GENERAL SUBJECT

PROF. F. A. F. SCHMIDT'S BOOK "VERBRENNUNGSMOTOREN. THERMODYNAMISCHE UND VERSUCHSMÄSSIGE GRUNDLAGEN UNTER BESONDERER BERÜCKSICHTIGUNG DER FLUGMOTOREN" – INTERNAL COMBUSTION ENGINES. THERMODYNAMIC AND EXPERIMENTAL PRINCIPLES WITH SPECIAL CONSIDERATION OF AIRPLANE ENGINES

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Investigator's Introduction

Prof. F.A.F. Schmidt's book on internal combustion engines meets the acute demand for a treatise embodying the pertinent physical-chemical developments on this subject. The author's background as an engineer makes him a particularly competent middle-man between the research scientist primarily interested in the kinetics and thermodynamics of combustion, and the pracitical motor designer. Since a book of this kind has been a long-felt need in the engineering world it is small wonder that the numerous investigators who have visited Professor Schmidt at the DVL-laboratory in Garmisch have shown the keenest interest in having copies available in their homelands. Thus, two of the three copies originally in Professor Schmidt's possession have been evacuated, while subsequent teams have wisely left the last remaining copy in situ. From this copy the present photolithographic reproduction has been made. The whereabouts of additional copies are not known to this investigator. There are, however, strong indications that the large stock originally in store at the Springer Verlag has been lost in the course of military events.

The first edition appeared in 1939. The present book comprises the second edition of 1944 and a typewritten supplement inserted between pages 319 and 320. Professor Schmidt has plans for a third edition featuring a more extensive treatment of recently gained knowledge including the subject of gas turbines and jet engines. However, it was felt to be inexpedient to delay the reproduction in favor of this more ambitious program which would involve extensive typesetting and other at present difficult complications.

Synopsis of the book: In its present form, the book is essentially a discussion of Otto and Diesel engines. Part A treats general engine problems and part B the special problems of aircraft engines. Each part is further subdivided. A(I) concerns essentially the thermodynamics of idealized engine cycles. A(I)2 concerns the actual cycle processes. The effect of engine conditions on intake and compression, the problems of carburetion and ignition in Otto engines are discussed (pp. 29-41). Then follows a discourse on the combustion in Otto engines (pp. 41-54). The propagation of the combustion wave is distinguished from the partial self-ignition of the charge in knocking combustion. The factors governing the rate of propagation of the combustion wave (mixture properties, turbulence and confinement-) and the connections between rate of propagation and motor performance are illustrated briefly but adequately; the knock-producing self-ignition of part of the charge is explained by the self-accelerating reaction induced by adiabatic compression and wall conditions and is clearly distinguished from detonation--a combined pressure and combustion wave exceeding sound velocity which cannot establish itself in the combustion space of the motor because of the small dimensions and the short time available. After a brief paragraph on fuel rating the individual phases of the Diesel cycle are discussed (pp. 54-86). This comprises a detailed consideration of the distribution of droplets and vapor in various phases of the fuel spray, effect of oszillations in the fuel line on the fuel discharge, and the ignition lag. This lag is composed of the thermal processes of evaporation and mixture formation at the spray boundary, and the self-accelerating reaction between fuel and oxygen in the mixing zone. The latter is the same process which in an Otto engine leads to knocking; hence a rough correlation of octane and cetene numbers becomes possible (p. 77). A semi-empirical treatment for calculating the duration of the self-accelerating reaction is also indicated (p. 72); this subject is again referred to in the appendix (p. 292). On the subsequent pages (78-86) various Diesel engine modifications aimed at improved mixing and ignition performance are described; then follows a discussion of the actual, as compared to the ideal, work cycle (pp 86-95) and the purging and intake process (pp. 95-103). In section A(I)3 (pp. 103-126) a study of the essential factors for efficient motor operation is made; this includes theoretical considerations and experimental data on the effect of such variables as mixture ratio, compression and ignition.

Section A(II), pp. 126-161, is entirely devoted to the subject of motor supercharging. Many additional considerations arise out of the various supercharger designs and the interaction of motors and chargers. Apart from modifications of the work diagram there are effects on the combustion process. These consist not so much of changes of the rate of flame propagation as in a reduction of the ignition lag, i.e., an increased knock tendency for Otto engines. The supercharge limits which are thus set can be raised by various means.

The separate treatment of aircraft motors in part B (pp. 161-232) reflects the complexities arising from operation in changing altitudes. Section B(I) concerns not-supercharged aircraft motors. Equations for the change of power with altitude are discussed. The effect of altitude on combustion is more pronounced in Diesel than in Otto engines. Supercharge systems driven directly by the motor are treated in section B(II), and exhaust-driven turbo superchargers in section B(III). These discussions deal with the complex relations between motor and charger performance, and the construction principles of exhaust turbines. Section B(IV) discusses the suitability of different motor systems for different types of aircraft, and some important relations between engine power and flight performance (pp. 232-265).

Appendix I contains four examples of numerical calculations: the work cycle of an ideal Diesel motor; thermodynamic evaluation of a test-bench experiment on a one-cylinder 4 cycle motor; calculation of power and fuel consumption of a motor with motor-driven charger at various altitudes; thermodynamic calculation of the changes of state in the exhaust gas.

Appendix II, 1 (pp. 265-273) is a treatise on the thermodynamic functions; in II, 2 (pp. 273-286) the calculation of dissociation equilibria and flame temperatures is shown. A very different subject, namely, the reaction kinetics of the ignition process, is enlarged upon in Appendix II, 3 (pp. 286-292); this is supplementary to preceding discussions in section A(I) 2 (p. 72). Assuming, for simplicity, a bimolecular reaction between oxygen and fuel gas, an equation for the ignition lag is obtained (p. 292) which can be solved after evaluating an integral expression relating the change of reaction rate with temperature. Although the assumption of a bimolecular reaction is not valid it is quite plausible that the true function of the ignition lag is of similar form. Appendix II, 4 (pp. 293-294) deals again with a thermodynamic subject, the maximum work of fuel combustion; this is followed by tables of thermodynamic functions and of the symbols used in the text.

The supplement (pp. 310-319 and insert between pages 319 and 320) deals with results of researches between 1940 and 1945. This has been particularly research on ignition. Special test apparatus have been built to simulate the adiabatic compression of fuel-air mixtures in Otto engines, and the fuel injection in Diesel engines. They permit the measurement of the ignition lags-either of a suddenly compressed gaseous mixture or of a fuel spray--at chosen values of the temperatures and pressures. The data with mixtures and sprays are largely parallel, inasmuch as they change with the variables in the same manner, though the absolute values of the ignition lags are, of course, quite different. This would indicate that under the test conditions the ignition lags of the sprays are determined by the chemical process rather than by evaporation. The values of the lags are described over a fairly large range of temperature and pressure by an empirical equation (p. 314) which is somewhat analogous to the earlier tentative equations derived from theoretical considerations (pp. 72 and 292) and contains three constants a', b' and n', of which the first is a general proportionality factor and the second and third are exponential factors determining the temperature and pressure dependence, respectively. These three constants characterize the fuel-air mixture and one should think that a new and superior method of fuel rating can now be devised roughly along the following lines: The fuel is fully characterized by tests in rapid compression apparatus using only a few cubic centimeter of sample. Engine tests are required only to the extent necessary to determine the thermal, etc., stresses on the fuel-air mixture, and generally, test engines can be dispensed with. This idea has not yet been followed through, however. Instead, the author is preoccupied with strengthening the premises of this method by enlarging the experimental material, discussing the limitations of the empirical ignition lag equation, and eliminating cases of anomalous behavior of fuels. This is indeed the immediate requirement. Unavoidably the text of the supplement becomes highly specialized reading matter, and as it constitutes not a full report but a summary of the pertinent DVL-work its digest demands additional study of the original reports. It is, however, clear that the subject is still in a preliminary stage and requires further experimental and theoretical exploration. Emphasis should be laid already at this stage on the point that studies of this kind promise larger dividends than indicated. Even though the problem of fuel rating for reciprocating engines may ultimately cease to be important, the general problem of the behavior of fuels under various stresses is bound to retain practical importance. There are, after all, performance limits on gas turbines as well. Ignition problems arise at critical altitudes.

The supplement also contains a brief treatment of the thermodynamics of gas turbines (pp. 319-g to m). Two types of operation--combustion at approximately constant volume and at approximately constant pressure-are considered. The work cycles are drawn and the power equations developed. Pre-compression, combustion in stages, heat exchange between exhaust and intake, engine aggregates are briefly discussed. On pp. 319-m to r, the cooling of turbine blades (pp. 215-217) is discussed on the basis of measurements and calculations.

Additional supplements to individual pages of the book are found on pp. 320-325. A literature and subject index is added. Finally, five graphs of completely calculated thermodynamic functions of combustion gasses of motor fuel are given.

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