·4056	—0·0171	0·0083	—0·1504	0·3659	0·0300	1820
1840	0·1557	3·4205	—0·0171	0·0083	—0·1509	0·3676	0·0301	1840
1860	0·1559	3·4351	—0·0171	0·0083	—0·1514	0·3693	0·0301	1860
1880	0·1560	3·4495	—0·0170	0·0083	—0·1519	0·3709	0·0302	1880
1900	0·1561	3·4636	—0·0170	0·0083	—0·1524	0·3725	0·0302	1900
1920	0·1561	3·4774	—0·0170	0·0082	—0·1529	0·3741	0·0303	1920
1940	0·1561	3·4910	—0·0169	0·0082	—0·1534	0·3756	0·0303	1940
1960	0·1561	3·5043	—0·0169	0·0082	—0·1539	0·3771	0·0303	1960
1980	0·1561	3·5173	—0·0168	0·0082	—0·1544	0·3786	0·0304	1980
2000	0·1561	3·5301	—0·0168	0·0082	—0·1549	0·3801	0·0304	2000

* Ω functions also.

TABLE 7

θ Functions for ψ (Entropy Function)

$$M'\psi = \psi_{\text{air}} + \frac{q}{1+q}(\bar{C}_F\theta_C + \bar{H}_F\theta_H + \bar{O}_F\theta_O + \ldots) + \frac{1}{1+q}(\bar{C}_m\theta_C + \bar{H}_m\theta_H + \bar{O}_m\theta_O + \ldots)$$

where ψ_{air} = entropy function of dry air at temperature T°K

$\bar{C}_F$, $\bar{H}_F$, $\bar{O}_F$, etc. = carbon, hydrogen, oxygen, etc., content of fuel by weight

$\bar{C}_m$, $\bar{H}_m$, $\bar{O}_m$, etc. = carbon, hydrogen, oxygen, etc., content of supporting medium by weight

q = fuel/medium ratio

$$M' = 1 + \frac{q}{1+q}(\bar{C}_Fk_C + \bar{H}_Fk_H + \bar{O}_Fk_O + \ldots) + \frac{1}{1+q}(\bar{C}_mk_C + \bar{H}_mk_H + \bar{O}_mk_O + \ldots)$$

	k_C −1·000	k_H 6·1848	k_O −0·0947	k_N 0·0340	k_S −1·000	k_W 0·6080	k_{CO_2} −0·3418	
T°K	θ_C	θ_H	θ_O*	θ_N*	θ_S	θ_W*	θ_{CO_2}*	T°K
200	−8·718	49·526	−0·381	0·188	−7·637	5·204	−2·656	200
220	−8·816	50·729	−0·394	0·194	−7·749	5·325	−2·692	220
240	−8·897	51·824	−0·406	0·199	−7·848	5·437	−2·723	240
260	−8·963	52·831	−0·417	0·203	−7·936	5·541	−2·749	260
280	−9·015	53·766	−0·427	0·207	−8·015	5·637	−2·771	280
300	−9·056	54·638	−0·436	0·211	−8·085	5·726	−2·789	300
320	−9·087	55·455	−0·445	0·215	−8·148	5·810	−2·803	320
340	−9·110	56·224	−0·453	0·218	−8·204	5·889	−2·814	340
360	−9·127	56·952	−0·460	0·221	−8·255	5·964	−2·823	360
380	−9·138	57·644	−0·466	0·223	−8·302	6·036	−2·831	380
400	−9·145	58·304	−0·472	0·225	−8·346	6·105	−2·838	400
420	−9·149	58·935	−0·477	0·227	−8·388	6·171	−2·843	420
440	−9·150	59·539	−0·482	0·230	−8·428	6·234	−2·847	440
460	−9·149	60·118	−0·486	0·232	−8·466	6·295	−2·850	460
480	−9·146	60·674	−0·490	0·234	−8·502	6·354	−2·852	480
500	−9·141	61·210	−0·494	0·236	−8·535	6·411	−2·853	500
520	−9·135	61·728	−0·497	0·237	−8·566	6·466	−2·854	520
540	−9·127	62·230	−0·500	0·238	−8·595	6·520	−2·854	540
560	−9·118	62·717	−0·503	0·240	−8·623	6·572	−2·854	560
580	−9·108	63·190	−0·506	0·241	−8·649	6·622	−2·853	580
600	−9·097	63·650	−0·508	0·242	−8·674	6·671	−2·851	600
620	−9·085	64·098	−0·510	0·244	−8·698	6·719	−2·849	620
640	−9·073	64·535	−0·512	0·245	−8·721	6·766	−2·847	640
660	−9·061	64·962	−0·514	0·246	−8·744	6·812	−2·845	660
680	−9·048	65·379	−0·516	0·247	−8·767	6·857	−2·843	680
700	−9·035	65·787	−0·518	0·248	−8·789	6·901	−2·841	700
720	−9·022	66·187	−0·520	0·249	−8·810	6·944	−2·839	720
740	−9·008	66·580	−0·522	0·250	−8·831	6·986	−2·837	740
760	−8·994	66·966	−0·524	0·251	−8·851	7·028	−2·835	760
780	−8·980	67·345	−0·526	0·252	−8·871	7·069	−2·833	780
800	−8·966	67·717	−0·527	0·253	−8·890	7·109	−2·831	800
820	−8·952	68·083	−0·529	0·254	−8·909	7·148	−2·828	820
840	−8·938	68·443	−0·530	0·255	−8·928	7·187	−2·825	840
860	−8·923	68·798	−0·532	0·255	−8·947	7·225	−2·822	860
880	−8·908	69·148	−0·534	0·256	−8·965	7·263	−2·819	880
900	−8·893	69·493	−0·535	0·257	−8·983	7·301	−2·816	900
920	−8·878	69·834	−0·537	0·258	−9·000	7·338	−2·813	920
940	−8·863	70·172	−0·539	0·259	−9·017	7·374	−2·810	940
960	−8·849	70·506	−0·540	0·260	−9·034	7·410	−2·807	960
980	−8·834	70·836	−0·541	0·260	−9·050	7·446	−2·804	980

* Ω functions also.

TABLE 7—*continued*

T°K	θ_C	θ_H	θ_O*	θ_N*	θ_S	θ_W*	θ_{CO_2}*	T°K
1000	—8·819	71·162	—0·543	0·261	—9·065	7·481	—2·802	1000
1020	—8·804	71·484	—0·545	0·262	—9·081	7·516	—2·799	1020
1040	—8·789	71·803	—0·546	0·263	—9·097	7·550	—2·796	1040
1060	—8·775	72·119	—0·548	0·264	—9·112	7·584	—2·793	1060
1080	—8·761	72·432	—0·550	0·265	—9·127	7·618	—2·790	1080
1100	—8·747	72·742	—0·551	0·265	—9·142	7·651	—2·787	1100
1120	—8·733	73·049	—0·553	0·266	—9·157	7·684	—2·785	1120
1140	—8·719	73·354	—0·554	0·267	—9·171	7·717	—2·782	1140
1160	—8·705	73·656	—0·556	0·268	—9·185	7·749	—2·779	1160
1180	—8·691	73·955	—0·557	0·268	—9·199	7·781	—2·776	1180
1200	—8·677	74·251	—0·559	0·269	—9·213	7·813	—2·774	1200
1220	—8·663	74·545	—0·560	0·270	—9·227	7·844	—2·771	1220
1240	—8·649	74·837	—0·562	0·271	—9·241	7·875	—2·768	1240
1260	—8·635	75·127	—0·563	0·271	—9·255	7·906	—2·766	1260
1280	—8·621	75·415	—0·565	0·272	—9·268	7·937	—2·763	1280
1300	—8·607	75·700	—0·566	0·273	—9·281	7·968	—2·760	1300
1320	—8·594	75·983	—0·568	0·274	—9·294	7·998	—2·758	1320
1340	—8·581	76·264	—0·569	0·274	—9·307	8·028	—2·755	1340
1360	—8·568	76·543	—0·570	0·275	—9·320	8·058	—2·752	1360
1380	—8·555	76·820	—0·572	0·276	—9·333	8·088	—2·750	1380
1400	—8·542	77·096	—0·573	0·277	—9·346	8·118	—2·747	1400
1420	—8·529	77·370	—0·575	0·277	—9·359	8·148	—2·745	1420
1440	—8·516	77·642	—0·576	0·278	—9·371	8·177	—2·743	1440
1460	—8·503	77·912	—0·577	0·279	—9·383	8·206	—2·740	1460
1480	—8·490	78·180	—0·579	0·279	—9·395	8·234	—2·738	1480
1500	—8·477	78·445	—0·580	0·280	—9·407	8·262	—2·735	1500
1520	—8·465	78·708	—0·582	0·281	—9·419	8·290	—2·733	1520
1540	—8·453	78·969	—0·583	0·281	—9·431	8·318	—2·731	1540
1560	—8·441	79·228	—0·584	0·282	—9·443	8·346	—2·728	1560
1580	—8·429	79·486	—0·586	0·282	—9·454	8·374	—2·726	1580
1600	—8·416	79·743	—0·587	0·283	—9·465	8·402	—2·724	1600
1620	—8·404	79·998	—0·588	0·284	—9·476	8·429	—2·721	1620
1640	—8·392	80·251	—0·590	0·284	—9·487	8·456	—2·719	1640
1660	—8·380	80·502	—0·591	0·285	—9·498	8·483	—2·717	1660
1680	—8·368	80·752	—0·592	0·286	—9·509	8·510	—2·715	1680
1700	—8·357	81·000	—0·594	0·286	—9·520	8·537	—2·712	1700
1720	—8·346	81·247	—0·595	0·287	—9·531	8·563	—2·710	1720
1740	—8·335	81·492	—0·596	0·287	—9·542	8·589	—2·708	1740
1760	—8·324	81·735	—0·597	0·288	—9·553	8·615	—2·706	1760
1780	—8·313	81·976	—0·599	0·289	—9·564	8·641	—2·704	1780
1800	—8·301	82·215	—0·600	0·289	—9·574	8·667	—2·702	1800
1820	—8·290	82·453	—0·601	0·290	—9·584	8·693	—2·700	1820
1840	—8·279	82·690	—0·602	0·290	—9·594	8·718	—2·698	1840
1860	—8·269	82·926	—0·604	0·291	—9·604	8·744	—2·696	1860
1880	—8·258	83·161	—0·605	0·291	—9·614	8·769	—2·694	1880
1900	—8·248	83·394	—0·606	0·292	—9·624	8·794	—2·692	1900
1920	—8·238	83·625	—0·607	0·293	—9·634	8·819	—2·690	1920
1940	—8·228	83·854	—0·608	0·293	—9·644	8·843	—2·687	1940
1960	—8·218	84·082	—0·609	0·294	—9·654	8·868	—2·685	1960
1980	—8·208	84·309	—0·610	0·295	—9·664	8·892	—2·683	1980
2000	—8·197	84·534	—0·611	0·295	—9·674	8·917	—2·681	2000

* Ω functions also.

TABLE 8

Effective Calorific Value θ Functions

$$\text{E.C.V.} = h_p - \Big[H_{\text{air}}\Big]_{288\cdot16}^{T} - \bar{\text{C}}\theta_{\text{C}} - \bar{\text{H}}\theta_{\text{H}} - \bar{\text{O}}\theta_{\text{O}} - \ldots$$

where $\Big[H_{\text{air}}\Big]_{288\cdot16}^{T}$ = total heat of dry air from 288·16 to T°K

h_p = constant pressure lower calorific value of reactant at 288·16°K (15°C)

$\bar{\text{C}}$, $\bar{\text{H}}$, $\bar{\text{O}}$, etc. = carbon, hydrogen, oxygen, etc., content of reactant by weight

T°K	θ_C	θ_H	θ_O	θ_N	θ_S	θ_W	θ_{CO_2}	T°K
200	+11·8	− 175·5	+ 2·0	−0·8	+15·4	− 18·0	+4·6	200
220	8·4	− 135·8	1·5	−0·6	11·9	− 14·0	3·3	220
240	5·5	− 96·0	1·0	−0·4	8·4	− 9·9	2·2	240
260	3·0	− 56·2	0·6	−0·3	4·9	− 5·8	1·2	260
280	+ 0·8	− 16·3	+ 0·2	−0·1	+ 1·4	− 1·7	+0·3	280
300	− 1·1	+ 23·7	− 0·2	+0·1	− 2·0	+ 2·4	−0·5	300
320	− 2·6	63·7	− 0·6	0·2	− 5·2	6·5	−1·2	320
340	− 3·8	103·8	− 1·0	0·4	− 8·2	10·6	−1·8	340
360	− 4·8	144·0	− 1·4	0·6	−11·1	14·8	−2·3	360
380	− 5·6	184·4	− 1·8	0·7	−14·0	19·0	−2·8	380
400	− 6·1	225·0	− 2·2	0·9	−16·9	23·2	−3·2	400
420	− 6·4	265·8	− 2·5	1·0	−19·8	27·4	−3·5	420
440	− 6·4	306·8	− 2·8	1·1	−22·6	31·7	−3·8	440
460	− 6·2	348·0	− 3·1	1·3	−25·3	36·0	−4·0	460
480	− 5·9	389·3	− 3·4	1·4	−27·9	40·4	−4·1	480
500	− 5·5	430·8	− 3·7	1·5	−30·5	44·8	−4·2	500
520	− 5·0	472·5	− 3·9	1·7	−33·1	49·3	−4·3	520
540	− 4·4	514·4	− 4·1	1·8	−35·7	53·8	−4·3	540
560	− 3·6	556·6	− 4·3	1·9	−38·3	58·3	−4·3	560
580	− 2·7	599·1	− 4·6	2·0	−40·8	62·8	−4·2	580
600	− 1·7	642·0	− 4·9	2·2	−43·3	67·4	−4·1	600
620	− 0·6	685·2	− 5·1	2·3	−45·8	72·0	−4·0	620
640	+ 0·6	728·7	− 5·3	2·4	−48·3	76·7	−3·8	640
660	1·8	772·5	− 5·5	2·5	−50·8	81·4	−3·6	660
680	3·1	816·6	− 5·7	2·6	−53·3	86·2	−3·4	680
700	4·5	861·0	− 5·9	2·7	−55·8	91·0	−3·2	700
720	6·0	905·8	− 6·1	2·8	−58·3	95·8	−2·9	720
740	7·6	951·0	− 6·3	2·9	−60·8	100·7	−2·6	740
760	9·3	996·6	− 6·5	3·1	−63·3	105·6	−2·3	760
780	11·0	1042·6	− 6·7	3·2	−65·8	110·5	−2·0	780
800	12·8	1089·0	− 7·0	3·3	−68·3	115·5	−1·7	800
820	14·6	1135·8	− 7·2	3·4	−70·8	120·5	−1·4	820
840	16·5	1183·0	− 7·4	3·5	−73·3	125·6	−1·0	840
860	18·4	1230·6	− 7·6	3·6	−75·8	130·8	−0·6	860
880	20·4	1278·6	− 7·8	3·7	−78·3	136·0	−0·2	880
900	22·4	1327·1	− 8·0	3·9	−80·8	141·2	+0·2	900
920	24·5	1376·0	− 8·3	4·0	−83·3	146·5	0·6	920
940	26·7	1425·4	− 8·5	4·1	−85·9	151·8	1·0	940
960	28·9	1475·2	− 8·7	4·2	−88·5	157·2	1·4	960
980	+ 31·1	+1525·5	− 9·0	+4·3	−91·1	+162·6	+1·8	980

TABLE 8—*continued*

T°K	θ_C	θ_H	θ_O	θ_N	θ_B	θ_W	θ_{CO_2}	T°K
1000	33·4	1576·3	− 9·2	4·5	− 93·7	168·1	2·3	1000
1020	35·7	1627·6	− 9·4	4·6	− 96·3	173·6	2·8	1020
1040	38·0	1679·4	− 9·7	4·7	− 98·9	179·2	3·3	1040
1060	40·4	1731·6	−10·0	4·9	−101·5	184·8	3·8	1060
1080	42·8	1784·3	−10·2	5·0	−104·1	190·5	4·2	1080
1100	45·3	1837·5	−10·5	5·1	−106·7	196·2	4·7	1100
1120	47·8	1891·2	−10·8	5·3	−109·4	202·0	5·2	1120
1140	50·4	1945·4	−11·0	5·4	−112·1	207·8	5·7	1140
1160	53·0	2000·1	−11·3	5·5	−114·8	213·6	6·2	1160
1180	55·6	2055·3	−11·6	5·7	−117·5	219·5	6·7	1180
1200	58·2	2110·9	−11·9	5·9	−120·2	225·5	7·2	1200
1220	60·8	2167·0	−12·2	6·0	−122·9	231·5	7·7	1220
1240	63·5	2223·5	−12·4	6·1	−125·6	237·6	8·2	1240
1260	66·2	2280·5	−12·7	6·3	−128·3	243·7	8·8	1260
1280	68·9	2338·0	−13·0	6·4	−131·0	249·9	9·3	1280
1300	71·7	2395·9	−13·3	6·6	−133·7	256·1	9·8	1300
1320	74·5	2454·3	−13·6	6·7	−136·4	262·4	10·3	1320
1340	77·3	2513·2	−13·9	6·9	−139·2	268·7	10·8	1340
1360	80·1	2572·5	−14·2	7·0	−142·0	275·1	11·4	1360
1380	82·9	2632·2	−14·6	7·2	−144·8	281·5	11·9	1380
1400	85·7	2692·4	−14·9	7·3	−147·6	287·9	12·4	1400
1420	88·6	2753·0	−15·2	7·5	−150·4	294·4	13·0	1420
1440	91·5	2814·0	−15·6	7·6	−153·2	301·0	13·6	1440
1460	94·4	2875·4	−15·9	7·8	−156·0	307·6	14·2	1460
1480	97·3	2937·2	−16·2	8·0	−158·8	314·2	14·8	1480
1500	100·3	2999·4	−16·5	8·1	−161·7	320·9	15·3	1500
1520	103·3	3062·0	−16·9	8·3	−164·6	327·6	15·9	1520
1540	106·3	3125·1	−17·2	8·4	−167·5	334·3	16·4	1540
1560	109·3	3188·6	−17·5	8·6	−170·4	341·1	17·1	1560
1580	112·3	3252·4	−17·8	8·8	−173·3	348·0	17·6	1580
1600	115·3	3316·5	−18·2	8·9	−176·2	354·9	18·2	1600
1620	118·3	3381·0	−18·5	9·1	−179·1	361·8	18·8	1620
1640	121·3	3445·9	−18·8	9·3	−182·0	368·8	19·4	1640
1660	124·3	3511·1	−19·2	9·4	−185·0	375·8	20·0	1660
1680	127·3	3576·6	−19·5	9·6	−188·0	382·8	20·6	1680
1700	130·4	3642·5	−19·8	9·8	−191·0	389·9	21·1	1700
1720	133·5	3708·7	−20·2	9·9	−194·0	397·0	21·7	1720
1740	136·6	3775·3	−20·5	10·0	−197·0	404·1	22·3	1740
1760	139·7	3842·2	−20·9	10·2	−200·0	411·3	22·9	1760
1780	142·8	3909·4	−21·2	10·4	−203·0	418·5	23·5	1780
1800	145·9	3976·9	−21·5	10·6	−206·0	425·8	24·1	1800
1820	149·0	4044·7	−22·0	10·8	−209·0	433·1	24·7	1820
1840	152·1	4112·8	−22·2	11·0	−212·0	440·4	25·3	1840
1860	155·2	4181·2	−22·5	11·1	−215·0	447·7	25·9	1860
1880	158·3	4249·9	−22·9	11·3	−218·1	455·1	26·5	1880
1900	161·4	4318·9	−23·2	11·4	−221·2	462·5	27·1	1900
1920	164·5	4388·1	−23·6	11·6	−224·3	470·0	27·7	1920
1940	167·7	4457·6	−23·9	11·8	−227·3	477·5	28·3	1940
1960	170·8	4527·3	−24·3	11·9	−230·3	485·0	28·9	1960
1980	173·9	4597·3	−24·6	12·1	−233·4	492·5	29·5	1980
2000	177·0	4667·6	−24·9	12·3	−236·5	500·1	30·1	2000

TABLE 9

Flame Temperature from Product Analyses

(*a*) Loss from measured constituents.

Temperature °K	Loss C.H.U./lb			
	Methane	Unburned fuel (Kerosene)	Hydrogen	Carbon monoxide
400	11936	10433	28790	2419
500	11927	10442	28900	2424
600	11920	10451	29010	2421
700	11920	10460	29115	2418
800	11925	10469	29215	2416
900	11929	10478	29305	2414
1000	11936	10488	29380	2412
1100	11942	10497	29450	2408
1200	11948	10506	29510	2404
1300	11955	10516	29560	2400
1400	11962	10525	29615	2396
1500	11969	10534	29660	2392
1600	11978	10543	29705	2388
1700	11986	10552	29740	2383
1800	11994	10561	29770	2378
1900	12003	10571	29800	2372
2000	12012	10580	29815	2367

(*b*) Equilibrium loss C.H.U./lb fuel for unmeasured constituents of dissociated products (NO, O, H, OH) C.H.U./lb kerosene.

Fuel/air ratio	0·03	0·04	0·05	0·03	0·04	0·05	0·03	0·04	0·05
Temperature °K	Pressure = 4·0 Atm			Pressure = 1·0 Atm			Pressure = 0·25 Atm		
1400	25	12	5	25	12	5	25	12	5
1600	40	26	18	40	26	18	40	26	18
1800	80	60	40	85	60	40	90	60	40
2000	180	130	96	210	145	98	215	151	105

TABLE 10

The Combustion of Standard Fuel in Dry Air*

$f = f_{air} + \frac{q}{1+q}\,\theta_{f(S)}$, where f and f_{air} are corresponding properties of the combustion products and of dry air

$q = (H_{air\,T_2} - H_{air\,T_1})/ECV_{T_2}$, where q is fuel/air ratio

T°K	Total heat $\theta_{H(S)}$	Entropy function $\theta_{\varphi(S)}$	Specific heat $\theta_{c_{p(S)}}$	Effective calorific value (C.H.U./lb) (T_F = 15°C)
200	16·4	−0·610	0·1255	10335·4
220	19·2	−0·528	0·1431	10327·9
240	22·2	−0·446	0·1601	10320·1
260	25·5	−0·362	0·1764	10312·0
280	29·1	−0·276	0·1919	10303·5
300	33·0	−0·188	0·2066	10294·7
320	37·2	−0·100	0·2204	10285·7
340	41·7	−0·013	0·2333	10276·4
360	46·5	+0·073	0·2454	10266·8
380	51·5	0·159	0·2566	10257·0
400	56·8	0·244	0·2670	10246·9
420	62·3	0·328	0·2766	10236·6
440	68·0	0·411	0·2856	10226·1
460	73·8	0·493	0·2941	10215·4
480	79·8	0·574	0·3022	10204·6
500	85·9	0·653	0·3099	10193·6
520	92·1	0·731	0·3173	10182·4
540	98·5	0·807	0·3244	10171·0
560	105·1	0·882	0·3313	10159·5
580	111·8	0·956	0·3380	10147·8
600	118·6	1·029	0·3444	10136·0
620	125·5	1·101	0·3506	10124·0
640	132·6	1·173	0·3567	10111·9
660	139·8	1·244	0·3626	10099·7
680	147·1	1·313	0·3684	10087·3
700	154·5	1·381	0·3742	10074·7
720	162·0	1·448	0·3799	10062·0
740	169·6	1·514	0·3855	10049·2
760	177·3	1·579	0·3911	10036·3
780	185·2	1·644	0·3966	10023·2
800	193·2	1·708	0·4021	10010·0
820	201·3	1·772	0·4075	9996·7
840	209·5	1·835	0·4129	9983·2
860	217·8	1·897	0·4183	9969·6
880	226·2	1·958	0·4236	9955·9
900	234·7	2·018	0·4288	9942·0
920	243·3	2·078	0·4340	9928·0
940	252·0	2·138	0·4392	9913·9
960	260·8	2·197	0·4444	9899·7
980	269·7	+2·256	0·4495	9885·4

* $\overline{C}$ = 0·8608, $\overline{H}$ = 0·1392, h_p = 10,300 C.H.U./lb at 15°C.

TABLE 10—*continued*

T°K	Total heat $\theta_{H(S)}$	Entropy function $\theta_{\varphi(S)}$	Specific heat $\theta_{c_p(S)}$	Effective calorific value (C.H.U./lb) (T_F = 15°C)
1000	278·8	2·314	0·4546	9870·9
1020	288·0	2·372	0·4597	9856·3
1040	297·3	2·429	0·4647	9841·6
1060	306·6	2·485	0·4697	9826·8
1080	316·0	2·541	0·4747	9811·9
1100	325·5	2·596	0·4796	9796·8
1120	335·1	2·651	0·4844	9781·6
1140	344·8	2·705	0·4892	9766·3
1160	354·6	2·759	0·4939	9750·9
1180	364·5	2·813	0·4985	9735·4
1200	374·5	2·866	0·5030	9719·8
1220	384·6	2·919	0·5075	9704·1
1240	394·8	2·972	0·5119	9688·3
1260	405·0	3·025	0·5163	9672·4
1280	415·4	3·077	0·5206	9656·4
1300	425·9	3·128	0·5248	9640·3
1320	436·4	3·179	0·5289	9624·1
1340	447·0	3·230	0·5329	9607·8
1360	457·7	3·280	0·5369	9591·4
1380	468·4	3·330	0·5409	9574·9
1400	479·2	3·380	0·5448	9558·3
1420	490·1	3·429	0·5486	9541·7
1440	501·1	3·478	0·5523	9525·0
1460	512·2	3·527	0·5559	9508·2
1480	523·4	3·575	0·5594	9491·3
1500	534·6	3·623	0·5629	9474·3
1520	545·8	3·670	0·5663	9457·2
1540	557·1	3·717	0·5696	9440·1
1560	568·5	3·764	0·5728	9422·9
1580	580·0	3·810	0·5759	9405·6
1600	591·5	3·856	0·5789	9388·3
1620	603·1	3·901	0·5819	9370·9
1640	614·7	3·946	0·5848	9353·4
1660	626·4	3·991	0·5876	9335·8
1680	638·2	4·036	0·5904	9318·2
1700	650·0	4·081	0·5931	9300·5
1720	661·9	4·125	0·5957	9282·8
1740	673·8	4·169	0·5983	9265·0
1760	685·7	4·213	0·6008	9247·2
1780	697·7	4·256	0·6032	9229·3
1800	709·8	4·299	0·6056	9211·3
1820	721·9	4·341	0·6079	9193·2
1840	734·1	4·383	0·6102	9175·1
1860	746·3	4·425	0·6124	9157·0
1880	758·6	4·467	0·6145	9138·8
1900	770·9	4·509	0·6165	9120·6
1920	783·2	4·550	0·6185	9102·3
1940	795·5	4·591	0·6204	9084·0
1960	807·9	4·631	0·6222	9065·7
1980	820·3	4·671	0·6240	9047·3
2000	832·8	4·711	0·6258	9028·9

(73938) F

TABLE 11

General Flow and Expansion Functions for any Gas

MC_p	γ	$\frac{\gamma}{\gamma - 1}$	$\frac{\gamma - 1}{\gamma}$	$\frac{2}{\gamma - 1}$	$\sqrt{\left(\frac{RJ}{M_o g\gamma}\right)}$
6·7	1·4213	3·374	0·2964	4·748	1·449
6·8	1·4125	3·424	0·2920	4·848	1·454
6·9	1·4041	3·475	0·2878	4·949	1·458
7·0	1·3961	3·525	0·2837	5·050	1·462
7·1	1·3883	3·575	0·2797	5·151	1·466
7·2	1·3809	3·626	0·2758	5·251	1·470
7·3	1·3737	3·676	0·2720	5·352	1·474
7·4	1·3668	3·726	0·2684	5·453	1·478
7·5	1·3601	3·777	0·2648	5·553	1·481
7·6	1·3537	3·827	0·2613	5·654	1·485
7·7	1·3475	3·877	0·2579	5·755	1·488
7·8	1·3416	3·928	0·2546	5·856	1·491
7·9	1·3358	3·978	0·2514	5·956	1·495
8·0	1·3302	4·028	0·2482	6·057	1·498
8·1	1·3248	4·079	0·2452	6·158	1·501
8·2	1·3196	4·129	0·2422	6·258	1·504
8·3	1·3145	4·180	0·2393	6·359	1·507
8·4	1·3096	4·230	0·2364	6·460	1·510
8·5	1·3049	4·280	0·2336	6·561	1·512
8·6	1·3002	4·331	0·2309	6·661	1·515
8·7	1·2958	4·381	0·2283	6·762	1·518
8·8	1·2914	4·431	0·2257	6·863	1·520
8·9	1·2872	4·482	0·2231	6·963	1·523
9·0	1·2831	4·532	0·2207	7·064	1·525
9·1	1·2791	4·582	0·2182	7·165	1·527
9·2	1·2753	4·633	0·2159	7·266	1·530
9·3	1·2715	4·683	0·2135	7·366	1·532
9·4	1·2678	4·733	0·2113	7·467	1·534
9·5	1·2643	4·784	0·2090	7·568	1·536
9·6	1·2608	4·834	0·2069	7·668	1·539
9·7	1·2574	4·885	0·2047	7·769	1·541
9·8	1·2541	4·935	0·2026	7·870	1·543
9·9	1·2509	4·985	0·2006	7·970	1·545
10·0	1·2478	5·036	0·1986	8·071	1·547
10·1	1·2447	5·086	0·1966	8·172	1·548
10·2	1·2418	5·136	0·1947	8·273	1·550
10·3	1·2389	5·187	0·1928	8·373	1·552
10·4	1·2360	5·237	0·1909	8·474	1·554
10·5	1·2332	5·287	0·1891	8·575	1·556
10·6	1·2305	5·338	0·1873	8·675	1·557
10·7	1·2279	5·388	0·1856	8·776	1·559
10·8	1·2253	5·438	0·1839	8·877	1·561
10·9	1·2228	5;489	0·1822	8·978	1·562
11·0	1·2203	5·539	0·1805	9·078	1·564
11·1	1·2179	5·590	0·1789	9·179	1·565

TABLE 11—*continued*

MC_p	γ	$\frac{\gamma}{\gamma - 1}$	$\frac{\gamma - 1}{\gamma}$	$\frac{2}{\gamma - 1}$	$\sqrt{\left(\frac{RJ}{M_o g \gamma}\right)}$
11·2	1·2155	5·640	0·1773	9·280	1·567
11·3	1·2132	5·690	0·1757	9·380	1·568
11·4	1·2109	5·741	0·1742	9·481	1·570
11·5	1·2087	5·791	0·1727	9·582	1·571
11·6	1·2066	5·841	0·1712	9·683	1·573
11·7	1·2044	5·892	0·1697	9·783	1·574
11·8	1·2023	5·942	0·1683	9·884	1·576
11·9	1·2003	5·992	0·1669	9·985	1·577
12·0	1·1983	6·043	0·1655	10·085	1·578
12·1	1·1963	6·093	0·1641	10·186	1·579
12·2	1·1944	6·143	0·1628	10·287	1·581
12·3	1·1925	6·194	0·1615	10·388	1·582
12·4	1·1907	6·244	0·1602	10·488	1·583
12·5	1·1889	6·295	0·1589	10·589	1·584
12·6	1·1871	6·345	0·1576	10·690	1·586
12·7	1·1853	6·395	0·1564	10·790	1·587
12·8	1·1836	6·446	0·1551	10·891	1·588
12·9	1·1820	6·496	0·1539	10·992	1·589
13·0	1·1803	6·546	0·1528	11·093	1·590
13·1	1·1787	6·597	0·1516	11·193	1·591
13·2	1·1771	6·647	0·1504	11·294	1·592
13·3	1·1755	6·697	0·1493	11·395	1·593
13·4	1·1740	6·748	0·1482	11·495	1·594
13·5	1·1725	6·798	0·1471	11·596	1·595
13·6	1·1710	6·848	0·1460	11·697	1·596
13·7	1·1695	6·899	0·1450	11·798	1·597
13·8	1·1681	6·949	0·1439	11·898	1·598
13·9	1·1667	6·999	0·1429	11·999	1·599
14·0	1·1653	7·050	0·1418	12·100	1·600

(73938) F 2

TABLE 12

Flow and Expansion Functions for Air and the Combustion Products of Standard Fuel in Dry Air

C_p (C.H.U./lb)	MC_p	γ	$\frac{\gamma}{\gamma-1}$	$\frac{\gamma-1}{\gamma}$	$\frac{2}{\gamma-1}$	$\sqrt{\left(\frac{RJ}{M_0 g\gamma}\right)}$
0·2380	6·89	1·4046	3·472	0·2880	4·944	1·458
0·2400	6·95	1·3998	3·501	0·2856	5·002	1·460
0·2420	7·01	1·3952	3·530	0·2833	5·060	1·463
0·2440	7·07	1 3907	3·559	0·2809	5·119	1·465
0·2460	7·13	1·3863	3·589	0·2787	5·177	1·467
0·2480	7·18	1·3820	3·618	0·2764	5·235	1·470
0·2500	7·24	1·3778	3·647	0·2742	5·294	1·472
0·2520	7·30	1·3737	3·676	0·2720	5·352	1·474
0·2540	7·36	1·3697	3·705	0·2699	5·411	1·476
0·2560	7·42	1·3657	3·734	0·2678	5·469	1·478
0·2580	7·47	1·3618	3·764	0·2657	5·527	1·480
0·2600	7·53	1·3581	3·793	0·2637	5·586	1·482
0·2620	7·59	1·3544	3·822	0·2616	5·644	1·484
0·2640	7·65	1·3507	3·851	0·2597	5·702	1·486
0·2660	7·71	1·3472	3·880	0·2577	5·761	1·488
0·2680	7·76	1·3437	3·909	0·2558	5·819	1·490
0·2700	7·82	1·3403	3·939	0·2539	5·877	1·492
0·2720	7·88	1·3369	3·968	0·2520	5·936	1·494
0·2740	7·94	1·3337	3·997	0·2502	5·994	1·496
0·2760	8·00	1·3304	4·026	0·2484	6·052	1·498
0·2780	8·05	1·3273	4·055	0·2466	6·111	1·499
0·2800	8·11	1·3242	4·085	0·2448	6·169	1·501
0·2820	8·17	1·3212	4·114	0·2431	6·227	1·503
0·2840	8·23	1·3182	4·143	0·2414	6·286	1·505
0·2860	8·29	1·3153	4·172	0·2397	6·344	1·506
0·2880	8·34	1·3124	4·201	0·2380	6·402	1·508
0·2900	8·40	1·3096	4·230	0·2364	6·461	1·510
0·2920	8·46	1·3068	4·260	0·2348	6·519	1·511
0·2940	8·52	1·3041	4·289	0·2332	6·578	1·513
0·2960	8·57	1·3014	4·318	0·2316	6·636	1·514
0·2980	8·63	1·2988	4·347	0·2300	6·694	1·516
0·3000	8·69	1·2962	4·376	0·2285	6·753	1·517
0·3020	8·75	1·2936	4·405	0·2270	6·811	1·519
0·3040	8·81	1·2912	4·435	0·2255	6·869	1·520
0·3060	8·86	1·2887	4·464	0·2240	6·928	1·522
0·3080	8·92	1·2863	4·493	0·2226	6·986	1·523
0·3100	8·98	1·2839	4·522	0·2211	7·044	1·525
0·3120	9·04	1·2816	4·551	0·2197	7·103	1·526
0·3140	9·10	1·2793	4·581	0·2183	7·161	1·527
0·3160	9·15	1·2770	4·610	0·2169	7·219	1·529
0·3180	9·21	1·2748	4·639	0·2156	7·278	1·530
0·3200	9·27	1·2726	4·668	0·2142	7·336	1·531
0·3220	9·33	1·2705	4·697	0·2129	7·394	1·533
0·3240	9·39	1·2684	4·726	0·2116	7·453	1·534
0·3260	9·44	1·2663	4·756	0·2103	7·511	1·535
0·3280	9·50	1·2642	4·785	0·2090	7·569	1·536
0·3300	9·56	1·2622	4·814	0·2077	7·628	1·538
0·3320	9·62	1·2602	4·843	0·2065	7·686	1·539
0·3340	9·68	1·2582	4·872	0·2052	7·745	1·540
0·3360	9·73	1·2563	4·901	0·2040	7·803	1·541
0·3380	9·79	1·2544	4·931	0·2028	7·861	1·542
0·3400	9·85	1·2525	4·960	0·2016	7·920	1·544

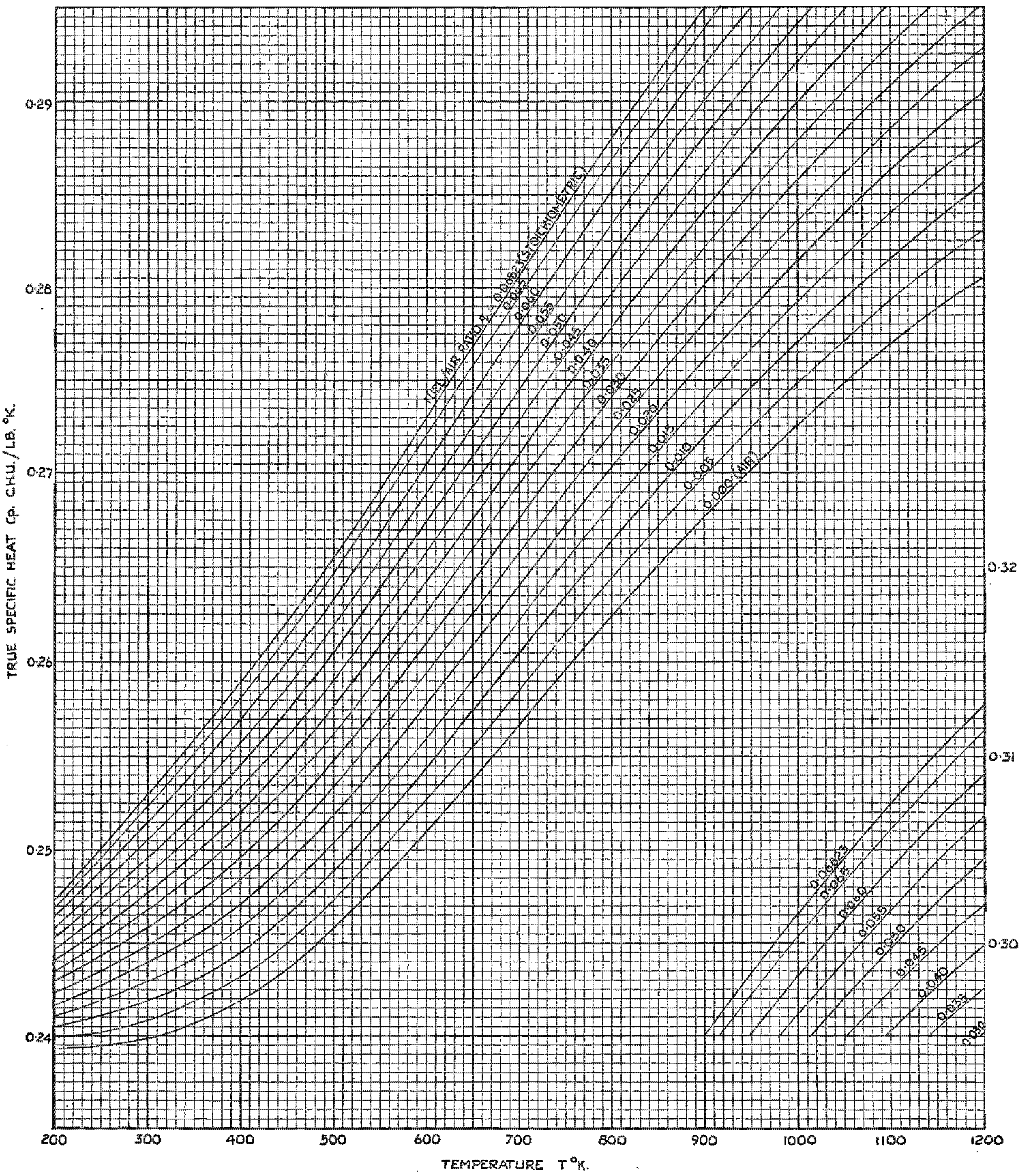


FIG. 1. Specific heat at constant pressure of standard fuel combustion products.

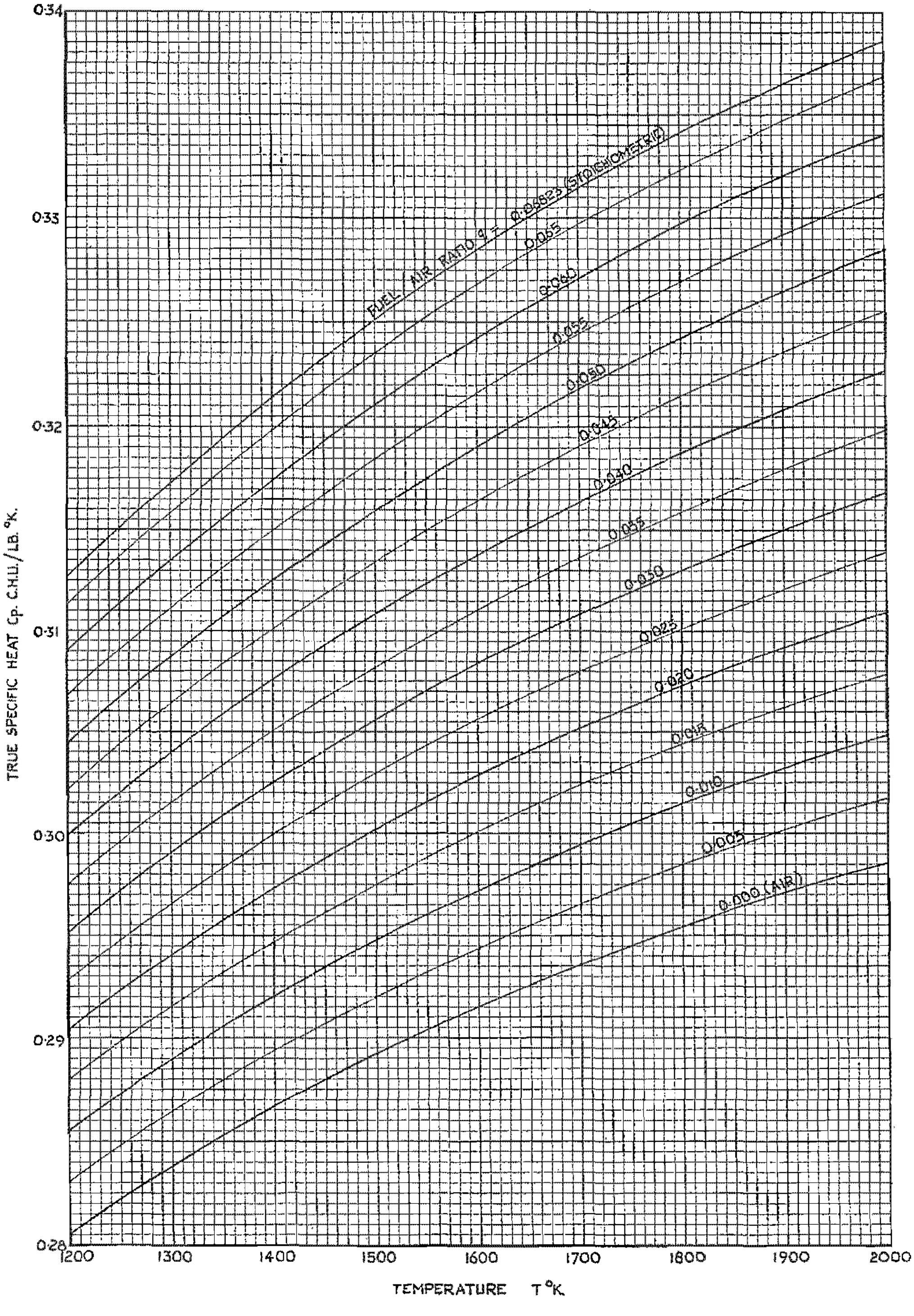


FIG. 2. Specific heat at constant pressure of standard fuel combustion products.

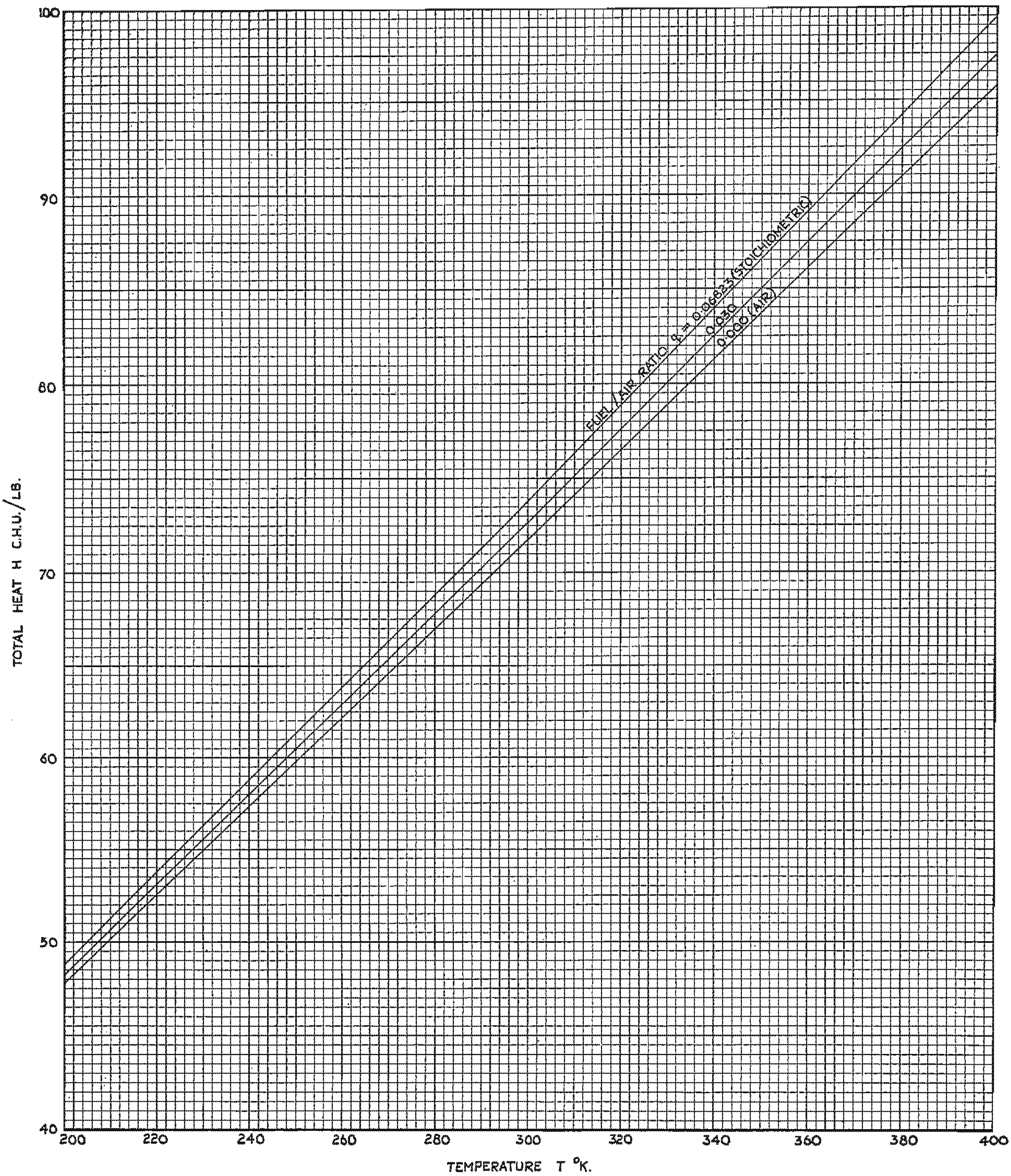


FIG. 3. Total heat above 0°K of standard fuel combustion products.

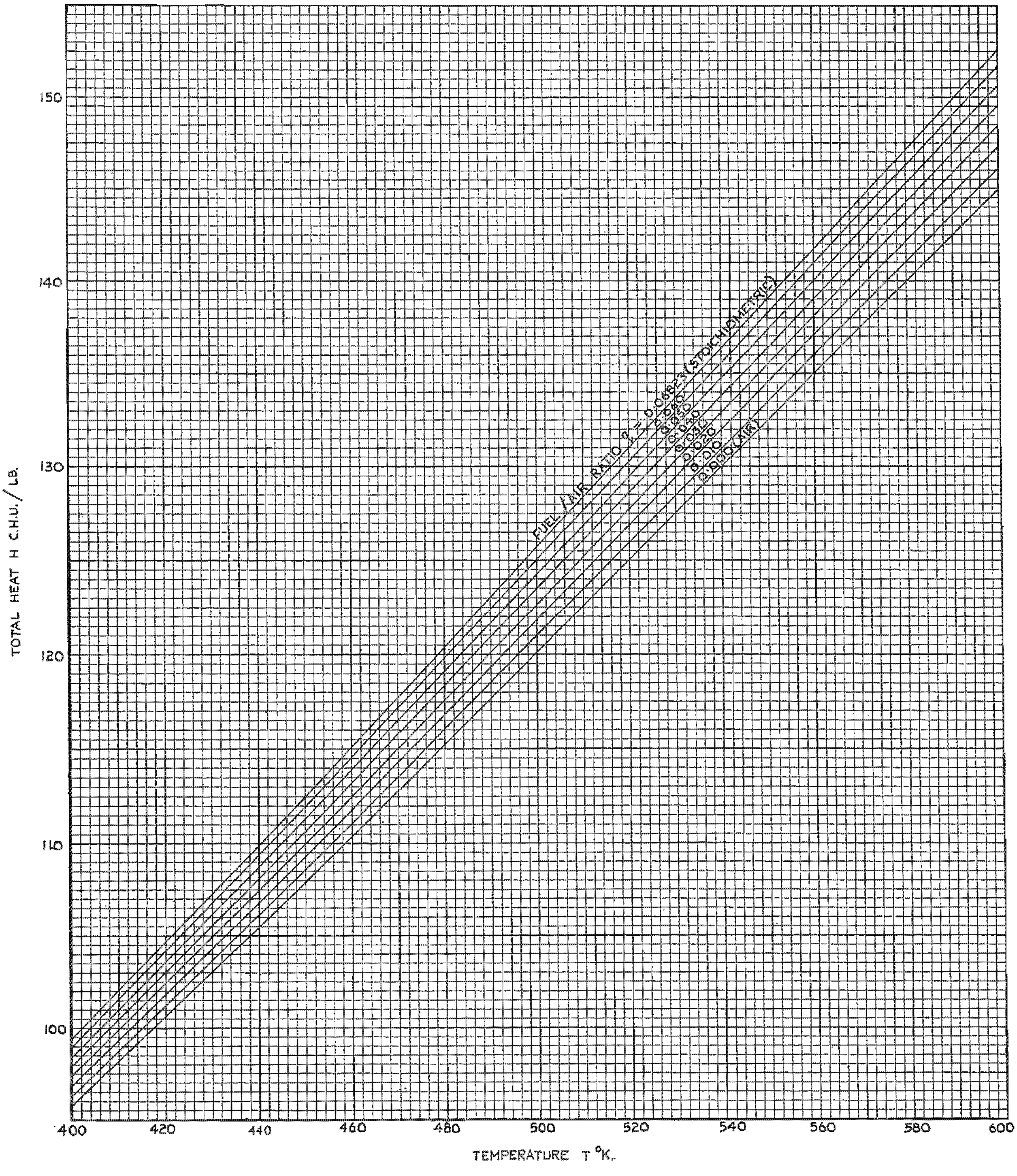


FIG. 4. Total heat above 0°K of standard fuel combustion products.

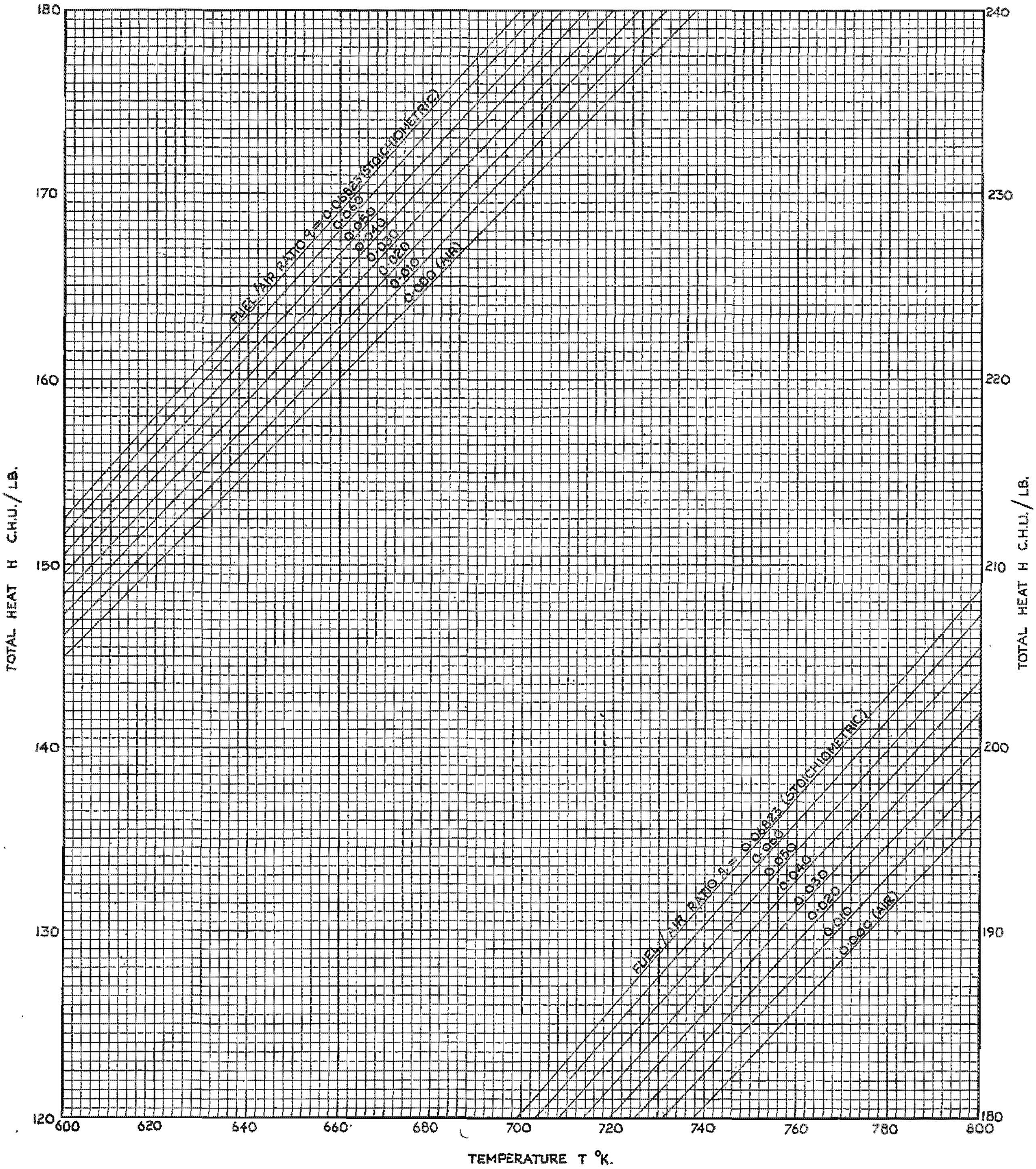


FIG. 5. Total heat above 0°K of standard fuel combustion products.

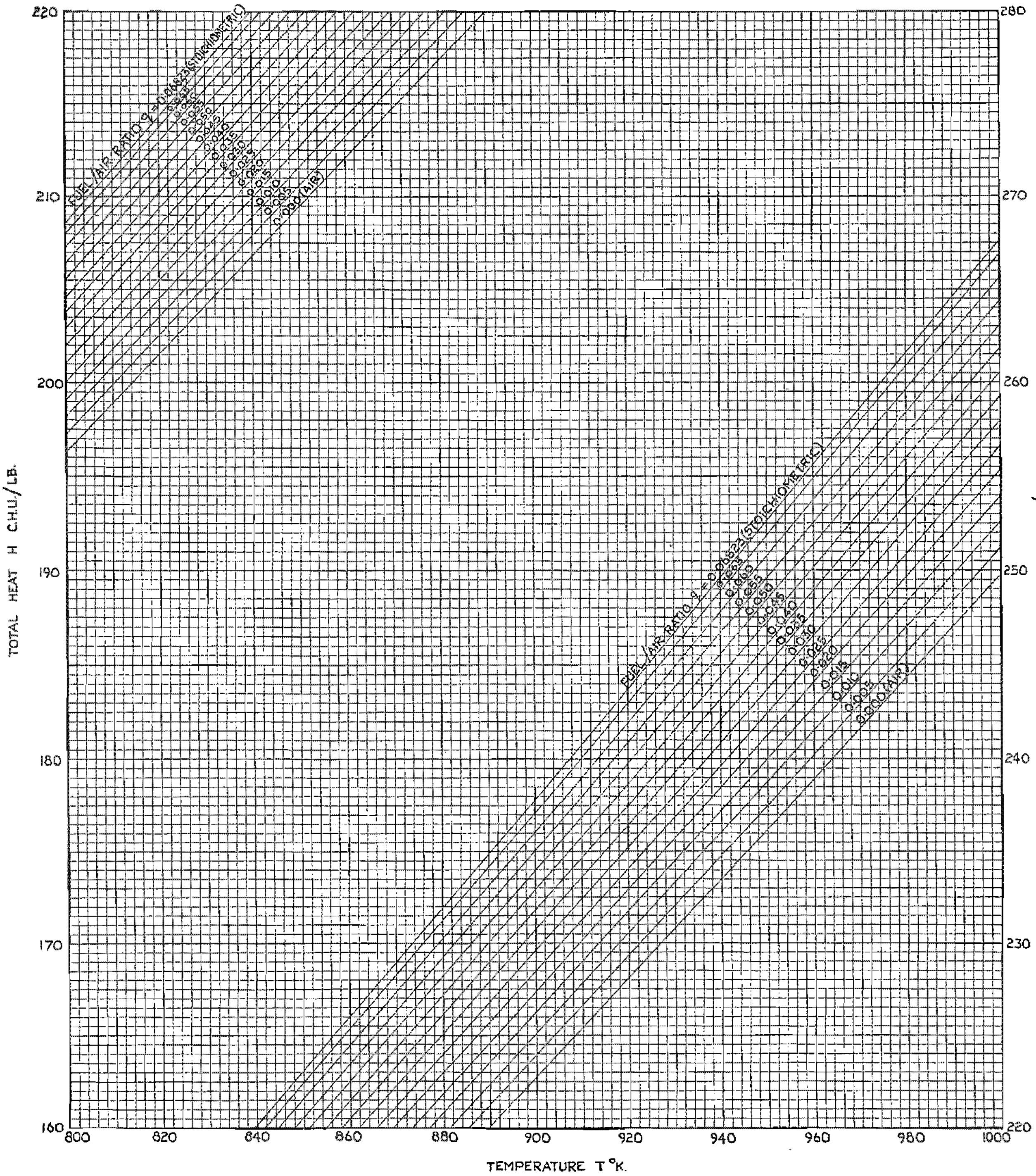


FIG. 6. Total heat above 0°K of standard fuel combustion products.

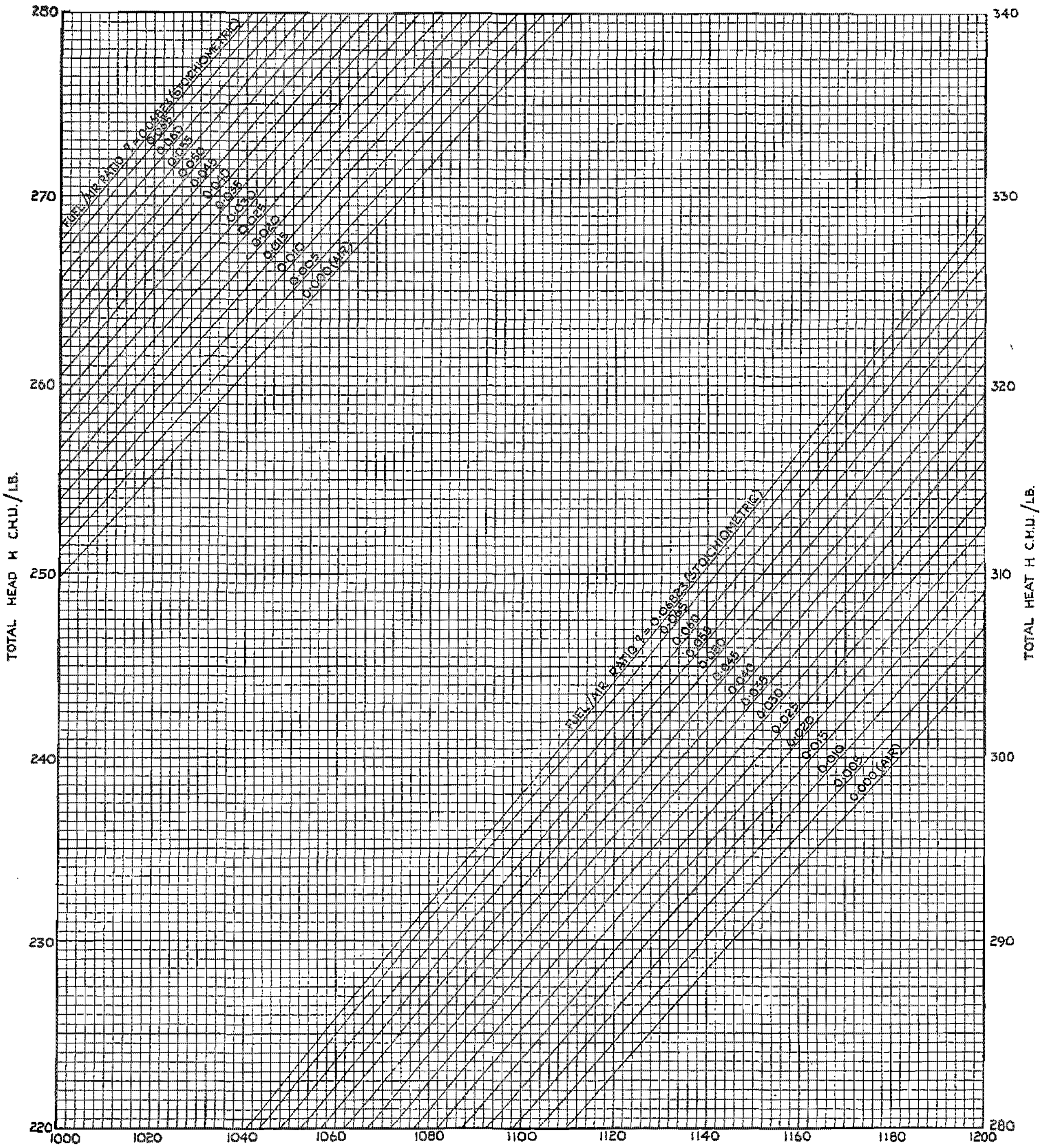


FIG. 7. Total heat above 0°K of standard fuel combustion products.

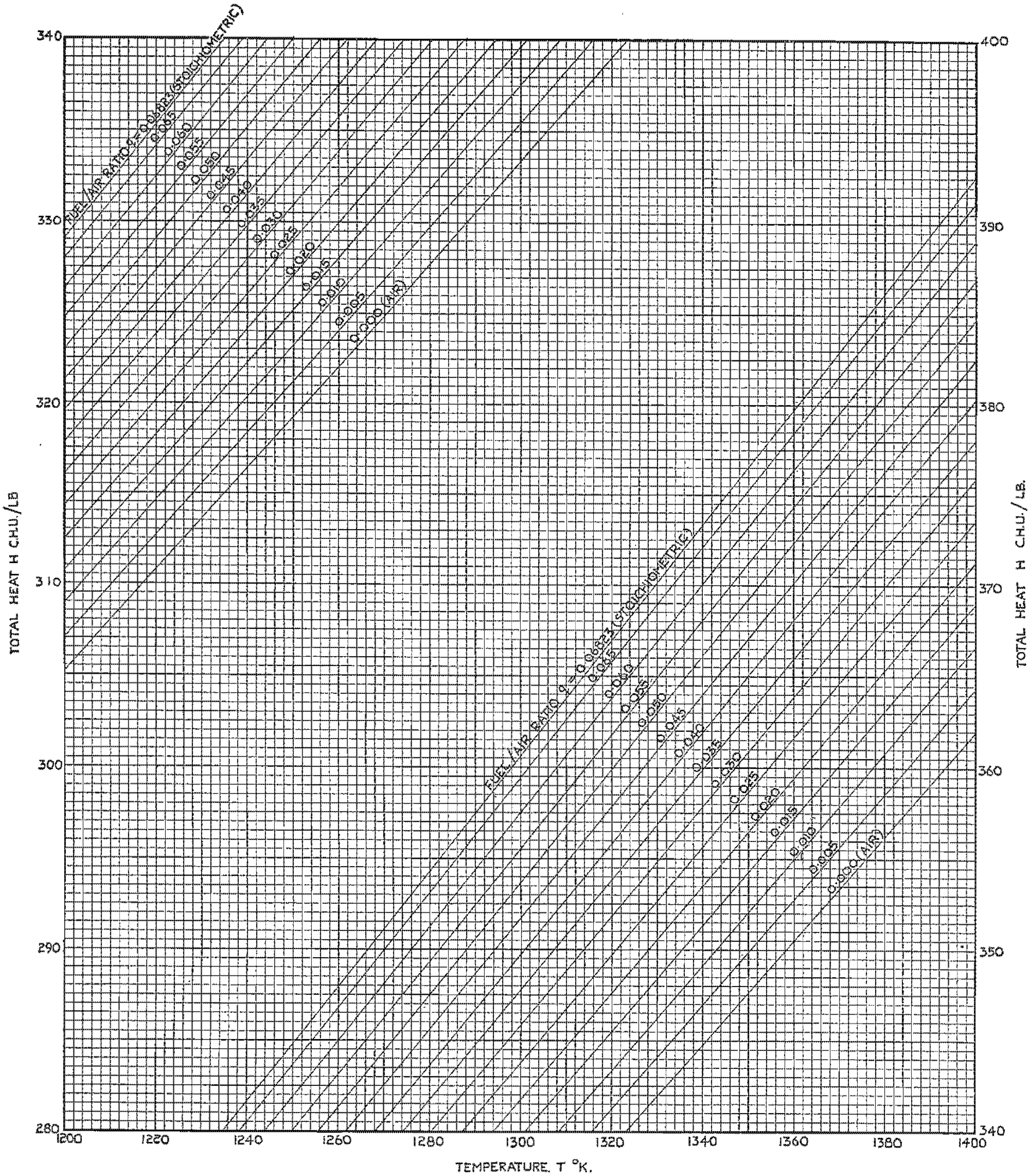


FIG. 8. Total heat above 0°K of standard fuel combustion products.

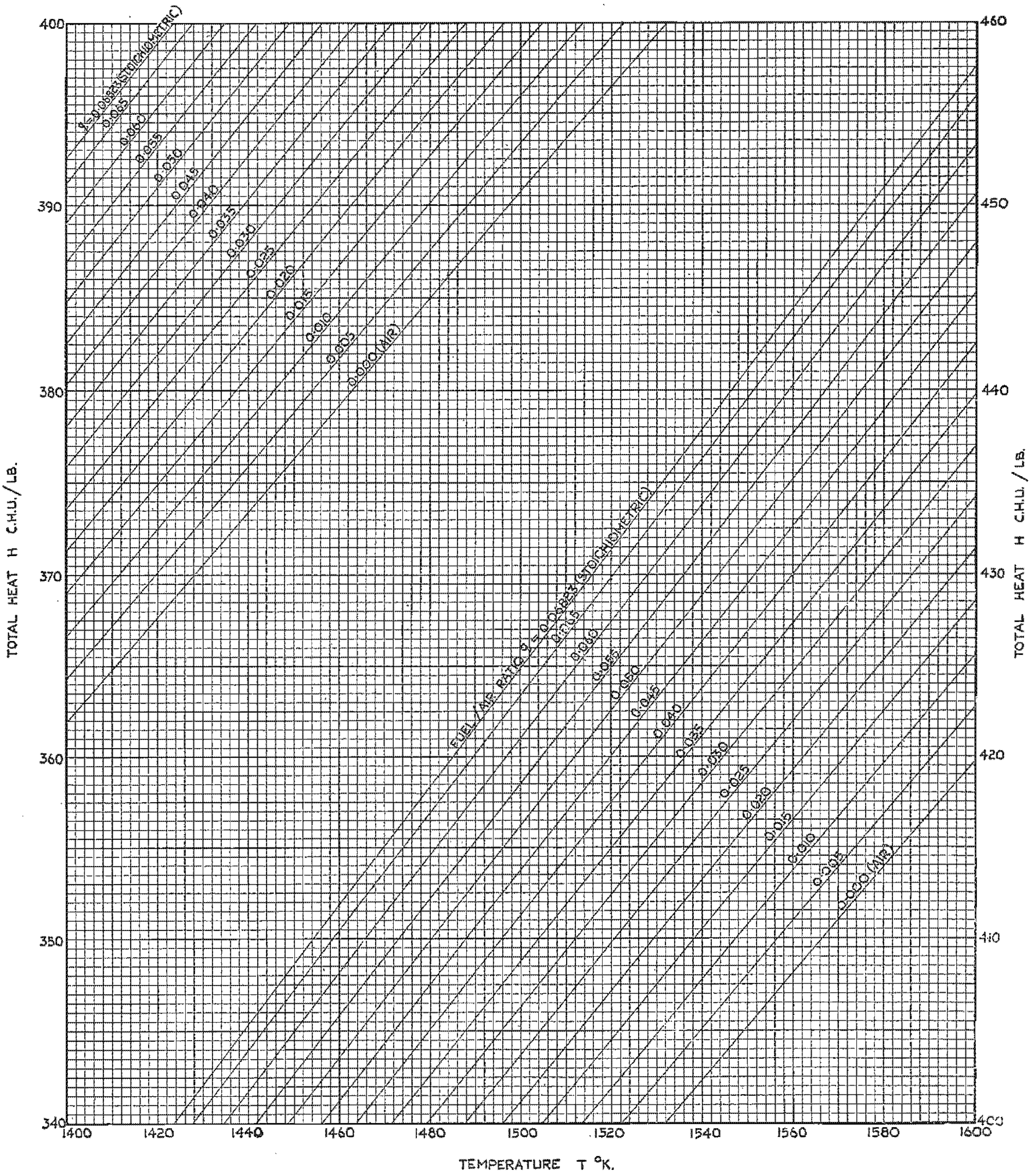


FIG. 9. Total heat above 0°K of standard fuel combustion products.

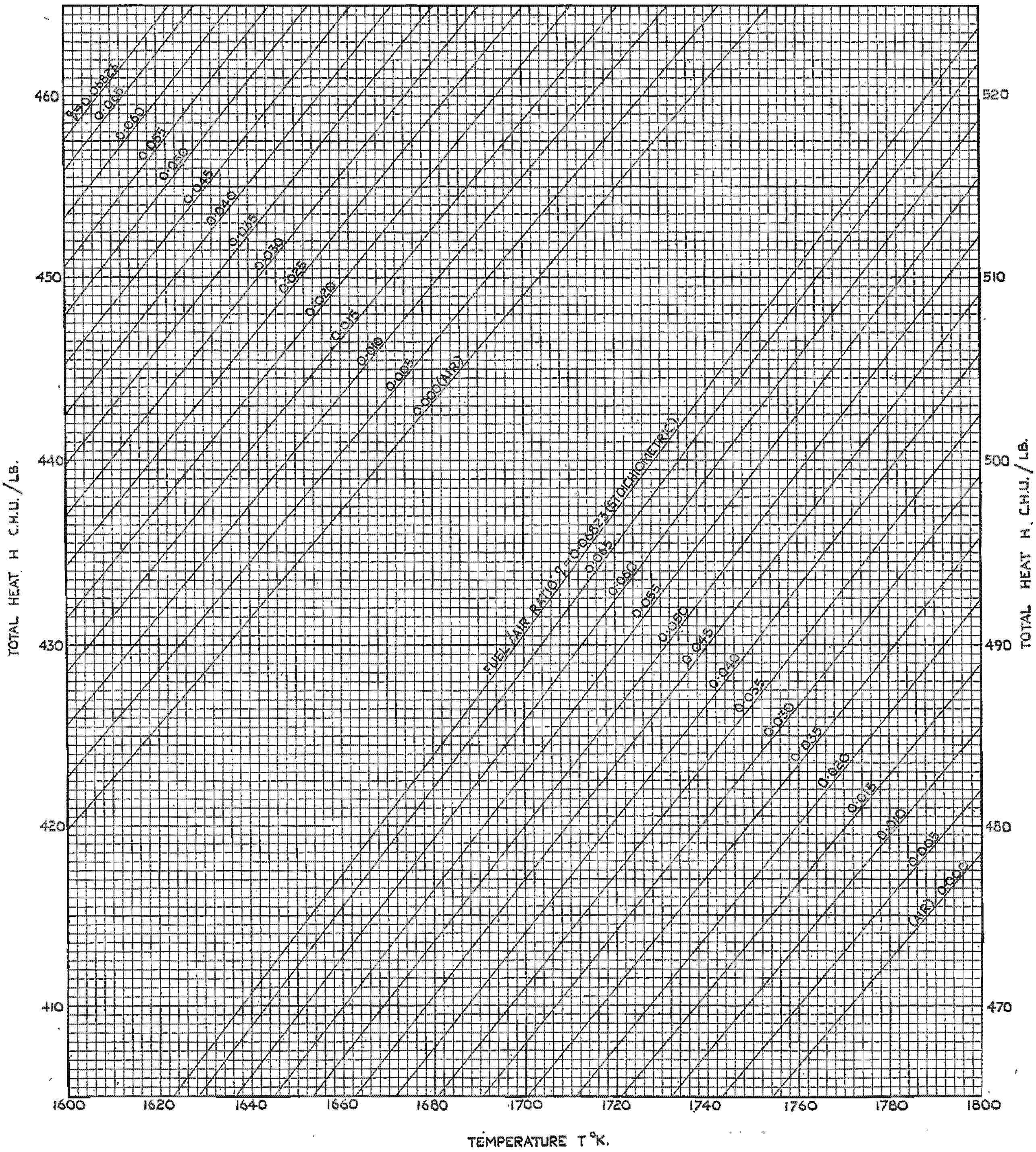


FIG. 10. Total heat above 0°K of standard fuel combustion products.

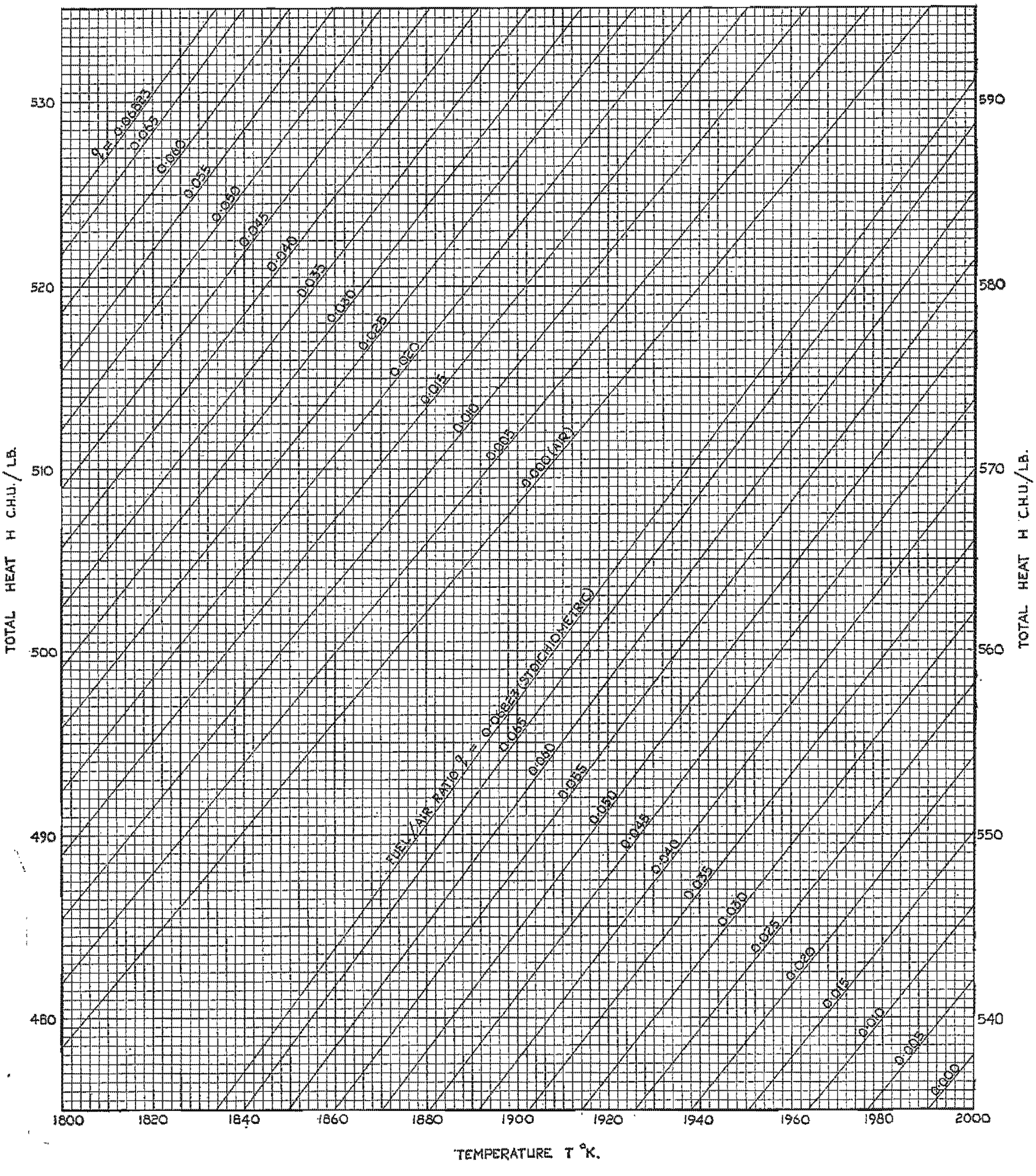


FIG. 11. Total heat above 0°K of standard fuel combustion products.

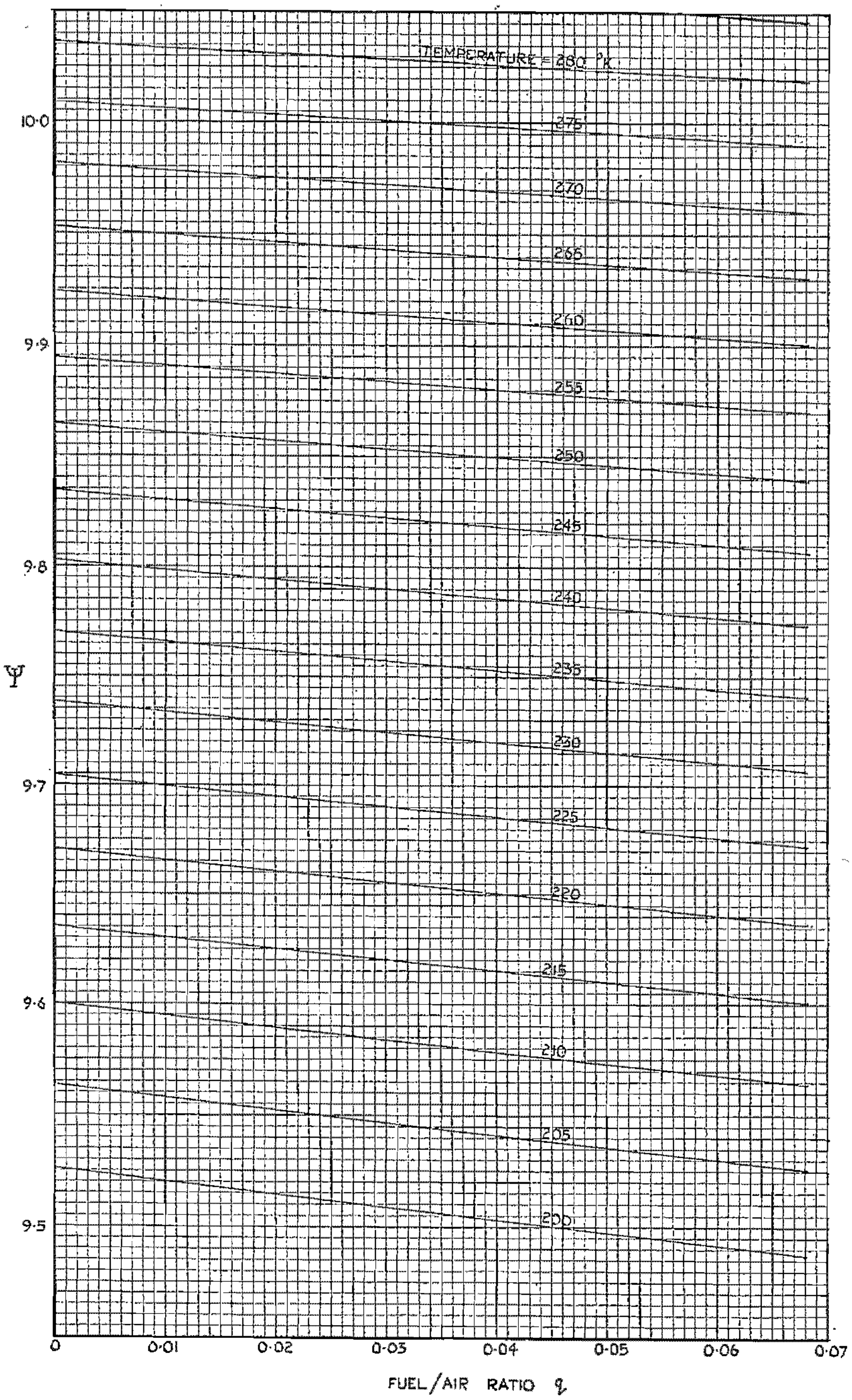


FIG. 12. Entropy function ψ of standard fuel combustion products.

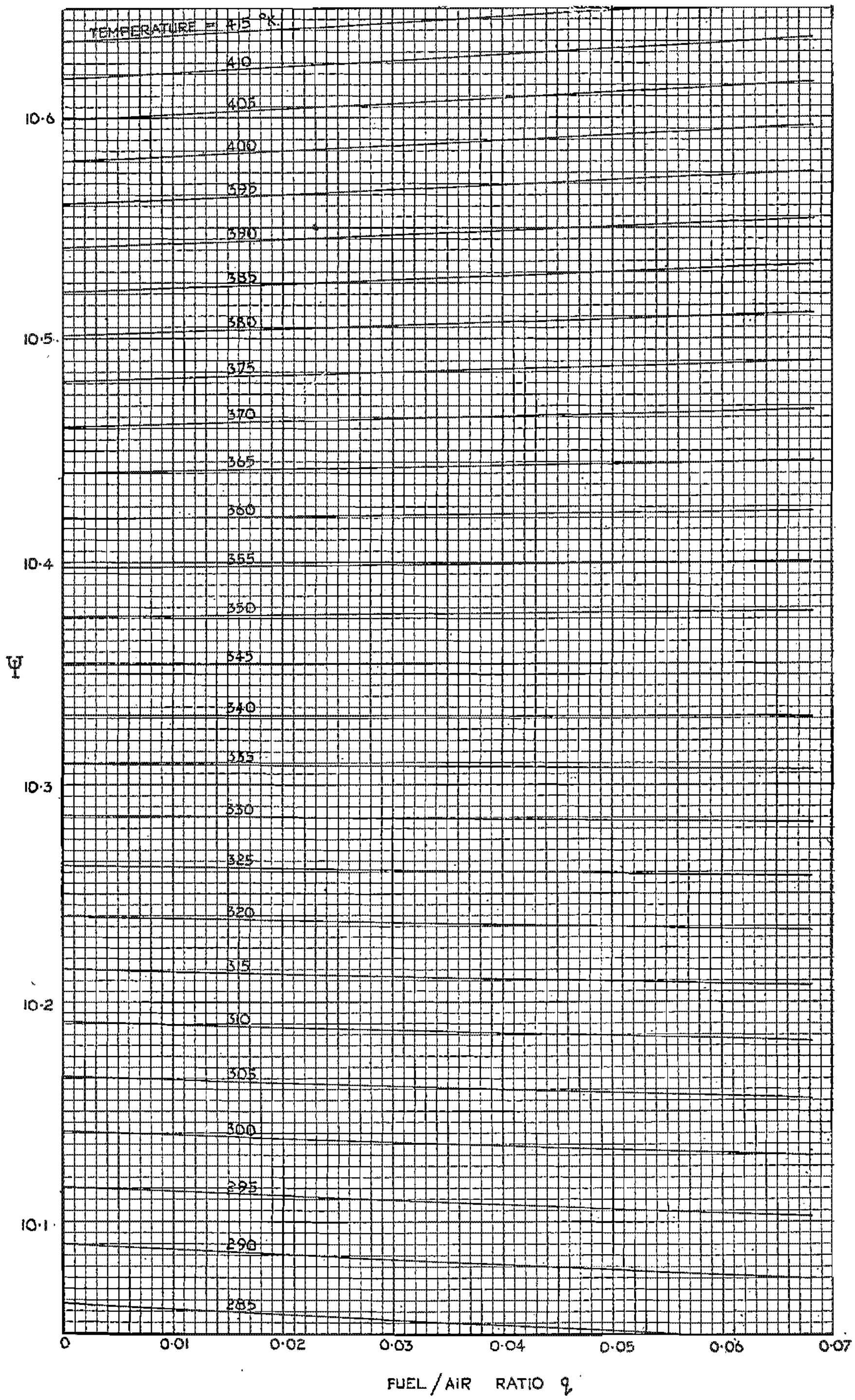


FIG. 13. Entropy function ψ of standard fuel combustion products.

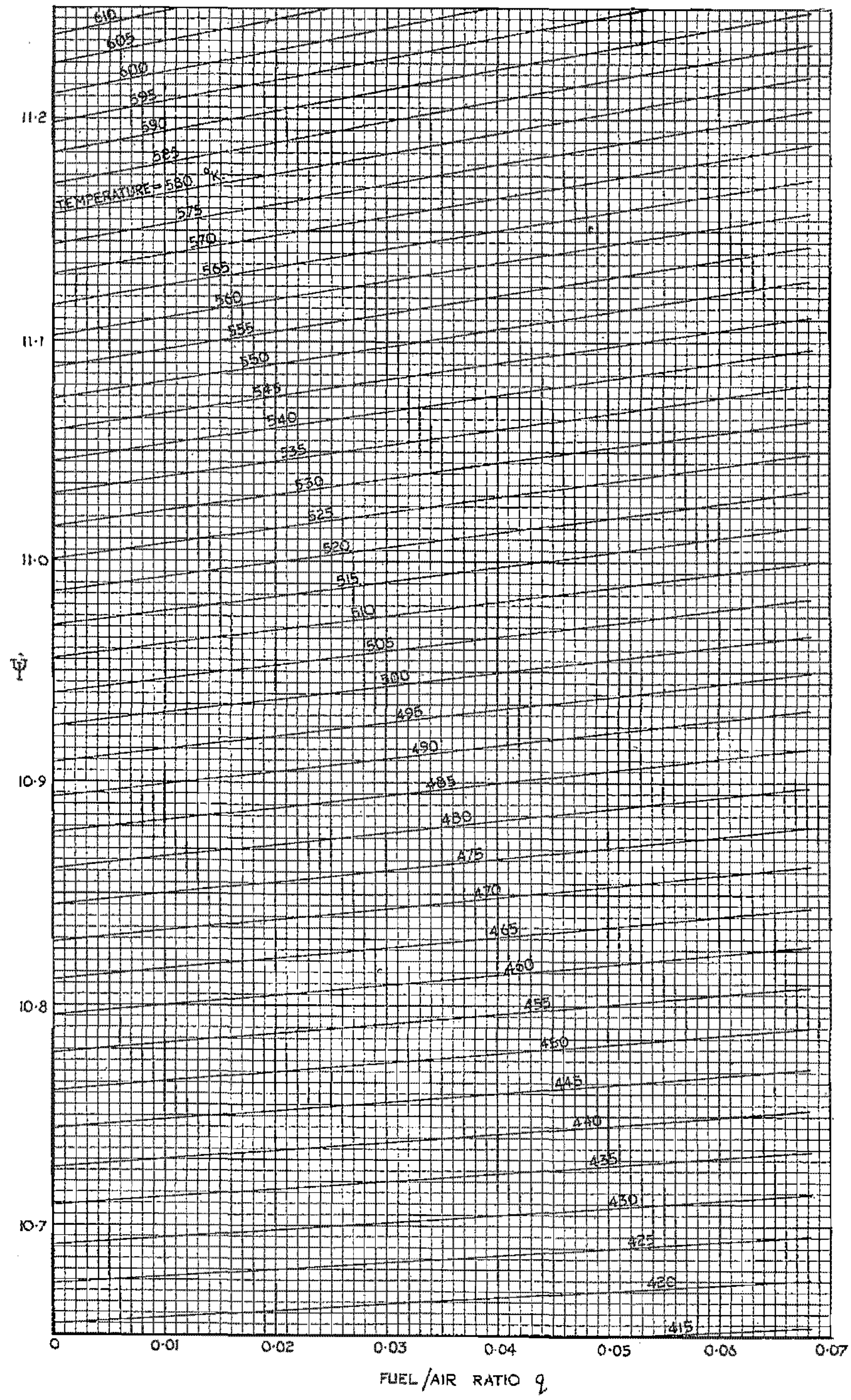


FIG. 14. Entropy function ψ of standard fuel combustion products.

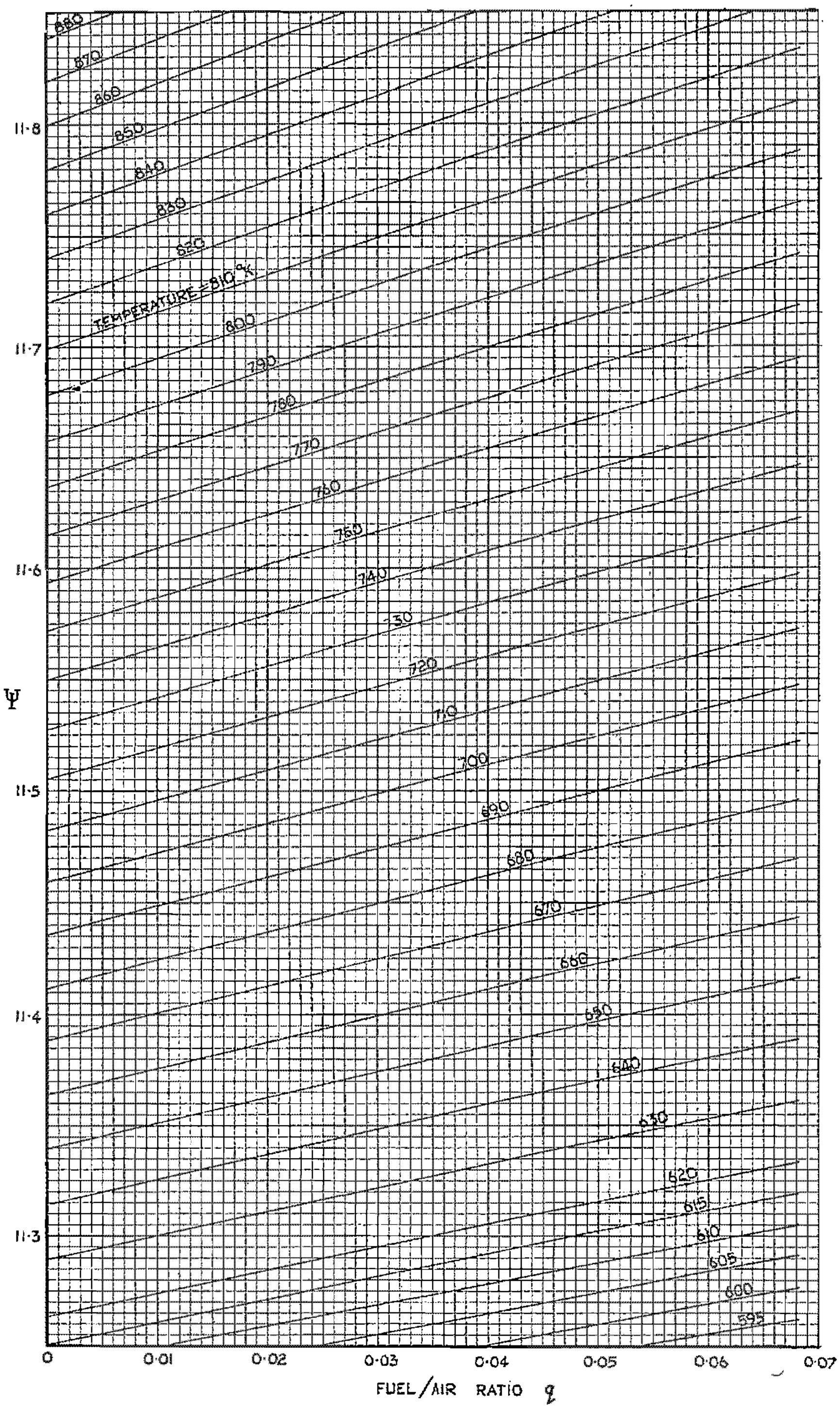


FIG. 15. Entropy-function ψ of standard fuel combustion products.

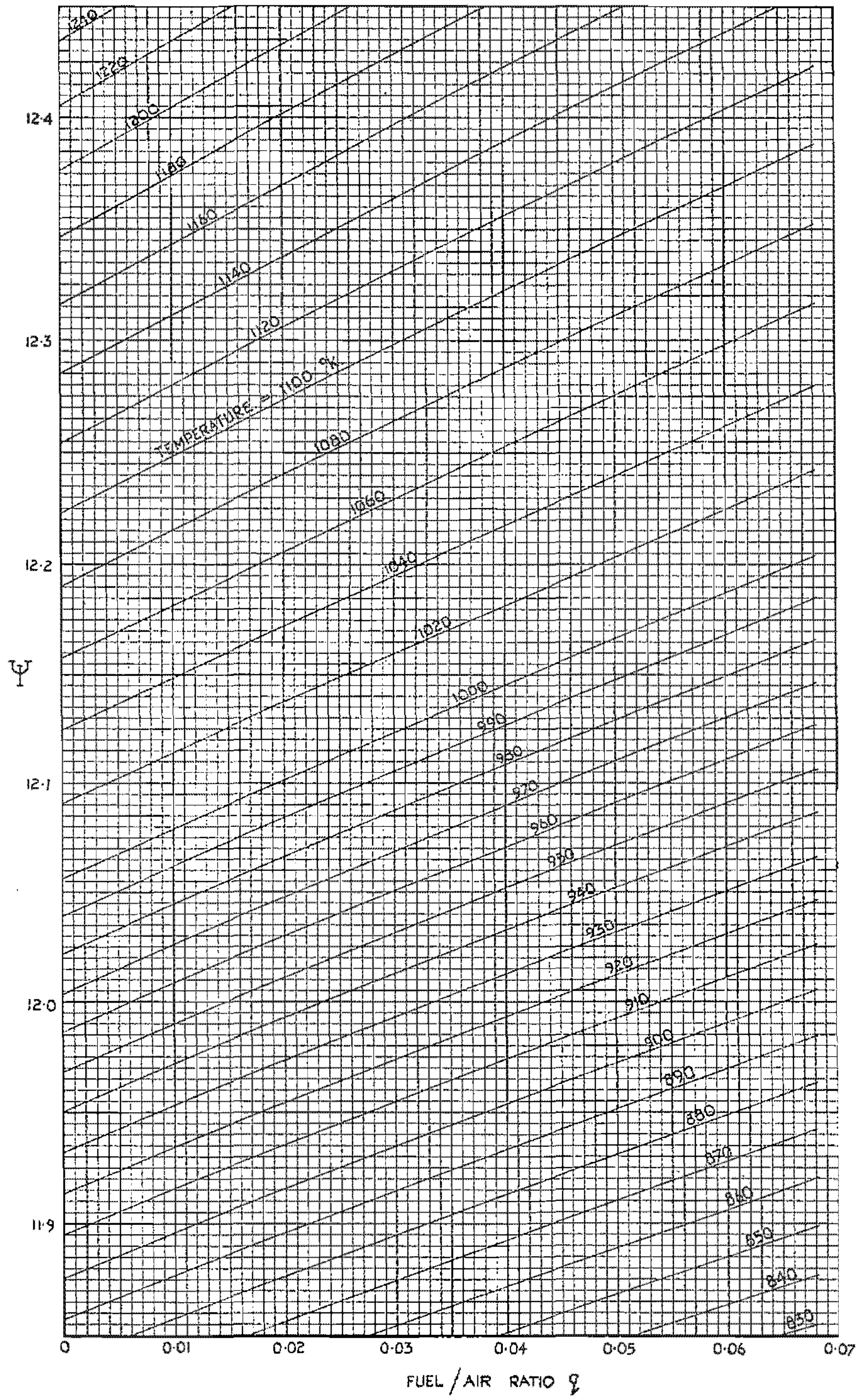


FIG. 16. Entropy function ψ of standard fuel combustion products.

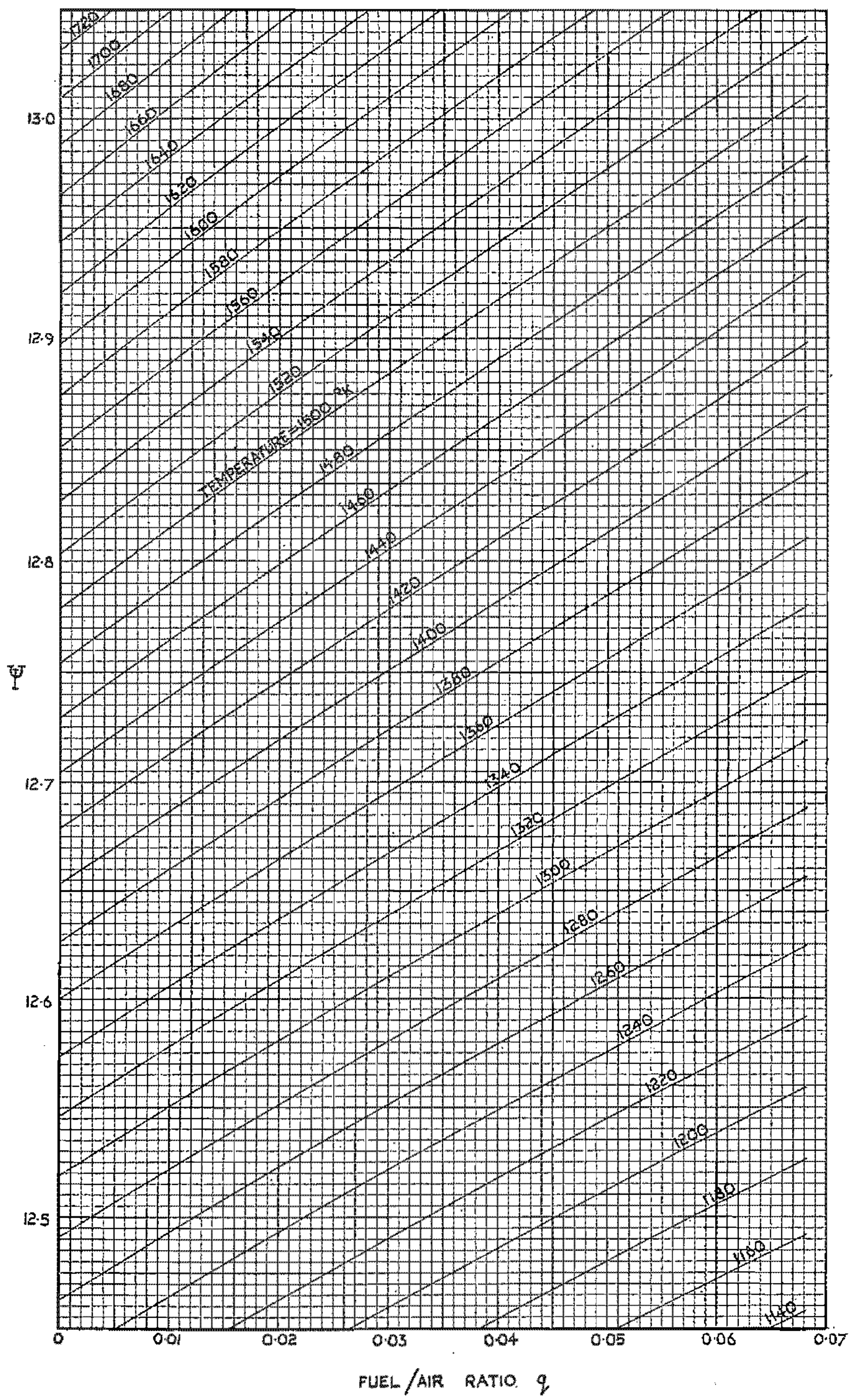


FIG. 17. Entropy function ψ of standard fuel combustion products.

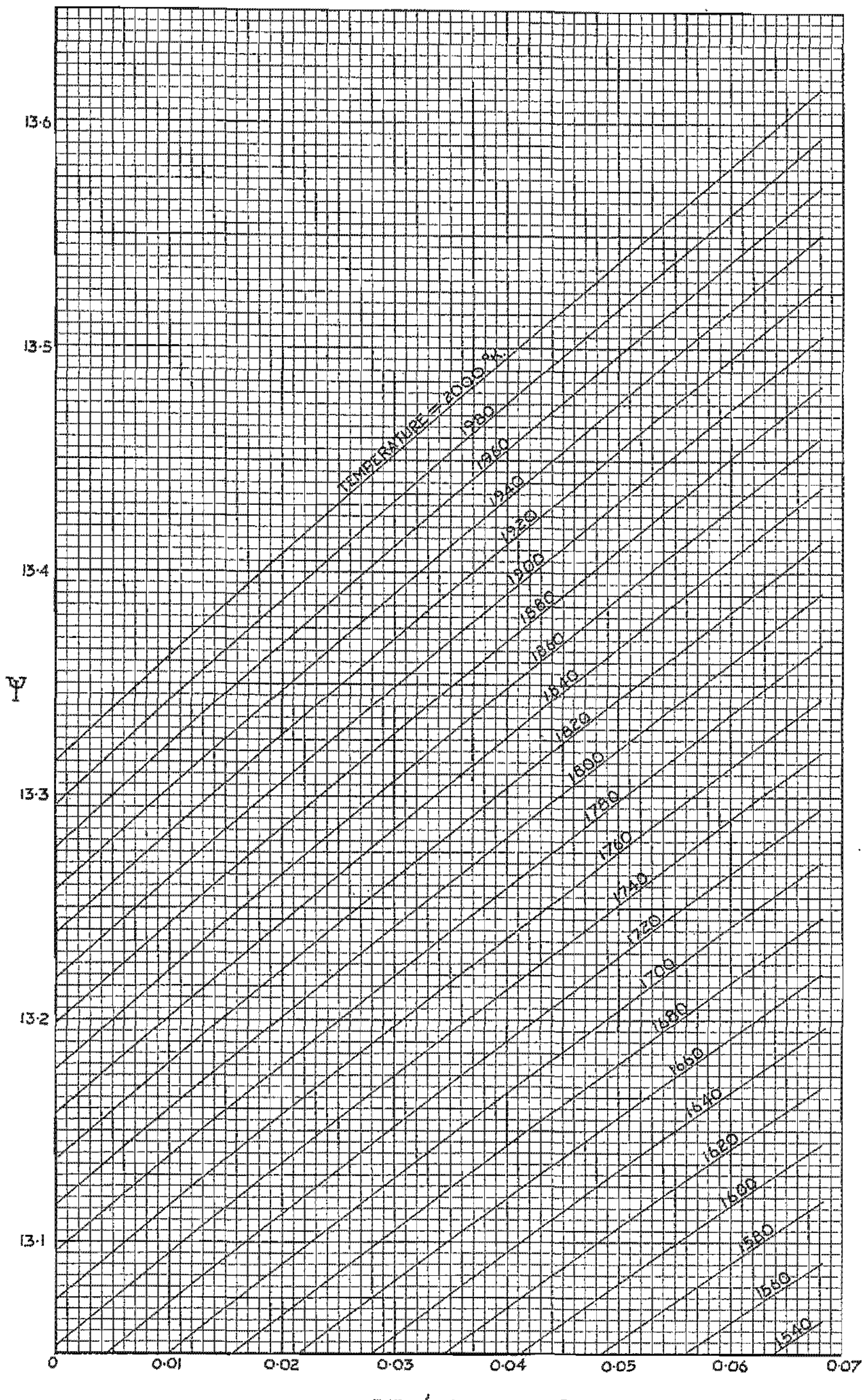


FIG. 18. Entropy function ψ of standard fuel combustion products.

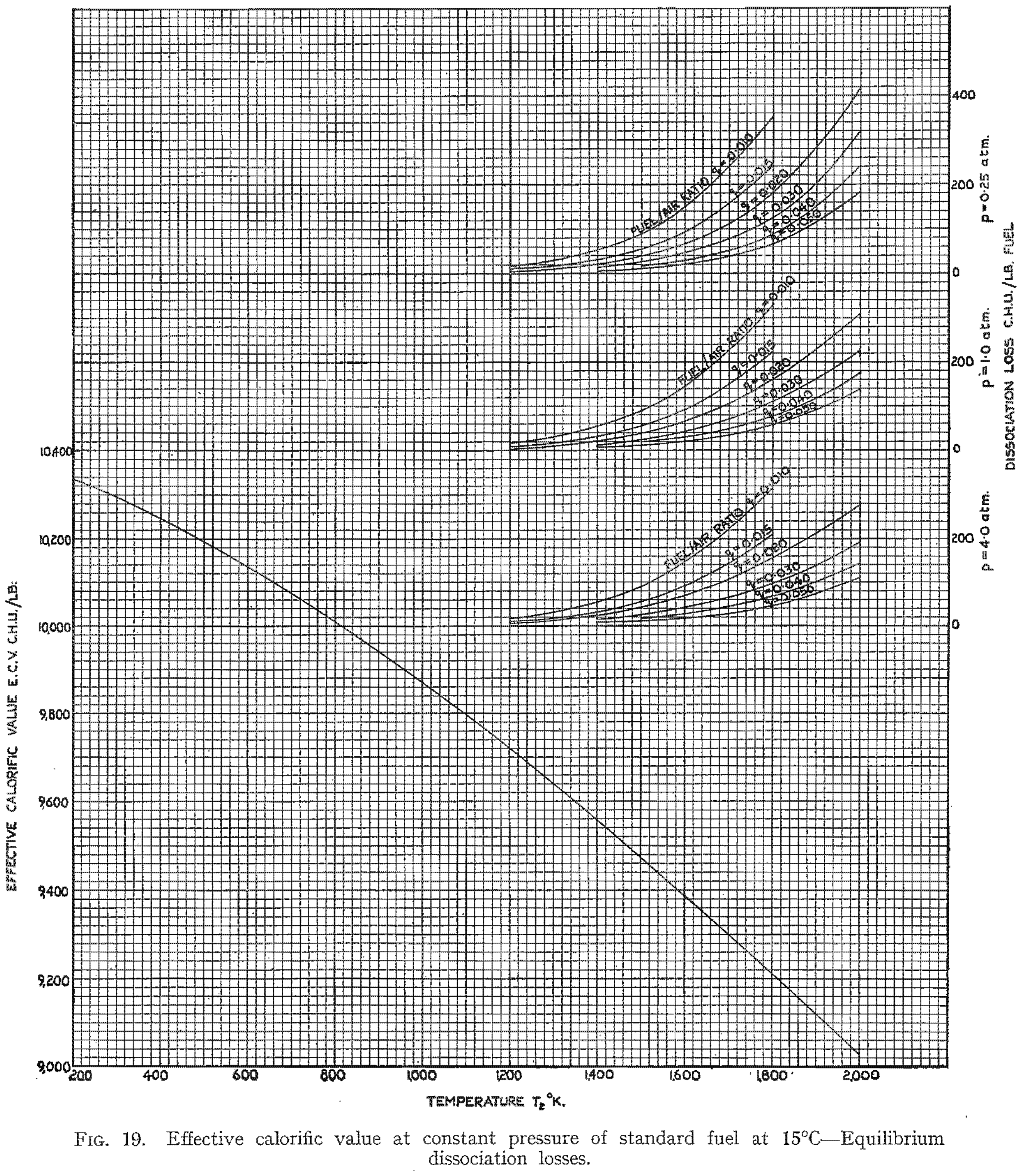


FIG. 19. Effective calorific value at constant pressure of standard fuel at 15°C—Equilibrium dissociation losses.

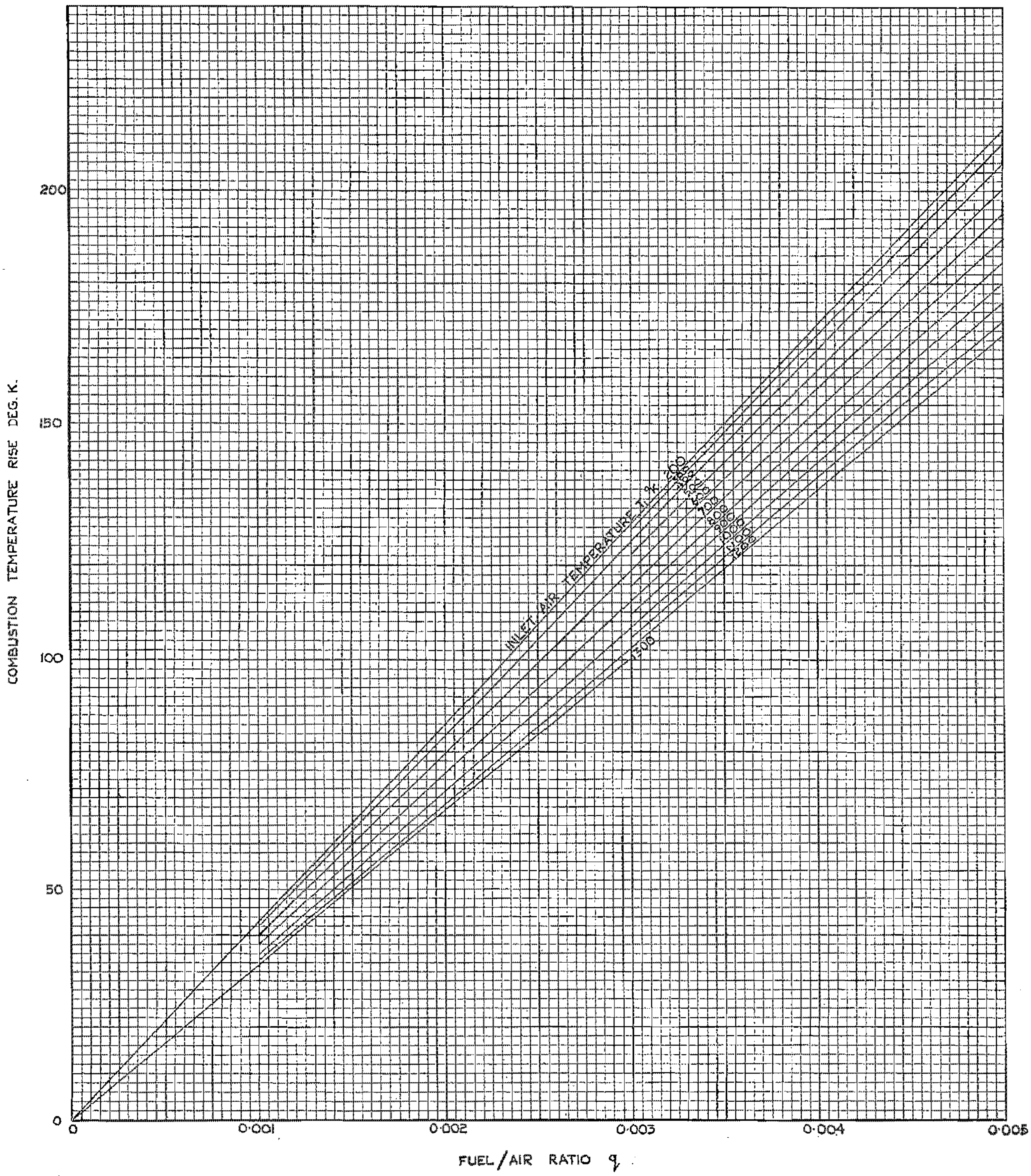


Fig. 20. Constant-pressure combustion temperature rise.—Standard fuel at 15°C and dry air.

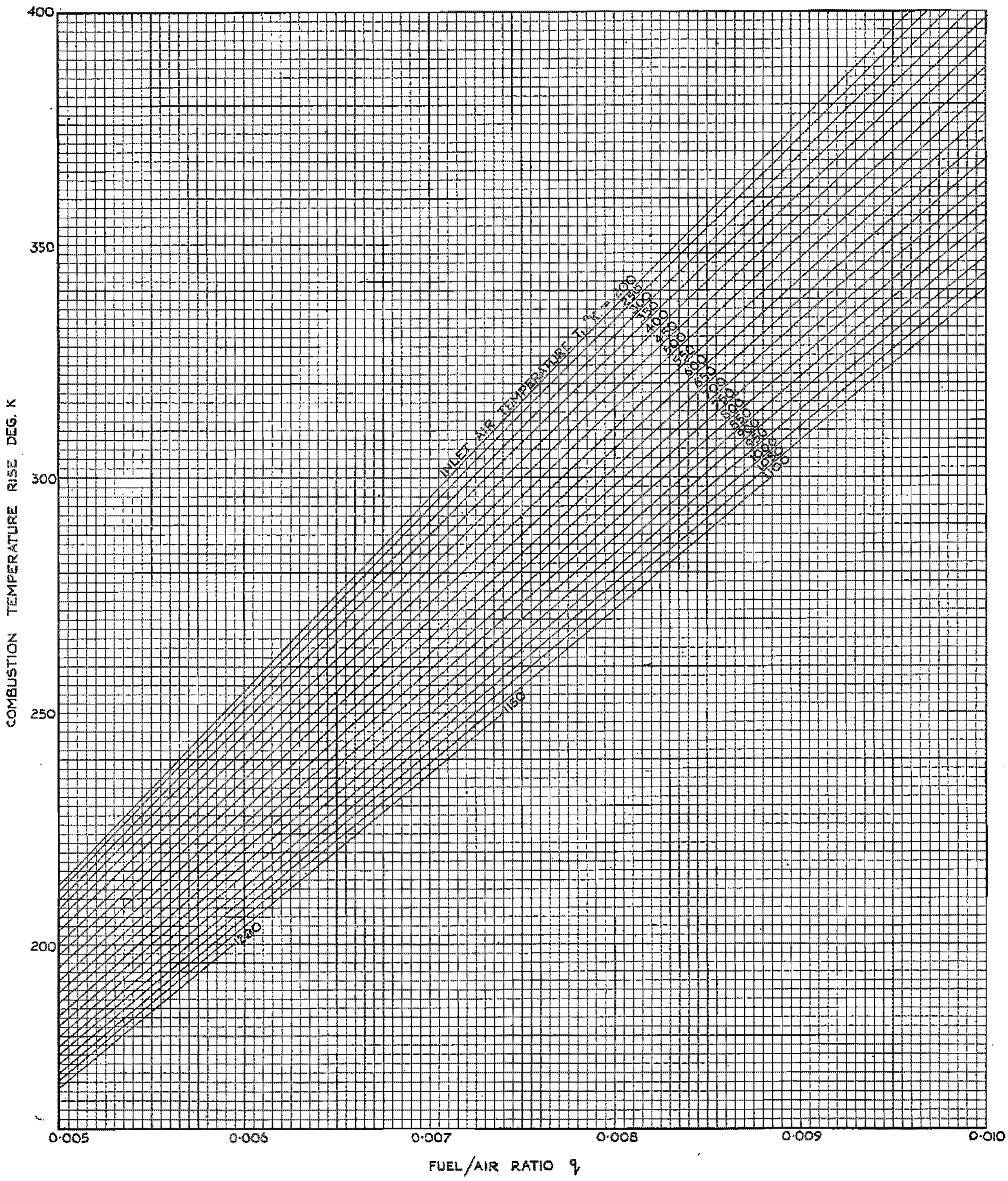


FIG. 21. Constant-pressure combustion temperature rise.—Standard fuel at 15°C and dry air.

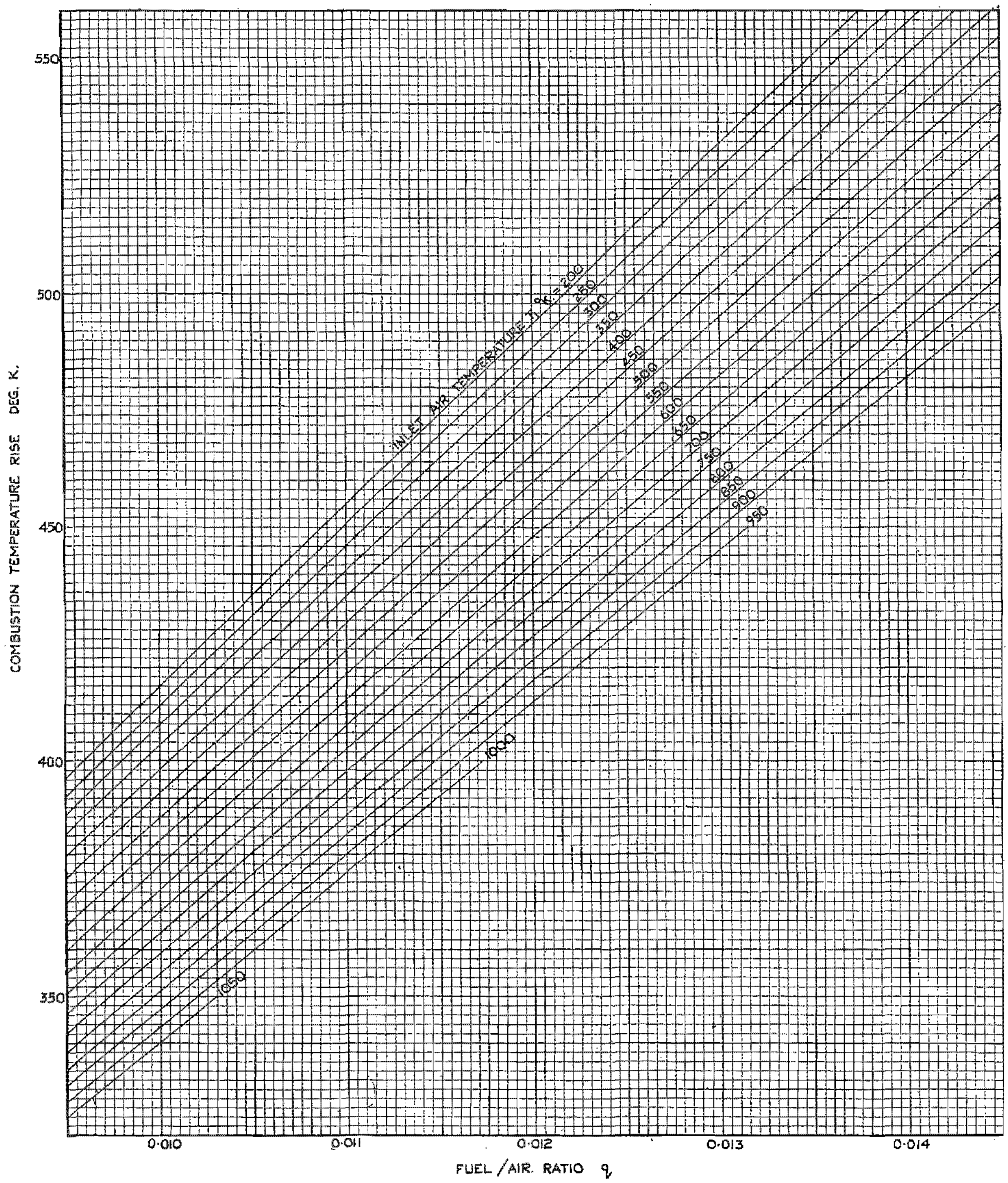


FIG. 22. Constant-pressure combustion temperature rise.—Standard fuel at 15°C and dry air.

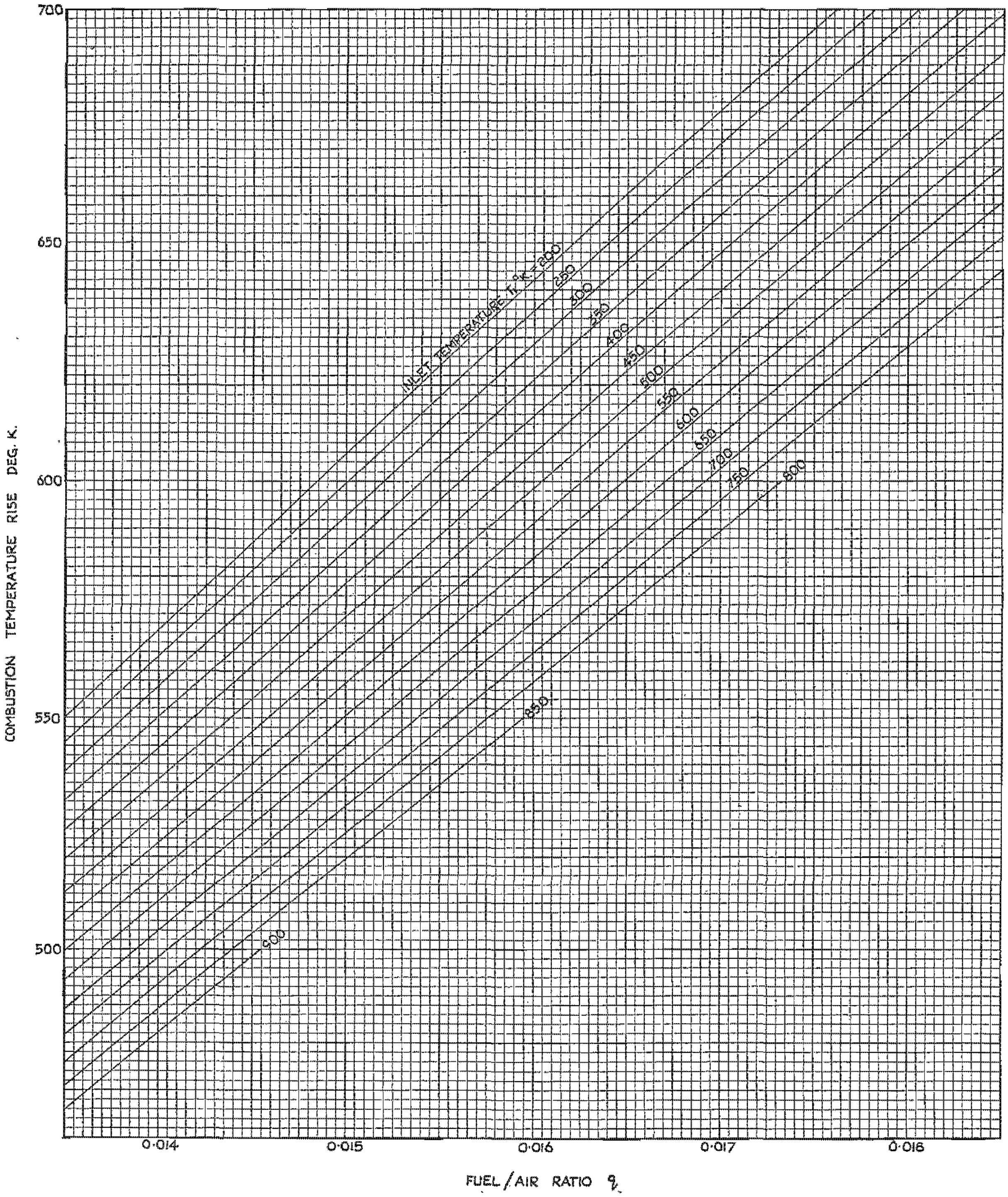


FIG. 23. Constant-pressure combustion temperature rise.—Standard fuel at 15°C and dry air.

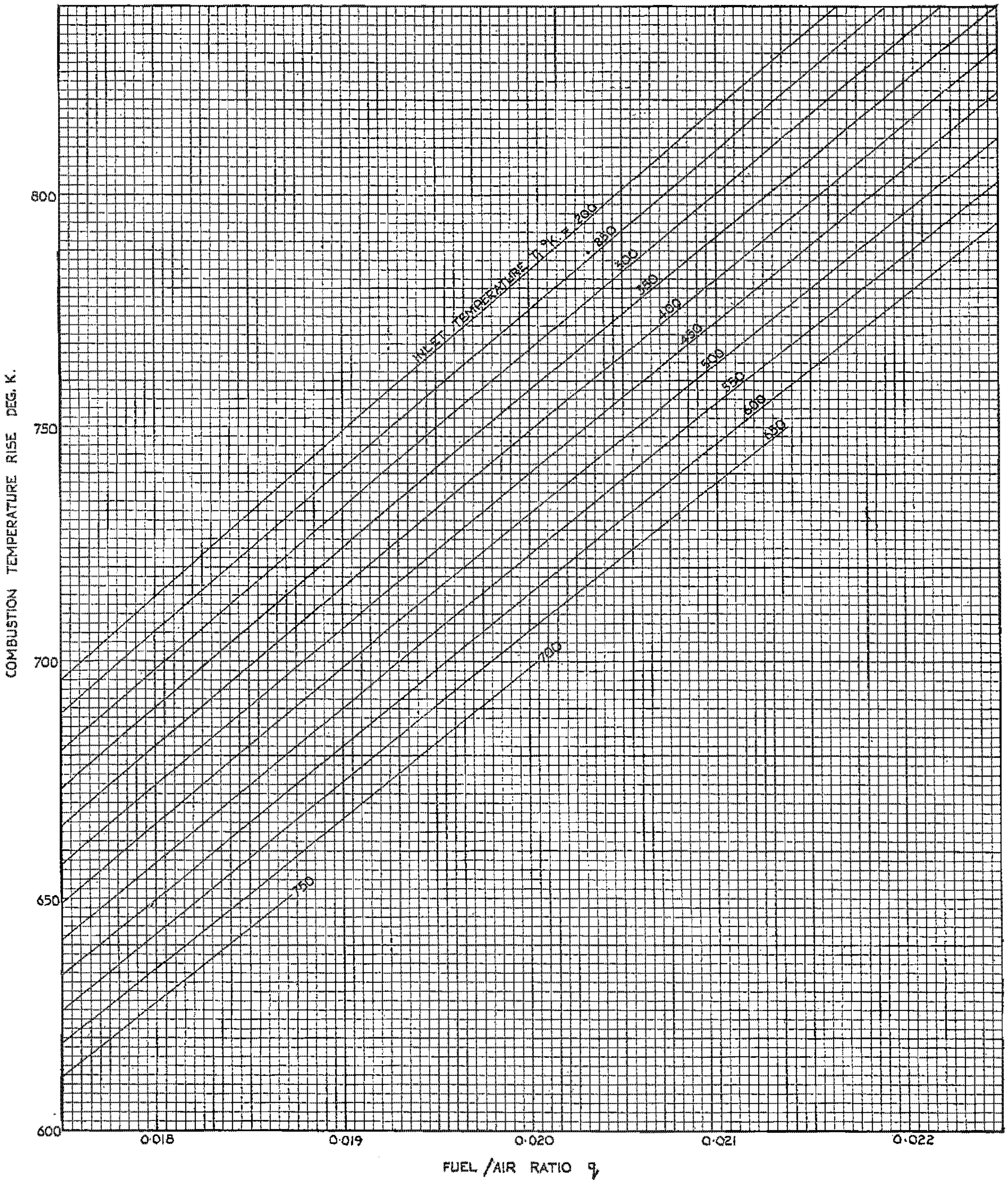


FIG. 24. Constant-pressure combustion temperature rise.—Standard fuel at 15°C and dry air.

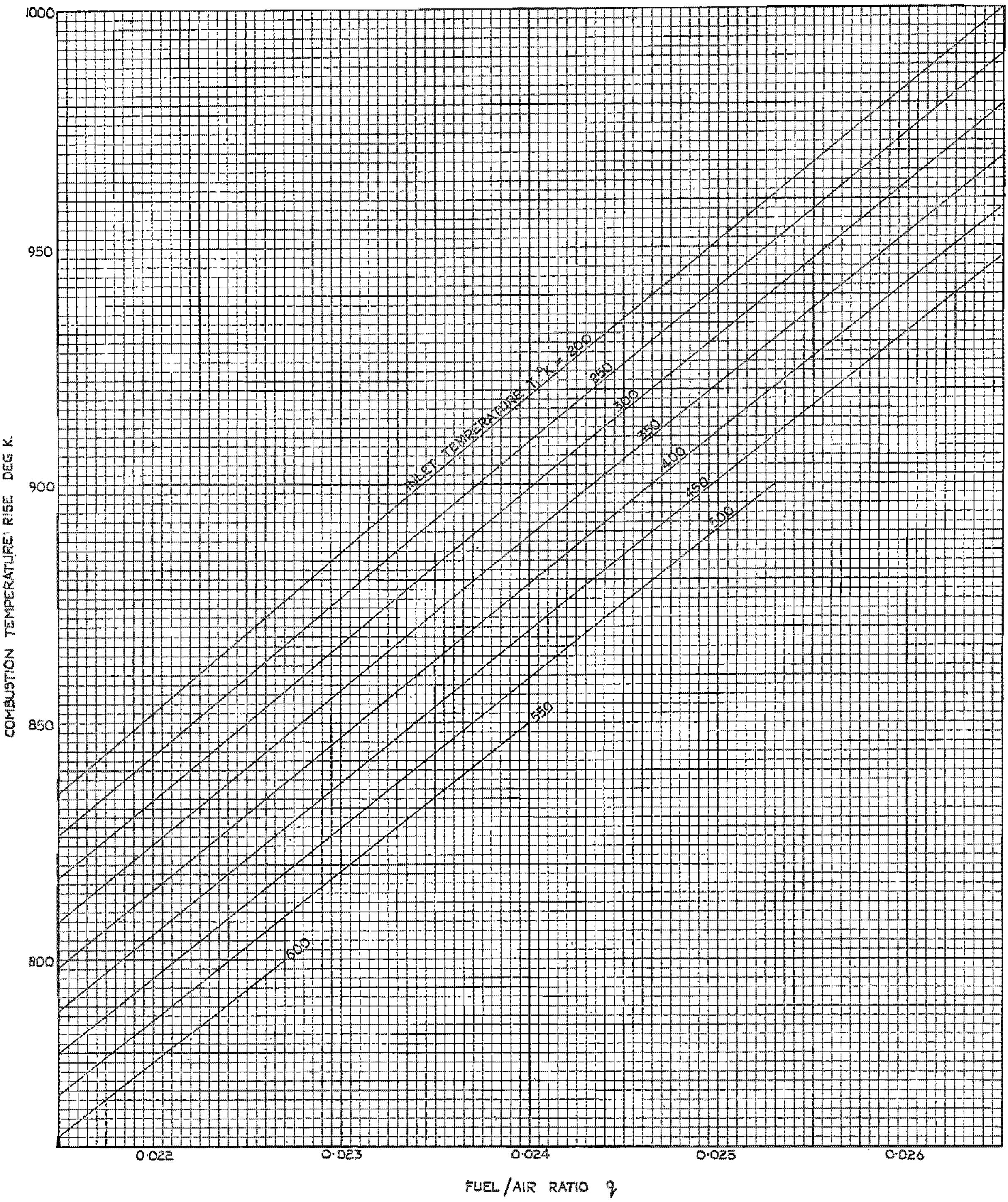


FIG. 25. Constant-pressure combustion temperature rise.—Standard fuel at 15°C and dry air.

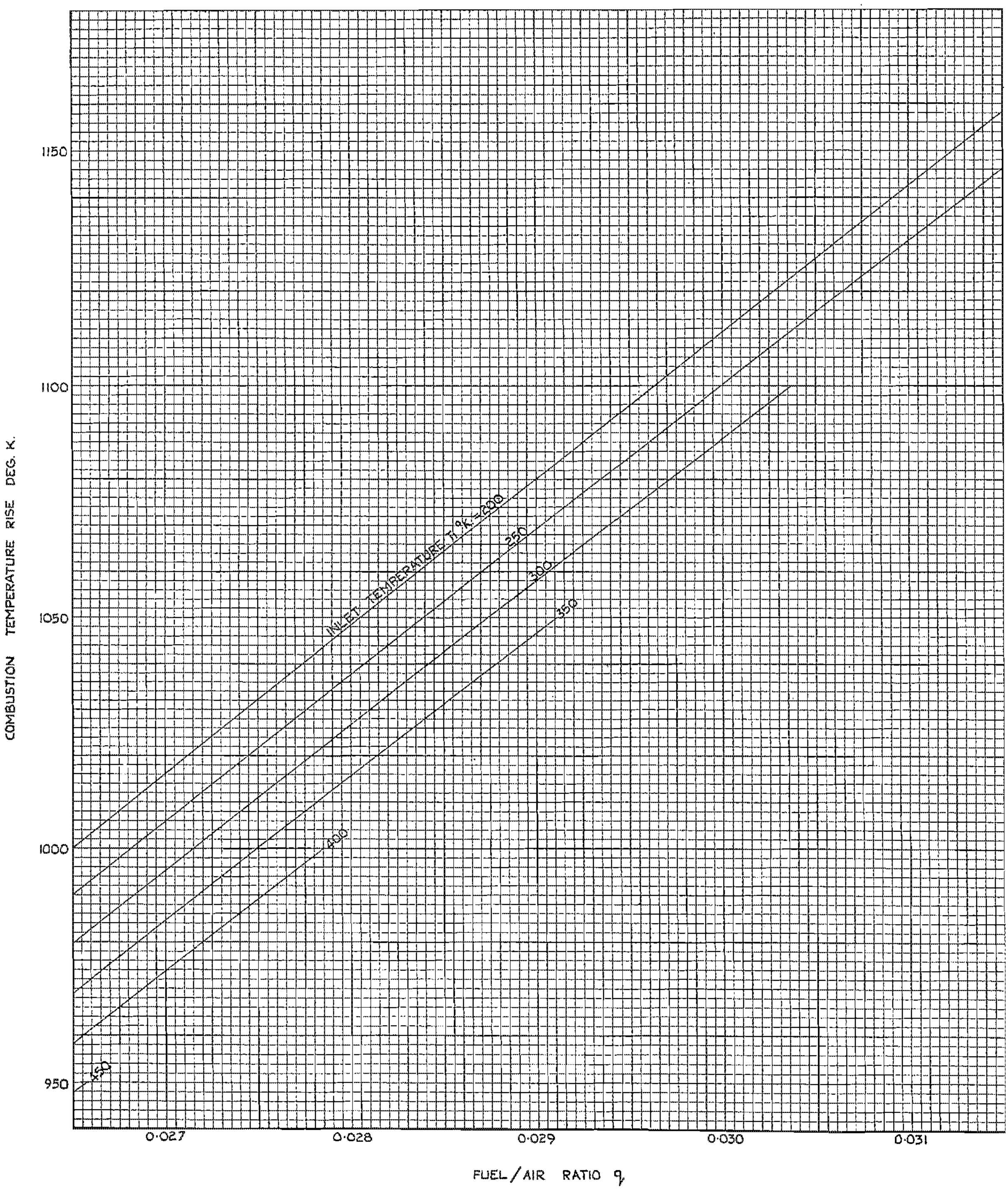


FIG. 26. Constant-pressure combustion temperature rise.—Standard fuel at 15°C and dry air.

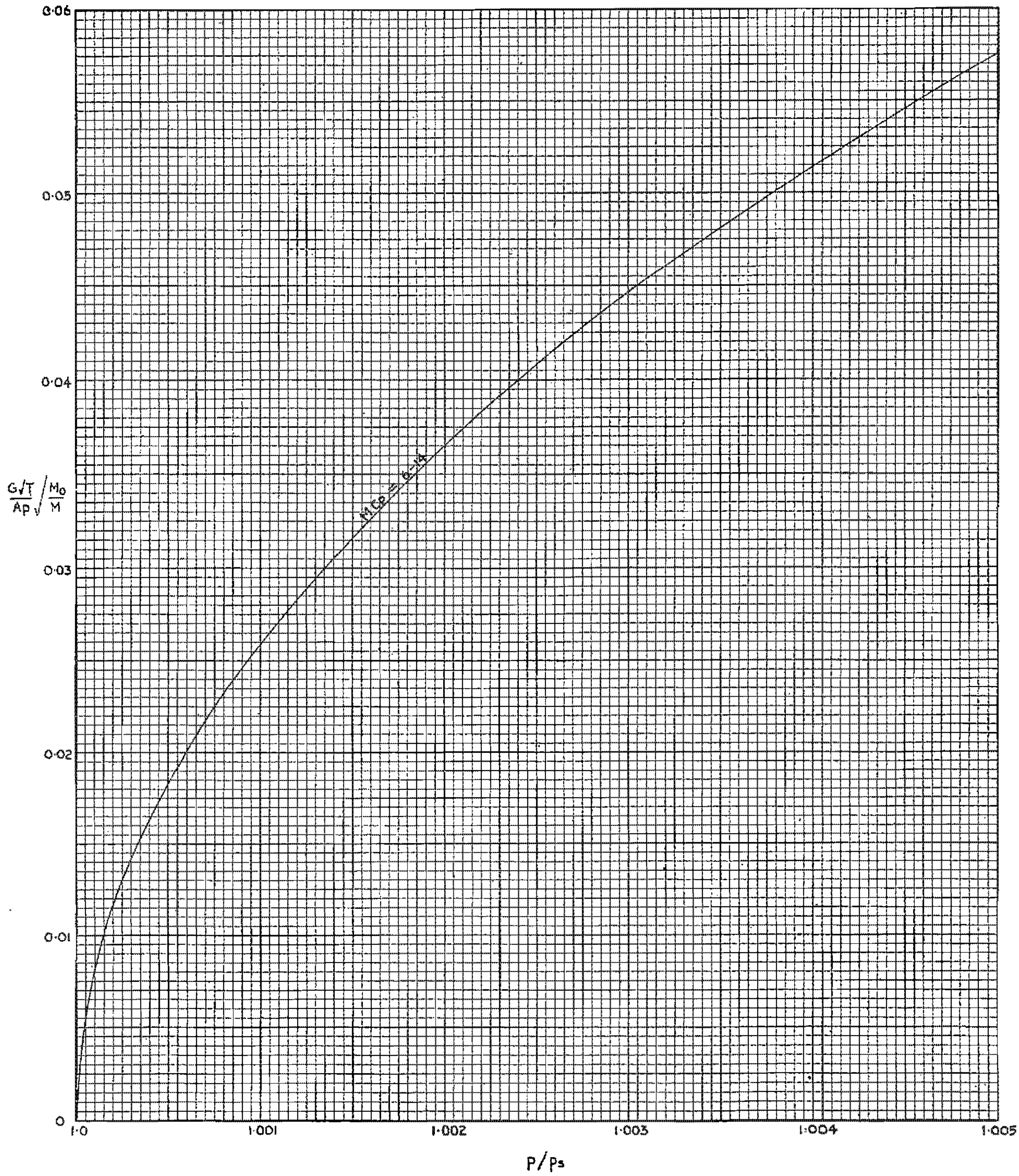


FIG. 27. The total-head flow parameter $\frac{G\sqrt{T}}{Ap}\sqrt{\left(\frac{M_0}{M}\right)}$.

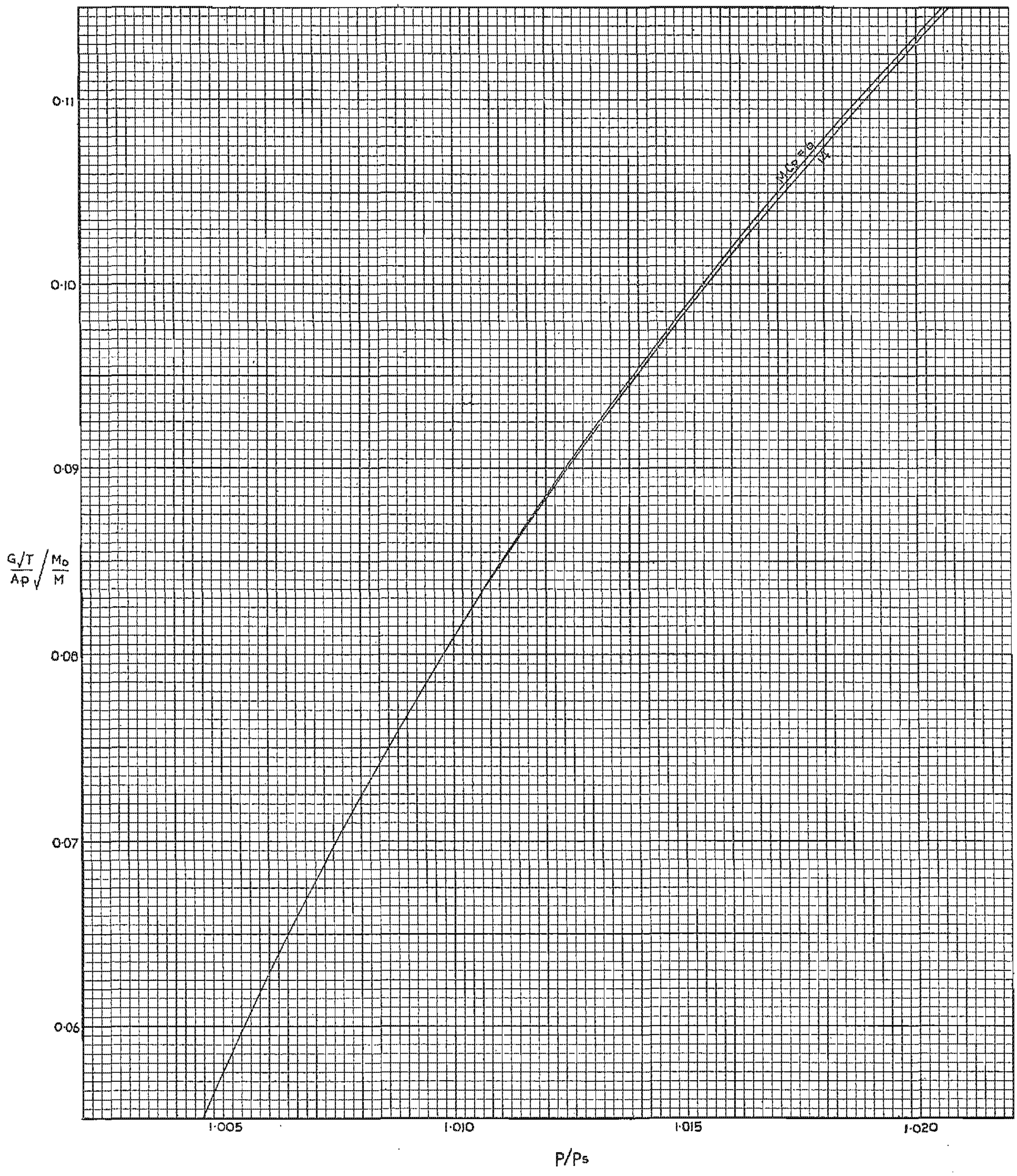


FIG. 28. The total-head flow parameter $\frac{G\sqrt{T}}{Ap}\sqrt{\left(\frac{M_0}{M}\right)}$.

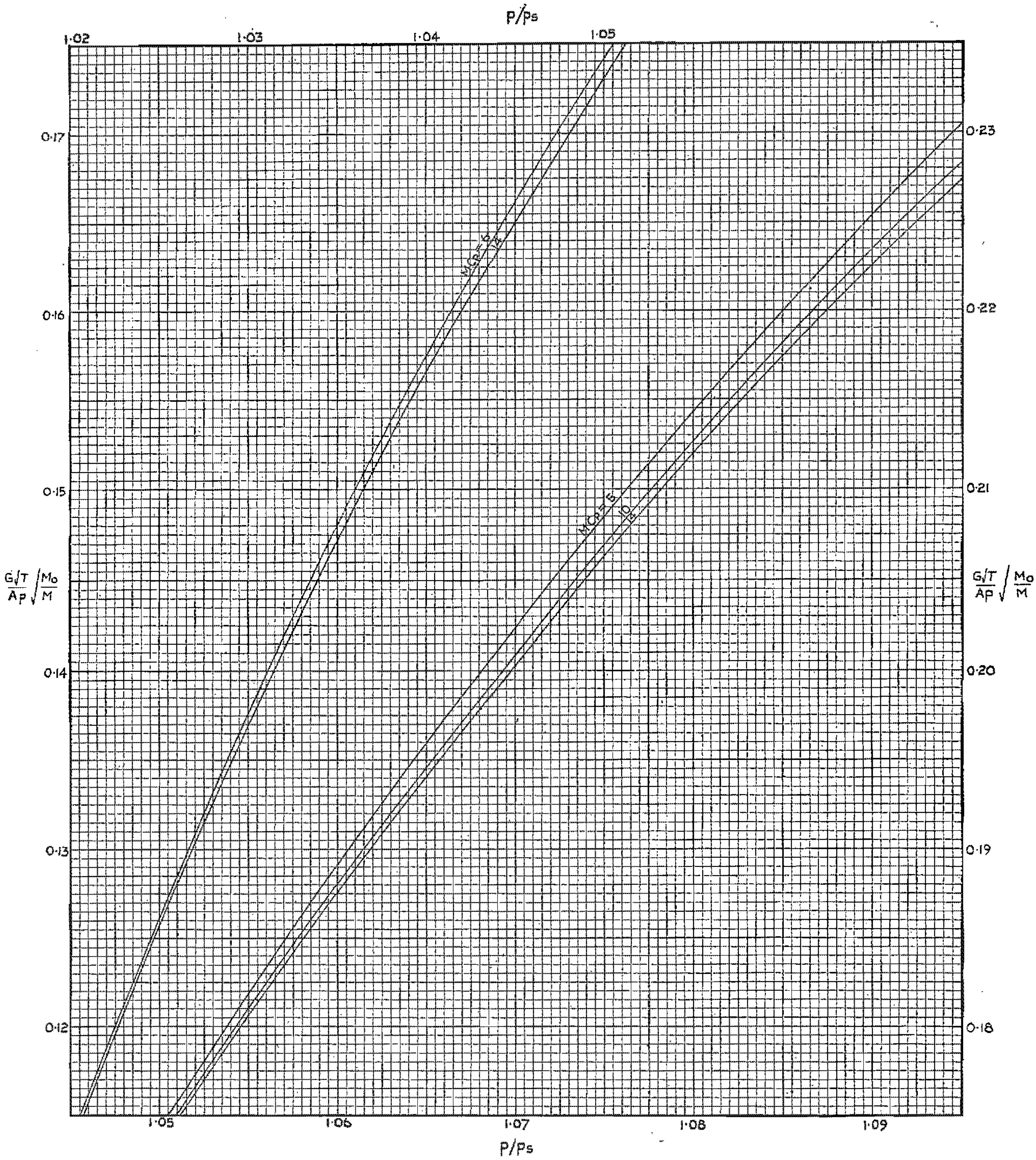


FIG. 29. The total-head flow parameter $\frac{G\sqrt{T}}{Ap}\sqrt{\left(\frac{M_0}{M}\right)}$.

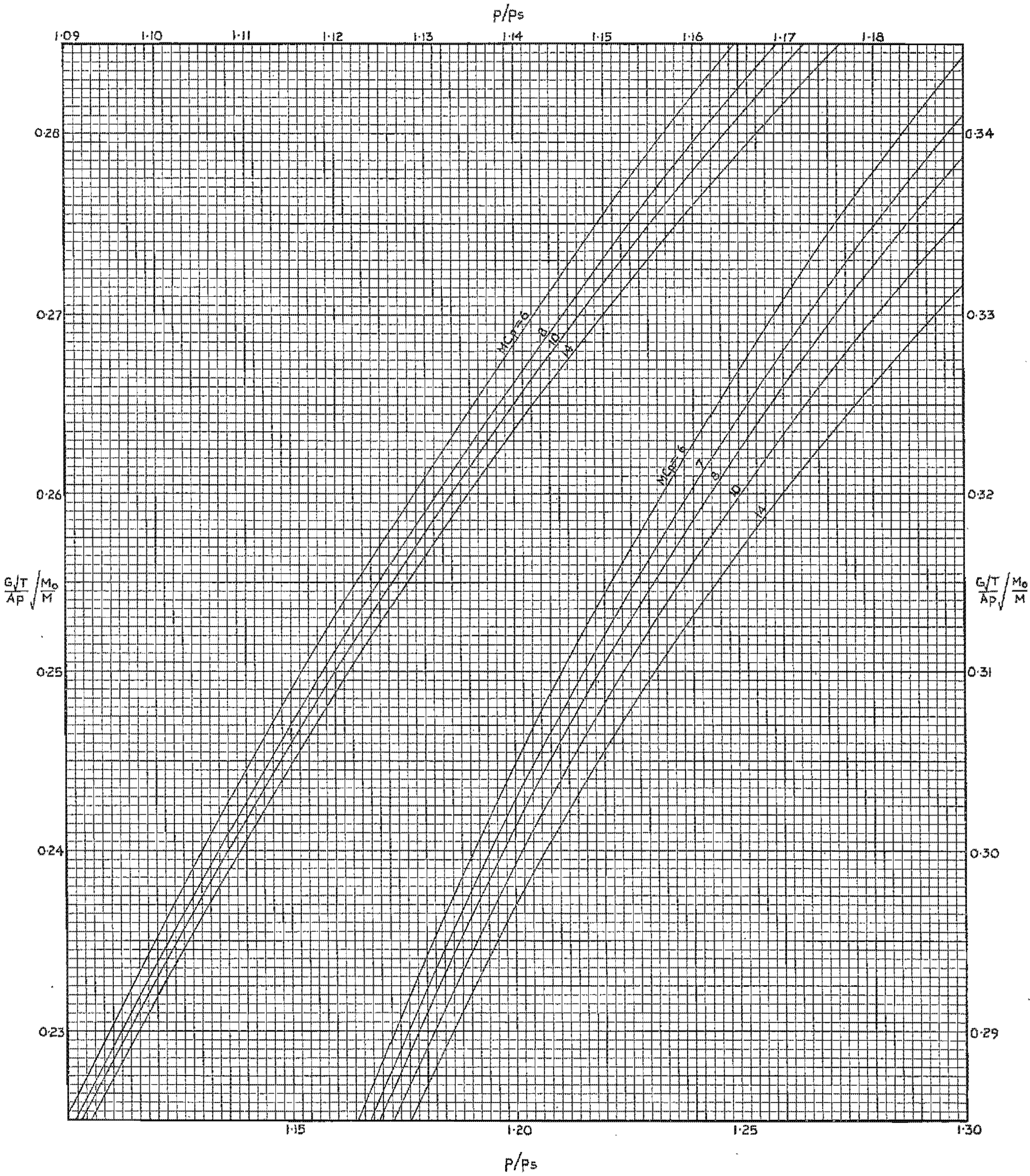


FIG. 30. The total-head flow parameter $\frac{G\sqrt{T}}{Ap}\sqrt{\left(\frac{M_0}{M}\right)}$.

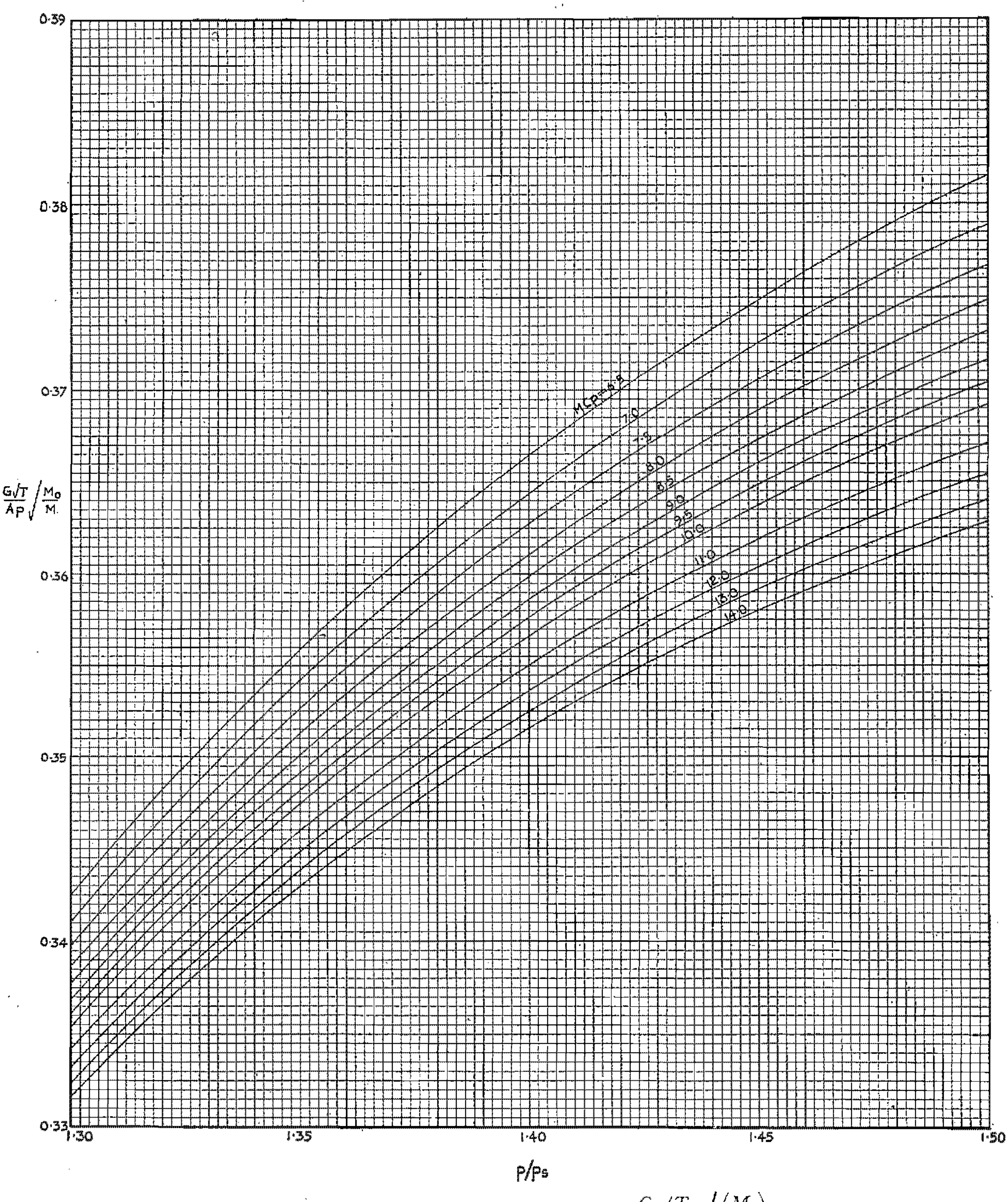


FIG. 31. The total-head flow parameter $\frac{G\sqrt{T}}{Ap}\sqrt{\left(\frac{M_0}{M}\right)}$.

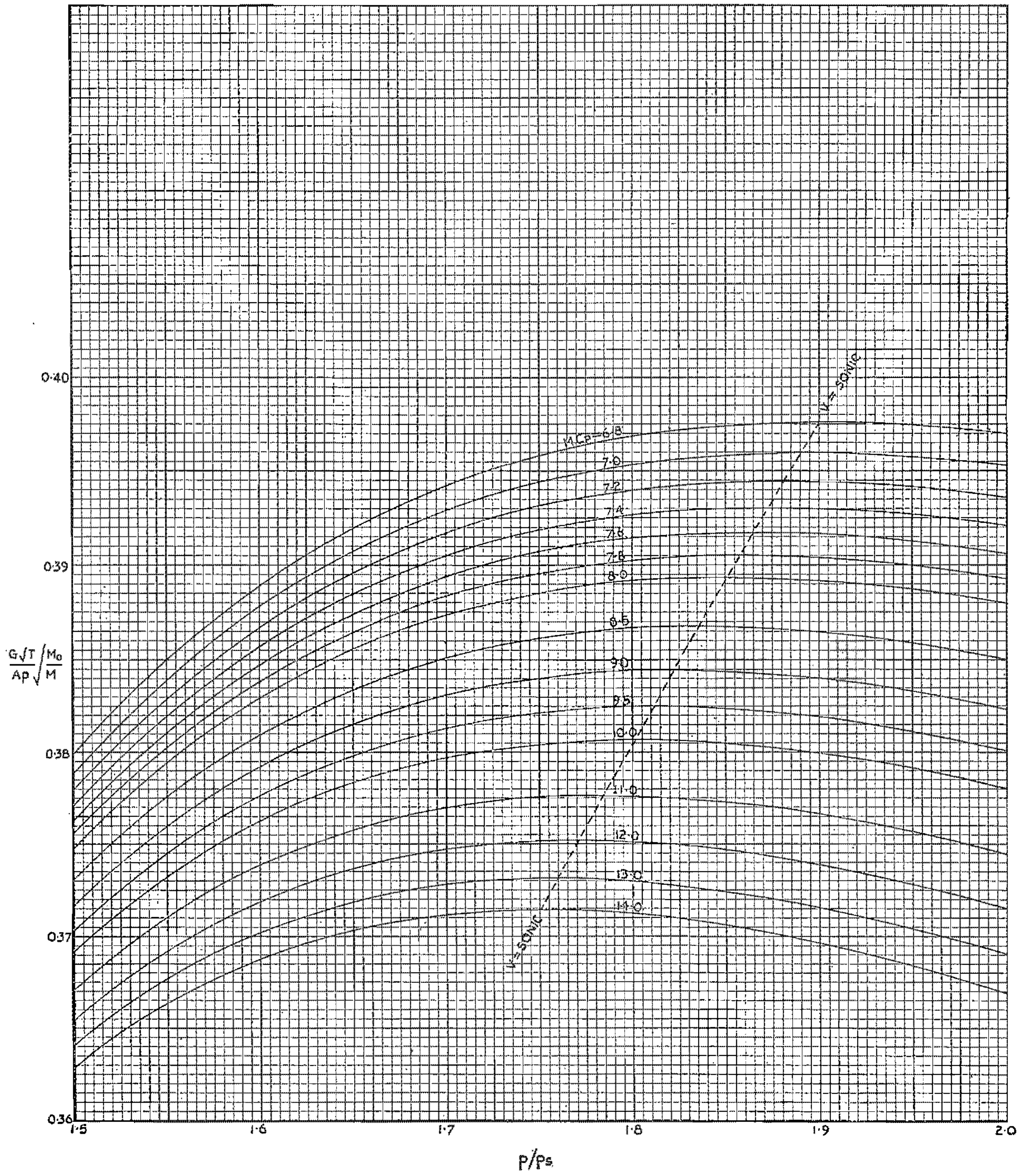


FIG. 32. The total-head flow parameter $\frac{G\sqrt{T}}{Ap}\sqrt{\left(\frac{M_0}{M}\right)}$.

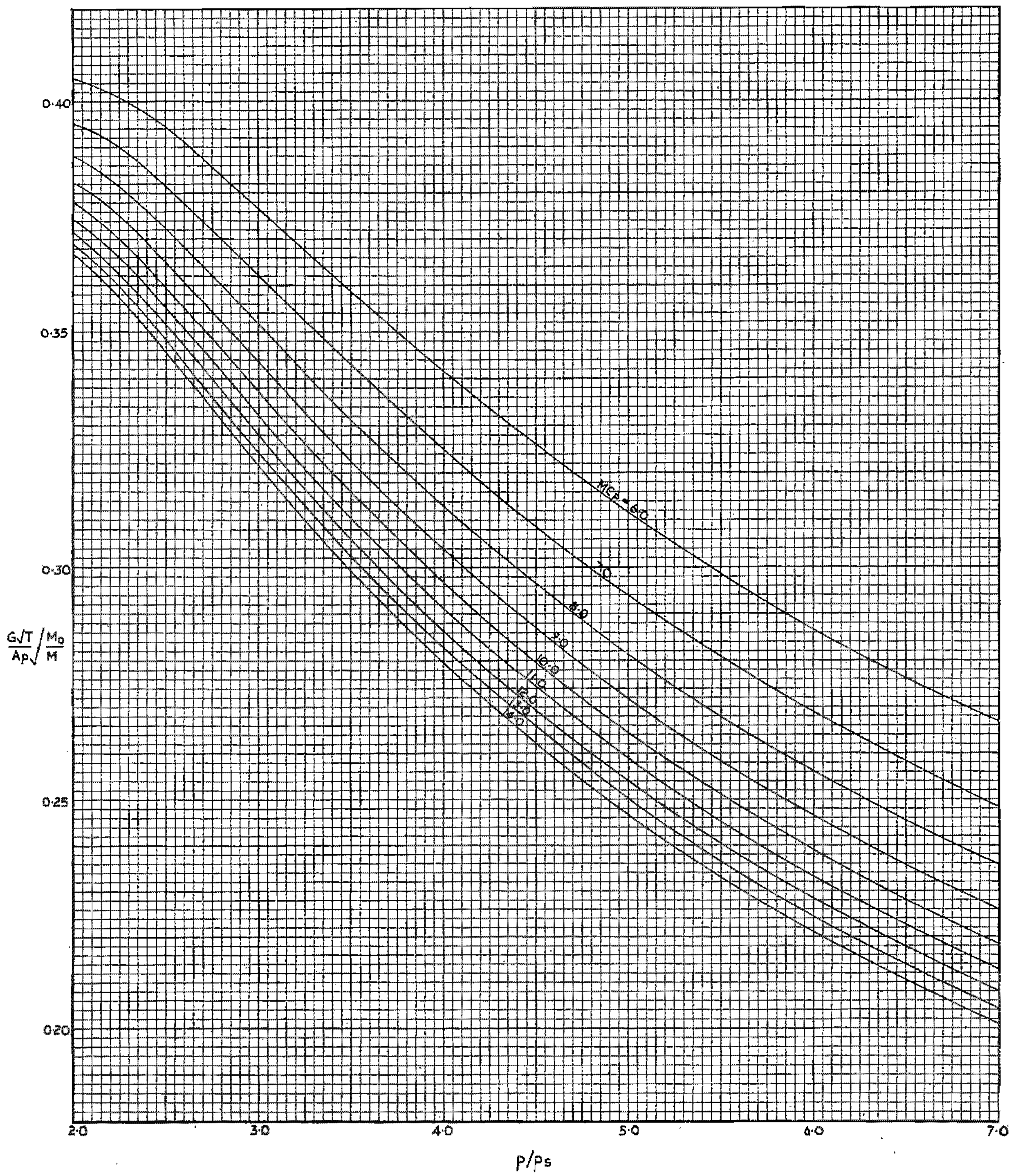


FIG. 33. The total-head flow parameter $\frac{G\sqrt{T}}{Ap}\sqrt{\left(\frac{M_0}{M}\right)}$.

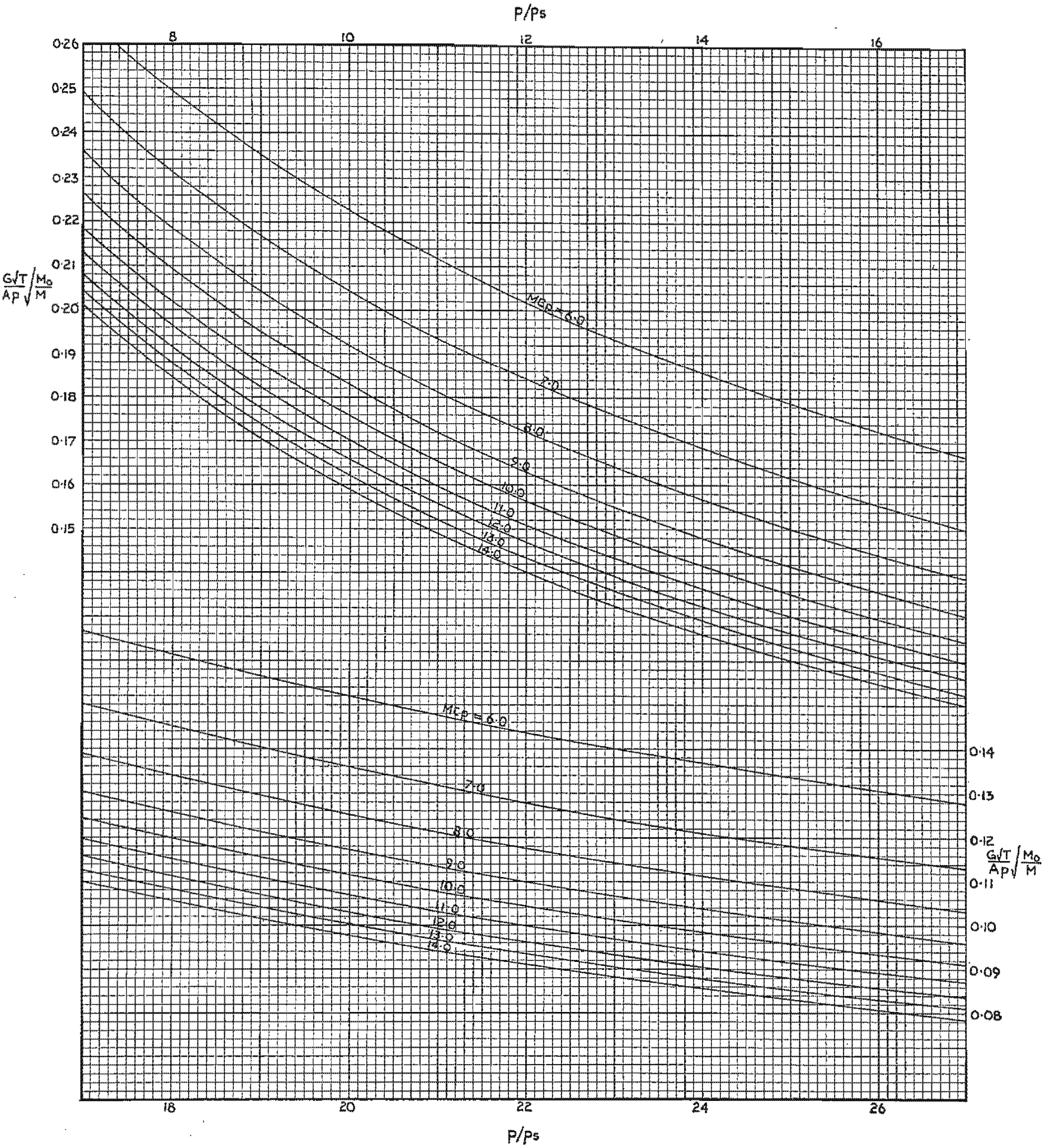


FIG. 34. The total-head flow parameter $\frac{G\sqrt{T}}{Ap}\sqrt{\left(\frac{M_0}{M}\right)}$.

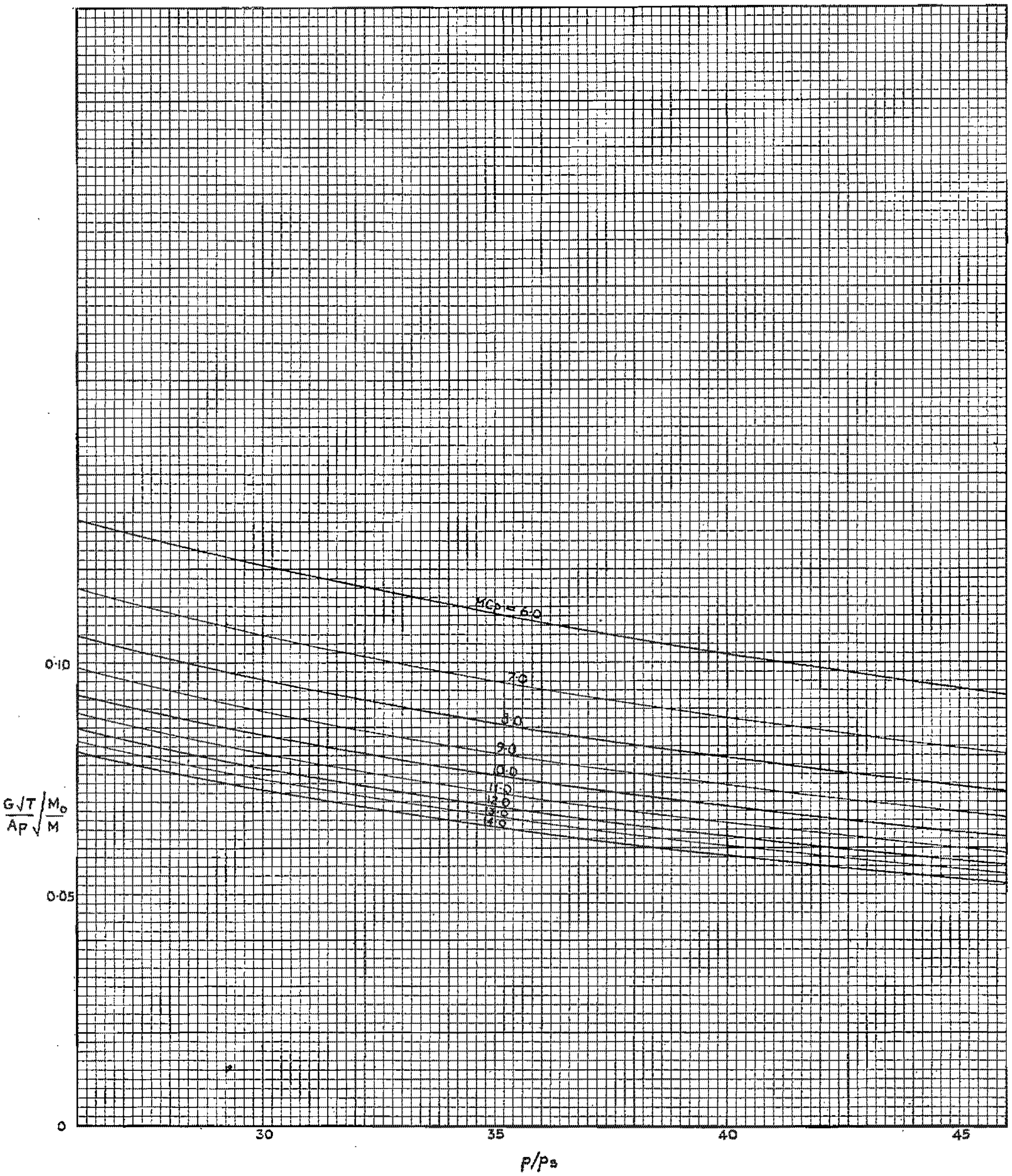


FIG. 35. The total-head flow parameter $\frac{G\sqrt{T}}{Ap}\sqrt{\left(\frac{M_0}{M}\right)}$.

(73938) Wt. 53/2293 K.5 9/59 Hw. PRINTED IN GREAT BRITAIN

S.O. Code No. 23-3099