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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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ABACUS GIVING THE VARIATION OF THE MEAN PRESSURE OF AN AVIATION ENGINE AS A FUNCTION OF ITS SPEED OF ROTATION.

By

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In the "Automobile Engineer" for 1919, an anonymous writer gives a formula for computing the mean pressure of an aviation engine for any number of revolutions, on condition of previously determining, by two bench tests, the values of two constants which enter into this formula. The formula in question is:

$$P = \frac{A}{e^{M/v^2}} \cdot \frac{n(n^{0.4} - 1)}{(n - 1)} \left(1 - \frac{v^2}{B} \right) \qquad (1)$$

in which

    P is the mean pressure in kg/cm^2

    A – a constant equal to 9.5

    n – the compression ratio

    v – the mean linear speed of the piston in m/sec.

    e = 2.718

    B – a first constant depending, according to the author, on the quality of the mixture and on the areas of the inlet ports.

    M – a second constant depending on the intensity of cooling and on the rapidity of combustion.

Comparing the results of the calculations with those of experiment, the writer, by numerous examples, shows the perfect agreement between them; and it is thus certain that his formula may render valuable service.

Unfortunately, since the constant M enters into the formula as an exponent of the term e, the computation of the values of the constants M and B is a very lengthy process. The method given by the English writer for this computation extends over two pages, and when M and B are determined, the computation of each value of P also takes up a good deal of time.

The same objections apply to a similar method of computation given by Mr. PETIT in an article which appeared in No. 105 of the "Technique Automobile" under the title "A Method for Abridging Engine Tests," and dealing with the same formula.

Now, though in fact the number of tests can be reduced to two by means of computation, this method requires, as we have just seen, a much longer time in the research laboratory, and it may be asked whether it would not be simpler to make a few more tests rather than calculate their results by the methods indicated by the two authors.

We will show that, by means of a special abacus we have drawn up, we can instantly plot the characteristics of the engine, that is, the $P = f(N)$ curve (N being the r.p.m. of the engine) and do, literally in one minute, the work which

would take several hours by the methods of computation.

Under these conditions the author's formula evidently again claims our interest and is worthy of adoption by research laboratories.

1. - TRANSFORMATION OF THE FORMULA.

The formula given above:

$$P = \frac{A}{e^{M/v^2}} \cdot \frac{n(n^{0.4} - 1)}{(n - 1)} \left(1 - \frac{v^2}{B} \right) \qquad (1)$$

may be written as follows:

$$\frac{P}{A} \cdot \frac{(n - 1)}{n(n^{0.4} - 1)} = \frac{\left(1 - \frac{v^2}{M} \cdot \frac{M}{B} \right)}{e^{M/v^2}} \qquad (2)$$

Let:

$$X = \frac{v^2}{M} = \left(\frac{Nc}{30,000} \right)^2 \cdot \frac{1}{M} \qquad (3)$$

where N is the r.p.m. of the engine and c the stroke of the piston in mm.

$$Y = \frac{P}{A} \cdot \frac{(n - 1)}{n(n^{0.4} - 1)} \qquad (4)$$

$$Z = \frac{M}{B} \qquad (5)$$

WE THUS INTRODUCE THE CONSTANT $Z = M/B$, instead of using B; so that in what follows we shall employ the two constants M and Z, which are to be determined by the two bench tests of the engine.

By introducing into equation (2) the terms X, Y, and Z, we have:

$$Y = \frac{1 - XZ}{e^{1/x}} \tag{6}$$

2. - DRAWING UP THE ABACUS.

Our abacus represents formula (6)

It belongs to the type of abacus called in French "abaques à images logarithmiques." Of these we have given numerous applications to the problems of the Mechanics of Aviation.

We cannot here go into lengthy details of the drawing up of this abacus, and will only give the principle on which it is based.

In a system of axes of rectangular coordinates such as

$$x = \text{Log } X \quad \text{and} \quad y = \text{Log } Y$$

plot the sheaf of iso-Z by equation (6).

UNDER THESE CONDITIONS EVERY BROKEN LINE COMPOSED OF SEG-MENTS OF STRAIGHT LINES, EACH MEASURING ONE OF THE VALUES: N, e, M, P, n, STARTING FROM THE ORIGIN OF THE AXES OF COORDINATES AND TERMINATING AT THE AXIS OF ONE OF THE ISO-Z, GIVES A SOLUTION OF EQUATION (6).

This method of CALCULATION BY LINE may be advantageously replaced by a NOMOGRAPHIC method, which consists of employing a basic diagram and a transparent on which are laid off sheaves of straight lines, plotted once for all.

3. - DESCRIPTION OF ABACUS AND METHOD OF USING IT.

On the BASIC DIAGRAM of the abacus (Pl.B.28) is laid off a

sheaf of iso-Z (experimental constant) and a scale graduated in
values of M (experimental constant).

On the TRANSPARENT of the abacus (Pl.S.P.5) is laid off on
the left a system of iso-c (piston stroke) and of iso-n (compres-
sion ratio), and on the right, a system of iso-N (r.p.m.) and of
iso-P (mean pressure in kg/cm²).

We will now show how the abacus is to be used and will give
an example referring to an aviation engine of 12 cylinders V-type,
130 x 165 mm., water-cooled, compression ratio 4.9, having given
in tests 7.94 kg/cm² at 1300 r.p.m. and 7.5 kg/cm² at 1600 r.p.m.
HOW TO USE THE ABACUS.

1st.   ON THE RIGHT HAND SYSTEM OF THE TRANSPARENT MARK THE
TWO POINTS REPRESENTING THE CORRELATIVE VALUES OF P AND N GIVEN
BY THE TWO TESTS OF THE ENGINE (i.e. the two points a and b).

2nd.   ON THE LEFT HAND SYSTEM OF THE TRANSPARENT INDICATE
THE POINT REPRESENTING THE VALUES OF c (STROKE) AND n (COMPRESSION
RATIO) OF THE ENGINE (i.e. the point d).

3rd.   THEN PLACE THE TRANSPARENT ON THE BASIC DIAGRAM (Pl.B.
28) AND SLIDE THE POINT d OF THE TRANSPARENT ALONG THE SCALE OF
M ON THE BASIC DIAGRAM, KEEPING THE ISO-n = 4.9 (horizontal pass-
ing through point d) OF THE TRANSPARENT COINCIDENT WITH THIS SCALE,
UNTIL THE TWO POINTS a AND b OF THE TRANSPARENT FALL ON ONE OF THE
ISO-Z CURVES OF THE BASIC DIAGRAM.

4th.   THE GRADUATION OF THE SHEAF OF ISO-Z CURVES WILL GIVE
THE DESIRED VALUE OF THIS CONSTANT, AND THE VALUE OF THE OTHER

CONSTANT M WILL BE READ ON THE M SCALE OF THE BASIC DIAGRAM IMME-
DIATELY BELOW THE POINT d OF THE TRANSPARENT.

5th.   ON THE TRANSPARENT WE TRACE THE ISO-Z PASSING THROUGH
THE POINTS a AND b; THIS CURVE WILL GIVE, IN THE SYSTEM OF ISO-N
AND ISO-P, THE DESIRED CHARACTERISTIC OF THE ENGINE.

In the example considered, the point d of the transparent
will fall on the point d' of the basic diagram corresponding to
M = 6.5 and the points a and b will fall on the iso-Z = 0.019.

Curve pq on the transparent represents the trace of the
iso-Z = 0.019 on the basic diagram; it is the desired character-
istic of the engine.

On this characteristic we can read the following correspond-
ing values of N and P.

N = 800	900	1000	1200	1400	1600	1800	2000 r.p.m.
P = 7.2	7.6	7.90	8	7.80	7.5	7	6.75

We have not plotted on the transparent the experimental curve
P = f(N) because it is identical with the curve pq. The perfect
accordance of these two curves justifies the practical interest
of the proposed formula.

4. - MAXIMUM MEAN PRESSURE OR ENGINE TORQUE AND MAXIMUM MOTICE
     POWER,

The curve C_p plotted on the basic diagram passes through
the points of the iso-Z for which the tangents are parallel to
the iso-P of the transparent, the latter being, of course, placed
in a suitable position (iso-P// to the M scale) with respect to

the basic diagram.

This curve thus represents the geometric locus of the maxima of the mean pressure and, consequently, of the engine torque.

The curve $C\pi$ laid off on the basic diagram passes through the points of the iso-Z for which the tangents make an angle of 26° 30' (tan 26° 30' = 1/2) with the iso-P of the transparent.

This curve represents the geometric locus of the curves P = f(N) corresponding to the maximum motive power.

In the example dealt with above, the curve C_P intersects the characteristic pq at the point: N = 1200 r.p.m., P = 8 kg/cm² which constitutes the maximum mean pressure or engine torque.

The curve $C\pi$ intersects the characteristic of the engine at the point N = 1970 r.p.m., P = 6.5 kg/cm², corresponding to maximum power.

5. - RELATION BETWEEN THE QUALITIES OF THE ENGINE AND THE CON-
    STANTS M AND Z.

In order to give a clear idea of the values of M and Z for the various types of aviation engines now existing, we give below a Table drawn from the information contained in the article in the "Automobile Engineer." In this Table are grouped the values of M and Z and also some data on the engines examined.

Type	Cooling System	Number of cylinders	Compression Ratio	M	Z	B
Rotary	Air	9	4.85	7.3	0.0539	135
"	"	"	4.75	6.3	0.0517	132
V-type	"	8	4.25	12.2	0.0459	266
"	"	12	4.25	13.6	0.0535	254
"	Water	"	4.80	6.9	0.0318	217
"	"	"	4.50	8.1	0.0259	312
"	"	"	4.90	4.7	0.0142	331
"	"	"	4.90	6.1	0.0181	337
Vertical	"	6	5.00	4.7	0.0116	402

From the Table we see that the highest values of M (about 13) are reached by stationary, air-cooled engines, and that for other engines, both rotary and stationary, M has a much smaller value, about 6.5; it falls to 4.7 for two stationary, water-cooled engines.

As regards the value of Z, its average is 0.05 for air-cooled engines and 0.02 for water-cooled engines.

By means of the abacus we see that an increase of M increases or diminishes the value of P for a given number of revolutions, according to whether this number of revolutions is greater or less than the number corresponding to the maximum of P.

On the other hand, a reduction of Z increases the value of P, irrespective of the number of revolutions.

The region utilized in practice by the engine being between the point of the maximum torque and the point of maximum power, the mean pressure in this region will be greater as the value of M is greater and the value of Z smaller.

We may recall that the author considers that the constant B depends on the quality of the mixture and on the area of the inlet ports, and that the constant M depends on the intensity of cooling and the rapidity of combustion.

As regards the system of constants Z and M which we have adopted, we consider that the constant Z depends specially on the area of the inlet ports and on the mechanical efficiency of the engine, while the constant M depends on the setting of the valve-gear.

But to enable us to pronounce definitely as to the influence of the various factors on the values of the constants, we should need to have a much more abundant documentation. If this were available we might employ the abacus for the predetermination of the curve $P = f(N)$ of an engine not yet tested.

NOTE.- The iso-Z = 0 gives the maximum mean pressure realizable with perfect filling and with a mechanical efficiency equal to 1. In the above example we find that at 1200 r.p.m. the pressure for Z = 0 is 9.1 kg/cm^2 instead of 8 kg/cm^2.

W. MARGOULIS.
ABACUS GIVING THE MEAN
PRESSURE OF AN AVIATION ENGINE
BASIC DIAGRAM

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS PARIS OFFICE

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DESIGNED   *M. Margoulis*
DRAWN   *Août 6/19/20*
CHECKED   *M. Margoulis*
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Note: *For the sliding*
transparent see: ST 5

HOW TO USE THE ABACUS

We will now show how the abacus is to be used and will give an example referring to an aviation engine of 12 cylinders V-type, 130 × 85 ⁄m, water cooled, compression ratio 4,9 having given in tests 7,94 kg/cm² at 1300 r.p.m. and 7,5 kg cm² at 1600 r.p.m.

1st. On the right hand system of the transparent, mark the two points representing the correlative values of P and N given by the two tests of the engine.

2nd. On the left hand system of the transparent, indicate the point representing the values of c_t (stroke) and n (compression ratio) of the engine.

3rd. Then place the transparent on the basic diagram (B 28) and slide the point d' of the transparent along the scale of M on the basic diagram until the iso-n = 4,9 (horizontal passing through point d') of the transparent coincides with this scale, and until the two points a and b of the transparent fall on one of the iso-z of the basic diagram.

4th. The graduation of the iso z will give the desired value of this constant, and the value of the other constant M will be read on the M scale of the basic diagram immediately below the point d' of the transparent.

5th. On the transparent we trace   the iso Z passing through the points a and b: this curve will give, in the system of iso-N and iso P, the desired characteristic of the engine.

In the example considered, the point d' of the transparent will fall on the point d' of the basic diagram corresponding to N = 6.5 and the points a and b will fall on the iso-Z = 0.019. Curve pq on the transparent represents the trace of the iso Z = 0.019 on the basic diagram; it is the desired characteristic of the engine. On this characteristic we can read the following correlative values of N and P.

N =	800	900	1000	1200	1400	1600	1800	2000	r.p.m.
P =	7.2	7.6	7.90	8	7.80	7.5	7	6.75	

d'

M scale