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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Tech. Memo. No. 38.

PRELIMINARY CALCULATION OF CYLINDER DIMENSIONS FOR AIRCRAFT ENGINES.

By

Otto Schwager.

Translated from
"Zeitschrift für Flugtechnik und Motorluftschiffahrt,"
December 31, 1920.

September, 1921.

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The hitherto customary methods for calculating cylinder dimensions rest on the assumption of a definite average working pressure, whose more or less accurate valuation depends on the results of previous experiments. Consequently they are to a certain extent unreliable. It is especially important in building aircraft engines to determine the requisite dimension as accurately as possible, in order that the weight required for a given power shall not be excessive. The following calculation method depends therefore on the air requirement of the fuel.

I. Air Requirement. Gasoline has a heat value of $h_u = 10000$ to 10500, or an average of 10250 heat units (HU) per kilogram. The composition of gasoline is not constant. We may assume an average composition (by weight) of

$$85.5\%\ C + 14.5\%\ H$$

The combustion of 1 kg. of gasoline therefore requires

$$0.855 \cdot \frac{8}{3}\ O + 0.145 \cdot 8\ \ O = 3.44 \text{ kg. } O$$

corresponding, for an average composition of the air of 23.6% O and 76.4% N, to

$$\frac{3.44}{0.236} \sim 14.6 \text{ kg. air.}$$

If we take as the normal conditions of the air 15°C and 760 mm Hg., corresponding to an air density of ~ 1.2 kg. per cu.m., then

* "Zeitschrift fur F & M," December 31, 1920, pp. 341-343.

$\frac{14.6}{1.2} \sim 12.2$ cu.m. of air will be required for the combustion of 1 kg. of gasoline.

For complete combustion a certain excess of air is, however, advisable, which for aircraft engines may be set at 10% for economical consumption. The actual air consumption for the combustion of 1 kg. of gasoline in a recently built aviation engine is therefore

$$(1 + 0.1) \cdot 12.2 = 13.4 \text{ m.}^3$$

The volume of 1 kg. gasoline vapor may be set at 0.27 cu.m. The volume of a mixture containing 1 kg. of gasoline, with an average of 10250 heat units, is therefore

$$13.4 + 0.27 = 13.67 \text{ m.}^3$$

and hence the thermal value of 1 cu.m. of the fuel mixture, at 15°C and 760 mm. Hg. is

$$H_o = \frac{10250}{13.67} \sim 750 \text{ HU/m.}^3$$

This thermal value of the mixture may be advantageously employed in the preliminary calculation of the cylinder dimensions for a given engine power.

Under other atmospheric conditions then 15°C and 760 mm. Hg., the thermal value of the mixture changes in proportion to the density of the air and the absolute "heat per cubic meter" may be expressed by

$$H = H_o \cdot \mu \text{ in } \mu = \frac{273 + 15}{273 + t} \quad \frac{b}{760}$$

or the relative density of the air.

II. Preliminary Calculation of Cylinder Dimensions and Fuel Consumption.

Designate by N_e the desired brake horsepower of the engine;

μ the relative air density for which N_e is desired;

n the r.p.m. of the engine;

η_m the mechanical efficiency;

η_t the thermal efficiency;

η_g the quality of the cycle efficiency (degree of completeness of the diagram);

Q the heat consumption of the engine in HU per hour;

q the heat consumption in HU per HP hour;

$(V_h)_{theoret}$, the theoretically required fuel mixture in cu.m. per hr.;

η_l the delivery efficiency of the engine working as an airpump;

$(V_h)_{eff} = \frac{(V_h)_{theoret}}{\eta_l}$, the actually required suction-stroke volume in cu.m. per hr.;

v_h the total stroke space of the engine in l;

η_w the economical efficiency;

b the fuel consumption in grams per HP hour;

The hourly heat consumption of the engine is calculated by

$$Q = \frac{N_e \cdot 632}{\eta_m \cdot \eta_t \cdot \eta_g} \text{ HU/hr.}$$

Since 1 cu.m. of the mixture at the relative air density μ has a heat content of $H = H_o \mu$, the theoretical hourly intake requirement of the mixture is calculated by

$$(V_h)_{\text{theoret}} = \frac{Q}{H_o \cdot \mu} = \frac{N_e \cdot 632}{\eta_m \cdot \eta_t \cdot \eta_g} \cdot \frac{1}{H_o \cdot \mu} \quad m^3/hr.$$

and the actually required suction-stroke volume by

$$(V_h)_{\text{eff}} = \frac{N_e \cdot 632}{\eta_m \cdot \eta_t \cdot \eta_g} \cdot \frac{1}{H_o \cdot \eta_l} \cdot \frac{1}{\mu} \quad m^3/hr.$$

For a four stroke cycle engine there follows herefrom the total stroke volume in l (liters)

$$v_h = \frac{N_e \cdot 632}{\eta_m \cdot \eta_t \cdot \eta_g} \cdot \frac{1}{H_o \cdot \eta_l} \cdot \frac{1}{\mu} \cdot \frac{1000 \cdot 4}{60 \cdot n \cdot 2} \, l.$$

$$\boxed{v_h = \frac{21100 \cdot N_e}{\eta_m \cdot \eta_t \cdot \eta_g \cdot n} \cdot \frac{1}{H_o \cdot \eta_l} \cdot \frac{1}{\mu} \, l.}$$

This general fundamental comparison for the total stroke volume of the engine applies to every kind of engine, whether it be an engine of ordinary construction whose power decreases with the altitude or a high altitude engine, over-compressed or over-dimensioned. For the latter μ must be given a value corresponding to the altitude until constant engine power is reached. For ordinary engines $\mu = 1$.

The degrees of efficiency to be used in the equation depend on the kind of engine, whether it is air or water cooled, fixed or rotary (ordinary or Siemens-Halske type) and further from the method of construction of the cylinders, whether the valves are in the cylinder heads or in side chambers. For the most important kinds of aircraft engines, the different degrees of efficiency are calculated as follows:

(a) Water-cooled fixed engines (hanging valves in the cylinder head).

η_m = 0.85 to 0.9 (For safety's sake, it is better to use 0.85 in calculations).

η_g = 0.8 to 0.85 (Average 0.825).

η_l = 0.85 (For gas velocities up to 100 m. per second based on the highest piston speed to be constantly attained with safety).

η_t depends on the degree of condensation. It is

$$\eta_t = 1 - \epsilon^{1-x}$$

in which x = 1.35.

(b) Air-cooled stationary engines.

On account of the hotter gliding surfaces, especially of the piston,

$$\eta_m = 0.82$$

The quality is not much poorer than for water-cooled engines, only for engines with lateral valve chambers it is poorer on account of the larger cooling surface of the combustion chamber. It may be set at

η_g = 0.77 for engines with lateral valve chambers and

η_g = 0.8 to 0.82 for engines with valves in the cylinder heads.

The efficiency of supply for like gas velocities, as for water-cooled engines depends according to the quality of the cooling, on the uniform laving of the heat conducting surfaces, the avoidance of overheated places in the combustion chamber, etc.

η_l = 0.77 to 0.8. Only under especially favorable conditions with gas velocities below 70 m. per second, can η_l = 0.85, as in water-cooled engines. Hereby, as in all other cases, mechanically operated intake valves are essential.

(c) Rotary engines.

The following values may be used:

η_m = 0.82;

η_l = 0.77 to 0.8;

η_g = 0.65 to 0.7 (average 0.68).

The quality is therefore considerably poorer than for fixed engines, because an excess of fuel is used for rotary engines, in order to prevent the combustion of the lubrication oil (which gets into the combustion chamber in considerable quantities) and to keep the engine cool. The thermal value of the mixture is therefore higher for these engines and indeed H_o equals 800 to 900 (average 850) heat units per cubic meter.

Furthermore, in the case of rotary engines, it must be remembered that a certain amount of power is absorbed by the cooling resistance, which in ordinary rotary engines, at 1250 r.p.m., is from 8 to 12%, and in the Siemens-Halske type, at 900 r.p.m., is from 4 to 6%.

A still broader efficiency, which may be called the cooling efficiency η_v and may be inserted in the general fundamental equation. The following may be taken as its average values:

η_v = 0.88 to 0.90 for ordinary rotary engines;

η_v = 0.95 to 0.96 for the Siemens-Halske type.

From the efficiency, the anticipated fuel consumption per HP-hour is calculated as follows.

The economical working or over-all efficiency is

$$\eta_w = \eta_m \cdot \eta_t \cdot \eta_q \quad \text{resp.} = \eta_m \, \eta_t \, \eta_g \cdot \eta_v$$

and the heat consumption per HP-hour is

$$q = \frac{632}{\eta_w} \text{ HU/HP-hr.}$$

from which is obtained the fuel consumption

$$b = \frac{q \cdot 1000}{h_u} \text{ g/HP-hr.}$$

III. Examples.

In the following examples, the serviceability of the above method of calculation and the correctness of the efficiency values are demonstrated.

(a) Water-cooled fixed engine (ordinary engine).

N_e = 180 HP, $\mu = 1$

n = 1400 r.p.m.

ϵ = 4.65, corresponding $\eta_t = 0.416$

$$v_h = \frac{21100 \cdot 180}{0.85 \cdot 0.416 \cdot 0.825 \cdot 1400} \cdot \frac{1}{750 \cdot 0.85} \cdot \frac{1}{1} \sim \underline{14.6} \; l$$

$$\eta_w = 0.85 \cdot 0.416 \cdot 0.825 = 0.292$$

$$q = \frac{632}{0.292} = 2160 \text{ HU/HP-hr.}$$

$$b = \frac{2160 \cdot 1000}{10250} \sim 210 \text{ g/HP-hr.}$$

This corresponds very closely to the 160 HP Daimler-Mercedes DIIIa, which gives about 180 HP at $d = 140$ mm., $s = 150$ mm., $i = 6$, hence $v_h = 14.7\ l$, $\epsilon = 4.65$ and $n =$ about 1400, and averages about 200 to 220 grams of gasoline per HP-hr.

(b) <u>Water-cooled engine (high altitude)</u>.

$N_e = 185$ HP, remaining constant to $\mu = 7$ =.7 = 0.7

$n = 1400$ r.p.m.

$\epsilon = 6.3$, corresponding $\eta_t = 0.47$

$$V_h = \frac{21100 \cdot 185}{0.85 \cdot 0.47 \cdot 0.825 \cdot 1400} \cdot \frac{1}{750 \cdot 0.85} \cdot \frac{1}{0.7} \sim \underline{19}\ l$$

$$\eta_w = 0.85 \cdot 0.47 \cdot 0.825 = 0.33$$

$$q = \frac{632}{0.33} = 1920 \text{ HU/HP-hr.}$$

$$b = \frac{1920 \cdot 1000}{10250} = 187 \text{ g/HP-hr.}$$

Here there is excellent agreement with the 185 HP-BMW IIIa engine, which still gives 185 HP with $d = 150$ mm., $s = 180$ mm., $i = 6$, hence $v_h = \overset{19.1}{191}\ l$, $n = 1400$ r.p.m., $\epsilon = 6.3$ and $\mu = 0.7$, with a fuel consumption of 185 to 190 g/HP-hr.

(c) <u>Air-cooled fixed engine (normal engine with lateral valves)</u>.

$N_e = 74$ HP, $\mu = 1$

$n = 1620$ r.p.m.

$\epsilon = 4$, corresponding $\eta_t = 0.384$