САМАРСКИЙ УНИВЕРСИТЕТ
SAMARA UNIVERSITY

Samara University
Institute of Aeronautical Engineering
Department of Aircraft Construction and Design

N.M. Borgest

Aviation power plants

Methodical instructions to laboratory and self-work
on discipline "Aviation power plants" for English-speaking students,
trained in the direction of 24.03.04 Aircraft building,
bachelors, profile "Aircraft construction"

2017

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Borgest N.M. Aviation power plants. Methodical instructions. Samara University. Samara, 2017. - 16 p.

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CONTENTS

LABORATORY PRACTICE

The laboratory practice on the discipline "Aviation power plants" consists of classes in motor classes of the Center for the History of Aviation Engines of the Samara University and classes in the aircraft class of the design and design department of aircraft.

1. The design of domestic and foreign engines of various types and their nodes is studied using the methodological guidelines:

> *Borgest N.M, Gusarov R.V. Aircraft engines in the museum of the Samara University. Methodical instructions for laboratory work. - Samara University. Samara. 2017. - 48 p.*

In addition, classes can be conducted to study the characteristics and parameters of aircraft engines at the training and test benches of the GTE Department of the Engine Theory of the Samara University (building 11).

2. Powerplant systems and engine mounts to the aircraft are studied in an aircraft class.

3. Calculation work for the selection of the engine for the projected aircraft is carried out in a computer class using the designer of the ontologies of Magent and methodical instructions:

> *Use of ontology in the selection of the engine for the projected aircraft: methodical instructions for laboratory work No. 4 / comp. N. M. Borgest, E.V. Simonova - Samara: Publishing House of the SSAU, 2008. - 36 p.*

4. The evaluation of the efficiency of design activities carried out on an engine in an airplane system is carried out on the basis of the methodology set forth in these guidelines.

5. A simplified procedure for reconciling aircraft and engine parameters is carried out according to the procedure given in these instructions.

6. In the classes that complete the study of the discipline, students make a report, presentation and jointly discuss a self-prepared essay on a specific aircraft power plant with an analysis of its compliance with the requirements of the Aviation Regulations.

The consolidated report on laboratory practice and the abstract "Aviation power plant XXX" are made in the format of the standard of the Samara University.

AUDITORY LESSONS

1. The design of engines and their components (the center of the history of aircraft engines of the engine design department, building 14).
2. Characteristics and parameters of power plants (the test bench of the engines of the Department of Theory of Engines). Powerplant systems and engine mounts to the aircraft (aircraft class of Department of Aircraft Construction and Design, building 10)
3. Selection of the engine for the aircraft (computer class of Department of Aircraft Construction and Design, designer of the ontology Magenta, building 10).
4. Evaluation of the efficiency of engineering activities on engine in the aircraft system.
5. Matching parameters aircraft and engines.
6. Report and presentation of the abstract "Aviation Power Plant XXX."

SELF-WORK OF STUDENTS

Development of the abstract (Word) and presentation (Power Point) for (selected by the student or a given teacher) power plant for a particular aircraft.

The abstract "Aviation power plant XXX" includes the following sections and the recommended volume in the pages:

1 History of the company 1-2

2 History of the engine (prototypes, modifications ...) 1-2

3 Design of the engine, components, materials used 2-3

4 Drawing (longitudinal section of the engine) 1

5 Characteristics and parameters of the engine (geometric, mass, traction-economic, ecological, cost) 3-4

6 Power plant systems (start-up, hydraulic, oil, cooling, fuel, air conditioning, fire-fighting, control, anti-icing ...) 3-5

7 Mounting and layout of the engine (s) on the airplane (diagram, drawing) 2

8 Analysis of the conformity of the engine and its systems to the requirements of AR 3

9 List of used sources 1

TOTAL 25-30 с.

The presentation should consist of 15-20 slides, and the duration of the report should not exceed 4-6 minutes.

EVALUATION OF THE EFFICIENCY OF ENGINEERING ACTIVITIES ON ENGINE IN THE AIRCRAFT SYSTEM

Criteria for evaluating design and engineering solutions

The most important component of optimal design is the choice of criteria for evaluating solutions. From what criterion is chosen, not only the value of parameters and characteristics depends, but also the fate of the designed aircraft.

The first aircraft were evaluated according to individual characteristics. The aircraft was considered the best if it had a higher speed compared to the prototypes, better weight returns with equal range of flight, and so on.

In general, the following requirements are imposed on the evaluation criteria in general and the aircraft in particular:

- the criterion must be a measurable quantity, the calculation method of which is known;
- the criterion should take into account the main purpose for which an object (aircraft) is created, as well as conditions and limitations of operation;
- the criterion should include those parameters and characteristics of the object, the impact of which needs to be assessed or that need to be optimized;
- it is necessary that at each decision-making level (at each design stage) the criteria are consistent;
- it is desirable that the criterion be unified at all stages of the design (see also [3]).

Calculation of economic criteria for the assessment of transport aircraft

The procedure for calculating the exponents is described in detail in [4].

<u>The flight speed of the aircraft (km / h)</u> or the flight speed according to the schedule allows for the loss of time for the following stages of the flight: starting and warming up the engines, taxiing to the runway before takeoff and after landing, take-off and climb, maneuvering in the air after take-off and before landing, and landing. For approximate calculations, we can take::

$$V_{рейс} = \frac{L \cdot V_{крейс}}{L + \Delta t \cdot V_{крейс}}$$

where

$$\Delta t = 0{,}16 + 1{,}85 \cdot 10^{-4} \cdot H^3;$$

L – distance between take-off and landing airports, km;

$V_{крейс}$- cruising speed, km / h;

H – flight altitude, km.

<u>The maximum commercial load (kg)</u> is determined depending on the number of passenger seats and the capacity of luggage and cargo spaces on the aircraft:

$$m_{ком} = 90 \cdot n_{пас} + 290 \cdot \left(V_{баг} - \frac{20 \cdot n_{пас}}{120} \right);$$

where

$n_{пас}$ - number of passenger seats;

$V_{баг}$ - olume of luggage and cargo spaces, m^3.

Costs for aircraft depreciation (rubles / h):

$$A_{AC} = k_1 \cdot C_c \cdot \frac{1 + k_{pc} \cdot \left(\frac{T_c}{t_c} - 1 \right)}{T_c};$$

where

k_1 = 1,05 – a coefficient that takes into account non-production exposure;

$$C_c = k_{сер.с.} \cdot k_V \cdot \left[m_{пуст} \cdot \left(40 + 4 \cdot 10^{-4} \cdot m_{пуст} \right) + \frac{4 \cdot 10^{-4}}{1 + \frac{500}{m_{пуст}}} \right]$$ - cost (rub.) of aircraft without engines;

$$k_{сер.с.} = \left(\frac{35 \cdot 10^5}{m_{пуст} \cdot \sum n_c} \right)^{0,4}$$ - coefficient taking into account seriality;

$$k_V = 0,5 \cdot \left(1 + \frac{V_{крейс}}{800} \right)$$ - coefficient taking into account the estimated speed of flight;

$$k_{р.с.} = 0,11 + \frac{2 \cdot 10^4}{C_c}$$ - the ratio of the cost of one major repair to the initial cost of the aircraft;

$\sum n_c$ - number of aircraft in the series;

T_C – depreciation (full) lifetime of the aircraft;

t_C – aircraft service life between overhauls.

For long-haul aircraft in the middle Tc = 30 000-40000 ч, tc = 5 000-10000 ч.

Costs for the depreciation of engines (rubles / h):

$$A_{А.Д.} = k_2 \cdot n_{дв} \cdot C_{дв} \cdot \frac{1 + k_{р.д.} \cdot \left(\frac{T_{дв}}{t_{дв}} - 1 \right)}{T_{дв}};$$

where

k_2 =1,07 – coefficient of non-industrial exposure;

$n_{дв}$ - number of engines per aircraft;

$C_{дв}$ - ost of one engine, rubles.;

For a turbofan engine, you can take $C_{дв} = k_{сх} \cdot k_{сер.дв.} \cdot P_{0i} \cdot \left(34 - 0,4 \cdot \sqrt[3]{P_{0i}} \right)$;

where

P_{0i} - takeoff thrust of one engine;

$k_{сх}$ – coefficient taking into account the type of engine;

$k_{сер.дв.}$ – coefficient taking into account the series of the engine;

$k_{сх}$ = 0,85 for turbojet; $k_{сх}$ = 1 – for a turbofan engine with M < 1;

$k_{сх}$ = 1,5 – with M > 1.

$$k_{сер.дв.} = \left(\frac{1500}{\sum n_{дв}} \right)^{0,25}.$$

The price of one turboprop engine with a propeller on the average

$$C_{ТВД} = 1{,}36 \cdot k_{сер.дв.} \cdot N_{0i} \cdot \left(40 - 0{,}52 \cdot \sqrt[3]{N_{0i}}\right);$$

where

N_{0i} - takeoff power of one engine, kW;

$k_{р.д.}$ - the ratio of the cost of one engine overhaul to its original cost;

For turbojet and turbofan engines

$$k_{р.д.} = 0{,}15 + 4{,}15 \cdot 10^{-5} \cdot \left[1 - 0{,}2 \cdot \left(\frac{T_{дв}}{t_{дв}} - 1 \right) \right] \cdot T_{дв}.$$

where

$T_{дв}$ - depreciation (full) service life of the engine;

$t_{дв}$ - engine service life between overhauls.

For calculations it is assumed Tдв = 6 000-10000 h. and tдв = 3 000-4000 h. For turboprop - $k_{р.д.}$ = 0,6.

Expenses for current repair and maintenance of the aircraft (rub / h):

$$A_{Т.О.С.} = k_3 \cdot m_{пуст} \cdot 10^{-3} \cdot \left(4{,}4 - 0{,}1 \cdot \sqrt[3]{m_{пуст}} + 0{,}15 \cdot 10^{-4} \cdot m_{пуст}\right)$$

where

k_3 = 1 – for subsonic airplanes with turbojet and turbofan; k_3 = 1,13 – for aircraft with turboprop; k_3 = 2 – for supersonic passenger aircraft.

Expenses for current repair and maintenance of engines (rub / h):

$$A_{Т.О.Д.} = \frac{0{,}16 \cdot k_2 \cdot k_4 \cdot n_{дв} \cdot \sqrt{P_{0i}}}{1 + 7 \cdot 10^{-5} \cdot T_{дв}}$$

where

k_4 = 1 – for subsonic airplanes with turbojet and turbofan; k_4 = 1,5 – for aircraft with turboprop.

The crew wage costs are calculated based on the number of members of the flight crew $n_{л.п.с}$ and the number of stewardesses $n_{бп}$ (see table 1).

$$A_{З.П.} = \overline{C}_{л.п.с.} \cdot n_{л.п.с.} + \overline{C}_{бп} \cdot n_{бп},$$

where

$\overline{C}_{л.п.с.}$ и $\overline{C}_{бп}$ - average hourly wage of flight crew and stewardesses. (see table 1).

The cost of fuel consumed in flight (rub / h):

$$A_{Т} = 0{,}051 \cdot k_5 \cdot m_{т.расх.} \cdot \frac{V_{рейс}}{L_{расч}},$$

where

$m_{т.расх.}$ - mass of fuel consumed in flight, kg.

Где k_5 = 1 – turbojet and turbofan engines for subsonic aircraft; k_5 = 1,03 – for aircraft with turboprop; k_5 = 1,06 – for supersonic passenger aircraft.

Indirect (airport) costs (rub / h):

$B_{АП} = 0{,}083 \cdot m_0^{0,7}$ **,**

where m_0 - in kg.

$$a := \frac{100 \cdot A}{k_{ком} \cdot m_{ком} \cdot V_{рейс}}$$

Cost of transportation**:**

$$a = \frac{100 \cdot A}{k_{ком} \cdot m_{ком} \cdot V_{рейс}};$$

where $A = A_{АС} + A_{А.Д.} + A_{Т.О.С.} + A_{Т.О.Д.} + A_{Т} + A_{З.П.} + B_{АП}$

$k_{ком}$ – see table 1.

Приведенные капиталовложения (коп\т км):

$$a_{кап.вл.} = \frac{10^2 \cdot E \cdot (1{,}05 \cdot C_c + 1{,}03 \cdot C_{дв} \cdot n_{дв} \cdot b)}{k_{ком} \cdot m_{ком} \cdot V_{рейс} \cdot B_{год}}$$

where E = 0,12 – capital efficiency ratio;

$$b = 1{,}17 + 0{,}29 \cdot \frac{B_{год}}{t_{дв}};$$

$$B_{год} = k_6 \cdot \frac{L_{расч}}{L_{расч} + k_7 \cdot V_{рейс}}$$ - flying hours per plane per year.

where

k_6 and k_7 see table 1.

The resulted expenses:

$$a_{пр} = a + a_{кап.вл.}$$

This calculation option is basic. Then the calculation is repeated, but already with the changed values of specific consumption - reduced by 5% (2nd option) and the weight of the power plant - decreases by 5% (version 3).

The weight of the power plant is not explicitly present, so we change the value $m_{пуст}$ according to the formula:

$$m'_{пуст} = m_{пуст}^{баз} - 0{,}05 \cdot m_{пуст}^{баз}$$

The change in specific consumption will lead to a change in the mass of fuel consumed in flight and, consequently, to a change in the cost of consumed fuel. Reducing the mass of the power plant will lead to a reduction in the mass of the aircraft as a whole by an appropriate amount (will change $m_{пуст}$ and m_0). The results of the calculation are reduced to a table and compared with the base one (by what percent the resulted costs, the cost of transportation, etc., have changed, see table 2).

Table 1. Coefficients for calculation

Type of aircraft	$К_{ком}$	Сл.п.с., rub / h	Сбп., rub / h	$к_6$	$к_7$
Subsonic	0,58	11	4	2700	0,42
Supersonic	0,65	20	7,5	2700	0,42
Local airlines	0,65	11	4	2600	0,53
Multi-purpose ($n_{пас} \leq 6$)	0,75	8	—	2000	0,61

Table 2. Summary table of calculation of the parameters of the aircraft

Calculated values	Basic option	Option – 2 (↓Ср 5%)	Option – 3 (↓Gс.у. 5%)
$А_{а.с.}$	+		+
$С_с$	+		+
$k_{сер.с.}$	+		+
$А_{т.о.с.}$	+		+
$А_т$	+	+	
$В_{ап}$	+		+
А	+	+	+
$а_{кап.вл}$	+		
а	+	+	+
$а_{пр}$	+	+	+

For the basic calculation, numerical values of the indicated quantities are written out, and for the 1 and 2 options of calculation, the cells marked with a dagger write out the change in the percentage value (Δ%) from the base calculation.

$$\Delta\% = \left(1 - \frac{X_{вар}}{X_{баз}}\right) \cdot 100\%$$

where

Хвар – value of 2 or 3 options
Хбаз – value from base option.

MATCHING PARAMETERS AIRCRAFT AND ENGINES

Conventions:

Y - lift, N
Cy - lift coefficient
X - drag, N
Cx - drag coefficient
$\mathbf{P_{потр}}$ - required thrust for flight, N
$\mathbf{P_{расп}}$ - available thrust, N
$\mathbf{P_0}$ - takeoff thrust, N
$\mathbf{Cp_0}$ - Specific fuel consumption for takeoff, kg / h H
$\mathbf{G_0}$ - take-off weight of the aircraft, kg
$\mathbf{G_т}$ - weight of fuel, kg
G - gravity, N
ρ - density of air, kg / m^3
V - flight speed, m / s
S - Wing area, m^2
H - flight altitude, m
Mп - Flight Mach
a - speed of sound, m / s
$\mathbf{P_h}$ - pressure at height h, mm. mercury column
$\mathbf{T_h}$ - temperature at altitude h, K
Cp - Specific fuel consumption, kg / N * h
t - flight time, h
Lп - range of flight, km

<u>Accepted assumptions for calculation:</u>
All modes of engine operation and flight altitude are replaced by one - cruising mode ($\mathbf{H_п}$, $\mathbf{M_п}$).

<u>Input for calculation:</u>
The initial data is taken from the abstract:

1. $G_{0,}$ $G_т$, S, P_0, Cp_0.
2. It is desirable to find aerodynamic characteristics (polars) of an airplane in open sources, or to use generalized polars, for example [4, c.582-584].
3. The altitude-speed characteristics of the engine are also desirable to be found in open sources, or to use generalized characteristics, for example [4, c.586-587].

We specify three values of flight altitude and Mach (H_1,H_2,H_3, и M_1,M_2,M_3), which are close to those values that a particular aircraft under study has for cruising flight conditions. Their values are entered in the summary table 4.

Values **ρ, T_h, P_h, a** are from the standard atmosphere table for a given flight altitude (see Table 3) and are also recorded in a summary table 4.

Table 3 - Standard atmosphere table

Flight altitude, m	**Pressure P_h, mm. mercury column**	**Temperature T_h, К**	Relative density of air	**Sound speeda, m/s**
0	760,0	288,0	1,000	340,2
500	716,0	284,7	0,953	338,3
1000	674,1	281,5	0,907	336,4
1500	634,2	278,2	0,864	334,4
2000	596,2	275,0	0,822	332,5
2500	560,1	271,7	0,781	330,5
3000	525,8	268,5	0,742	328,5
3500	493,2	265,2	0,705	326,5
4000	462,2	262,0	0,669	324,5
4500	432,9	258,7	0,634	322,5
5000	405,1	255,5	0,601	320,5
5500	378,7	252,2	0,569	318,4
6000	353,8	249,0	0,538	316,3
6500	330,2	245,7	0,509	314,3
7000	307,8	242,5	0,481	312,2
7500	286,8	239,2	0,454	310,1
8000	266,9	236,0	0,429	308,0
8500	248,1	232,7	0,404	305,9
9000	230,5	229,5	0,381	303,7
9500	213,8	226,2	0,358	301,6
10000	198,2	223,0	0,337	299,4
10500	183,4	219,7	0,316	297,2
11000	169,6	216,5	0,297	295,0
12000	144,8	216,5	0,2536	295,0
13000	123,7	216,5	0,2166	295,0
14000	105,6	216,5	0,1849	295,0
15000	90,2	216,5	0,1579	295,0
16000	77,0	216,5	0,1349	295,0
17000	65,8	216,5	0,1152	295,0
18000	56,2	216,5	0,0983	295,0
19000	48,0	216,5	0,0840	295,0
20000	41,0	216,5	0,0718	295,0
21000	35,0	216,5	0,0613	295,0
22000	29,9	216,5	0,0523	295,0
23000	25,5	216,5	0,0447	295,0
24000	21,8	216,5	0,0382	295,0
25000	18,6	216,5	0,0326	295,0

ρ=1,22 kg / m^3 is the density of air on the surface of the earth.

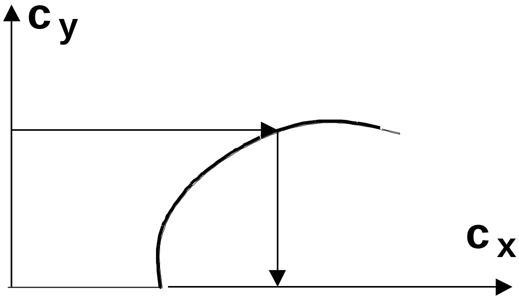
Calculation algorithm

(All received values are recorded in the summary table 4.)

1. Determines the speed of flight Vп at altitude H by the formula:
   $V_H = M_H \cdot a$
2. Determines Cy:
   $G = G_0 - G_т/2$ [H] – airplane weight
   $Y = Cy \cdot (\rho \cdot V^2/2) \cdot S$,   for cruising flight Y=G. Then

$$Cy = \frac{G}{\rho \cdot \frac{V^2}{2} \cdot S}$$

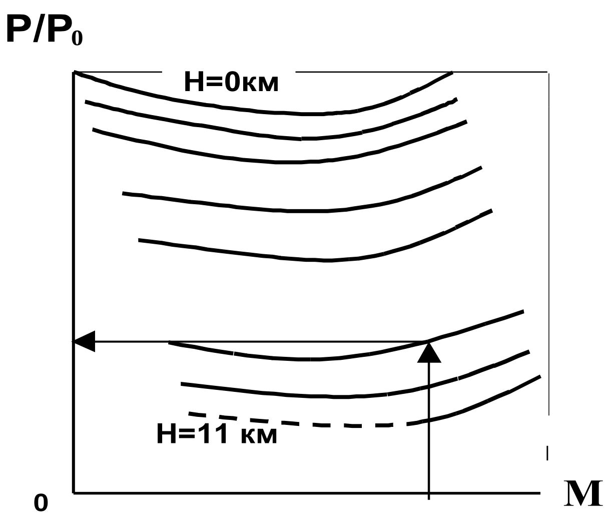
3. According to the calculated value Cy graphically determine Cx by polar for this aircraft Cy=f(Cx) :



4. From the value found Cx determine the required thrust of the engines $P_{потр}$ to complete a flight:

$X = Cx \cdot (\rho \cdot V^2/2) \cdot S$ (2),   for cruising flight $X = P_{потр}$.

5. Determines $P_{расп}$:
6. Knowing the Mach number of flight, one can find the graphical method (P/P_0) using the high-speed characteristic of this type of engine:



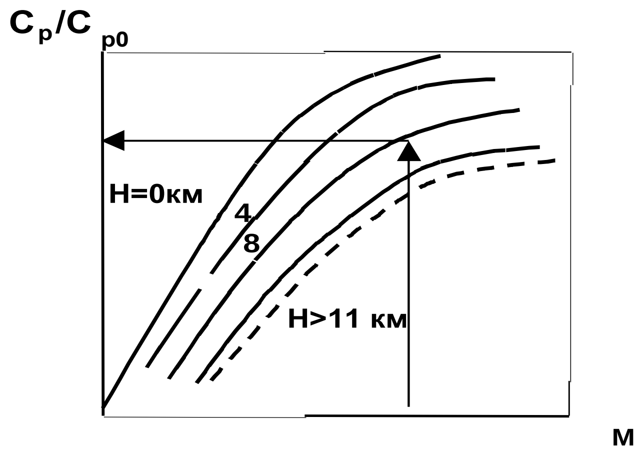
Then, knowing the value of take-off thrust P_0,

$$P_{расп} = P_0 \cdot (P/P_0).$$

The condition $P_{расп} \geq P_{потр}$. If it is not satisfied, then change the take-off thrust P_0 (engine size).

6. We find the specific fuel consumption for a given altitude and flight Mach Cp:

By generalized altitude-speed characteristics of the engines can be found $\overline{C}_{уд}$ =Cp/Cp$_0$ from Cp/Cp$_0$=f(M):



Knowing Cp$_0$ for this engine from (3) we obtain the specific fuel consumption for a given altitude and flight Mach

$Cp=\overline{C}_{уд} \cdot Cp_0$

7. From the equation of fuel consumption $G_т=Cp \cdot P_{расп} \cdot t$ the flight time is determined $t=G_т/Cp \cdot P_{расп}$, then $L_п=V_h \cdot t$ – aircraft flight range.

The results of the calculation will be reduced to a table 4.

Table 4 - Summary table of calculation results

H, м	H_1			H_2			H_3		
Мп	M_1	M_2	M_3	M_1	M_2	M_3	M_1	M_2	M_3
ρ,кг/м^3									
T_h,°К									
P_h,мм Рт.ст.									
a, м/с									
V,м/с									
Cy									
Cx									
$P_{пот}$,Н									
$P_{расп}$,Н									
Cp									
t, ч									
Lп, км									

From Table 4 we find the mode where $\Delta P = P_{расп} - P_{потр} = \min$. For this mode, we find $\bar{p} = \frac{P_{расп}}{P_{потр}}$, after that we find a new value of take-off thrust: $P_{0_{нов}} = \frac{P_0}{\bar{p}}$.

According to the calculation, it is concluded at what altitude and speed of flight it is better to fly, based on the calculated value of the flight range, for this aircraft. Also, you should indicate and analyze - whether the take-off thrust of the engines (the size of the power plant).

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