Ways of measuring the number of foreign particles in the gas turbine engine air intake

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Resume

The article analyzes the problems of creating a device for measuring the physical and geometric parameters of foreign particles in the air intake device of aircraft gas turbine engines and suggests possible solutions based on various physical principles.

The flow in the air intake, which contains solid bodies together with the air, is considered as the two-phase flow in the pipe (gas / solid bodies) and the appropriate method is selected to measure the solid phase parameters in the flow under the above conditions. The measures required to establish a device for measuring the total number of masses of foreign bodies in the air intake equipment of aircraft gas turbine engines.

Keywords: Gas turbine engines, air intake equipment, two-phase flow, measuring device, concentration of heavy and light components in the flow.

Introduction

As it is known, a certain number of aircraft air turbine engines are removed from the aircraft before the warranty period is exhausted, the main reason being damage to the compressor, combustion chamber and air turbine and other parts of the engine as a result of objects falling into the engine air intake device. External items may include: small particles of dust or sand of various sizes, pebbles, runway and pavement concrete products, ice fragments, surface cleaning machine brush wires, etc.

Atmospheric air pollution with dust occurs as a result of the movement of air masses both horizontally (wind) and vertically (ascending currents).

As the flight altitude increases, the concentration of dust in the air decreases. The average value of dust concentration in the air is: 1 mg / m3 above the sea, 3 mg / m3 above the mountains, 5 mg / m3 above the large industrial cities, 10 mg / m3 above the runways.

The maximum concentration of dust is observed in the lower zone of the bearing screw rotor of the aircraft at a distance of 15-30 m from its axis and reaches 5 g / m3 for sandy runways. During the operation of the helicopter, the concentration of dust at the altitude of 2-2.5 m decreases and does not exceed 0.5 g / m3. At this time, coarse dust particles (above 200 mg) make up about 20% of the mass and 2-3% of the mass at 2-2.5 m at height. If the distance between the helicopters on the runway is less than 50 m, then the dust from one helicopter due to the movement of air currents significantly affects the performance of the engines of the other helicopter.

It is known that during the operation of aircraft turbine engines, they are periodically inspected in accordance with the established regulations to determine the degree of damage to its components. If it is determined that damage to the engine is dangerous for its further operation and it is impossible to repair it, then the engine is removed from the aircraft and replaced with a new one.

But if the aircraft takes off before the engine inspection time has elapsed so that the degree of engine damage was above or close to the limit, then there is a risk not only of the engine malfunctioning but also of the aircraft crashing. Therefore, it is advisable to equip the aircraft with a device that will detect dust and other solid particles as they enter the engine air intake device, also evaluate their composition and concentration, as well as their number during the flight (s) and display the data on the appropriate screen.

Using such a device, it is possible to operatively determine the degree of damage to the engine, the level of approach to the limit of the warranty resource and decide on the need for its repair, thus avoiding premature engine failure, as well as the risk of impending catastrophe.

To create a device for measuring the physical and geometrical parameters of foreign particles in the air intake equipment of aircraft gas turbine engines, the air intake in the intake manifold, which contains solid bodies together, can be considered as a two-phase flow in the tube and select the appropriate flow method in the above-mentioned flow method. As can be seen from the above data, in our case the solid phase parameters (dust concentration, particle size and density, velocity, etc.) will not be uniform along the trajectory of the aircraft, as well as across the air intake device, for different flight time intervals, which complicates Determine the type and number of foreign particles in the device during the long life of the aircraft.

Fig. 1. A photo that shows how a non-uniform flow is going into the aircraft engine air intake device

In the case of any substance flow, including two-phase flow, the mass or volume of substance per unit time per tube, or flow rate - Qm or Qv, depends on flow parameters such as mixture composition and heterogeneity, component phase velocities (usually different from each other).) Structure and concentration of substances in each phase, etc. Often the concentration of a single phase of the mixture varies along the length of the tube, so instantaneous flow measurements will never be relevant to the actual flow. In this case, the average value of the flow in a defined time interval is used to characterize two-phase flow. The average velocities of the heavy phase (in our case solid particles) are usually less than the velocities of the light phase.

Depending on the method of measurement (mass or volume) the concentration of the substance can also be mass or volume.

The actual concentration over a section of pipe of a certain length, i.e. the share of one of the constituent components in a mixture, such as a heavy component, is its volume V (heavy comp) or mass M (heavy comp) = V (heavy comp) ρ (heavy comp) Is proportional to the total volume V (s) = V (heavy comp) + V (light comp) Or to the total mass M (s) = V (heavy comp) **ρ** (heavy comp) + V (light comp) **ρ** (ms. K). Here V (light comp) is the volume of the light component of the mixture, while ρ (heavy comp) And ρ (light comp) Are the densities of the heavy and light components of the mixture. The relationship between the concentrations of both components is expressed by the equations:

$$\varphi_v = 1 - \eta_v; \qquad \varphi_m = 1 - \eta_m,$$

Where: φv and φm are the volumetric and mass concentrations of the light component, while ηv and ηm are similar concentrations of the heavy component [1, p. 622].

If we are interested in determining the total mass of the heavy components of the mixture M (heavy comp) that can be trapped in the aircraft turbine engine air intake unit before take-off, flight time T Should be divided into n equal sections Δti, during which it will be possible by any selected method to measure the mass of heavy components in the receiving device in each i-th time Mi (heavy comp) and sum them for the entire time of engine operation:

$$\mathbf{M}_t(\text{heavy comp}) = \Sigma\, \mathbf{M}_i(\text{heavy comp})$$

Since the magnitude of the Ti part of the selected time is known, the mass flow rate of the heavy components Qim (heavy comp) must be measured and multiplied by Ti to determine the mass of the heavy components in the receiving device at this time.

As it is known [1, p. 632], for a two-phase flow where the velocities of the heavy and light components of the flow are equal to each other, the mass flow rate of the heavy components Q_i^m (heavy comp) can be determined by the formula

$$\mathbf{Q}_i^m(\text{heavy comp}) = \mathbf{k}_i\, (\boldsymbol{\rho}_i(\text{mix}) - \boldsymbol{\rho}_i(\text{light comp}))\, \mathbf{Q}_i^v(\text{mix}),$$

where $\mathbf{k}_i = \boldsymbol{\rho}_i(\text{heavy comp})/(\boldsymbol{\rho}_i(\text{heavy comp}) - \boldsymbol{\rho}_i(\text{light comp}))$.

In the case when the velocities of the heavy and light components of a two-phase flow **differ significantly from each other**, then

$$\mathbf{Q}_i^m = \mathbf{k}_i(\boldsymbol{\rho}_i(\text{mix}) - \boldsymbol{\rho}_i(\text{light comp}))\mathbf{F}\boldsymbol{\upsilon}_i(\text{heavy comp}),$$

where **F** - Is the cross-sectional area of the pipe.

It follows from these equations that to determine the Q_i^m mass flow of a heavy component in two-phase flow, we need to know for each i-th period of time:

- A) in case of equal velocities (in case of dust the average velocities of the heavy and light components of the flow can be considered equal to each other)
- $\boldsymbol{\rho}_i$(mix) - The flow density of the mixture entering in the air intake device;
- $\boldsymbol{\rho}_i$(heavy comp) - Density of heavy components in the mixture stream;
- $\boldsymbol{\rho}_i$(light comp) - Density of light components in the mixture stream;

- **Q_i^v**(mix) - Volumetric flow rate.

B) in case of different speeds

- **ρ_i**(mix) - The flow density of the mixture entering in the air intake device;
- **ρ_i**(heavy comp) - Density of heavy components in the stream (in most cases - dust, sand or their mixture);
- **ρ_i**(light comp) - Density of light components in the flow (in our case - air);
- **υ_i** (heavy comp) - Average speed of movement of heavy components (in case of sand or other heavy particles, the average speed of their movement will be different from the average speed of air flow entering in the air intake device);
- **F -** The cross-sectional area of the pipe (in our case it is equal to the cross-sectional area of the air intake device).

By measuring the above values and then delivering them digitally to the appropriate computing devices, a device can be created to measure the total mass of foreign bodies in the engine air intake (see Fig. 2).

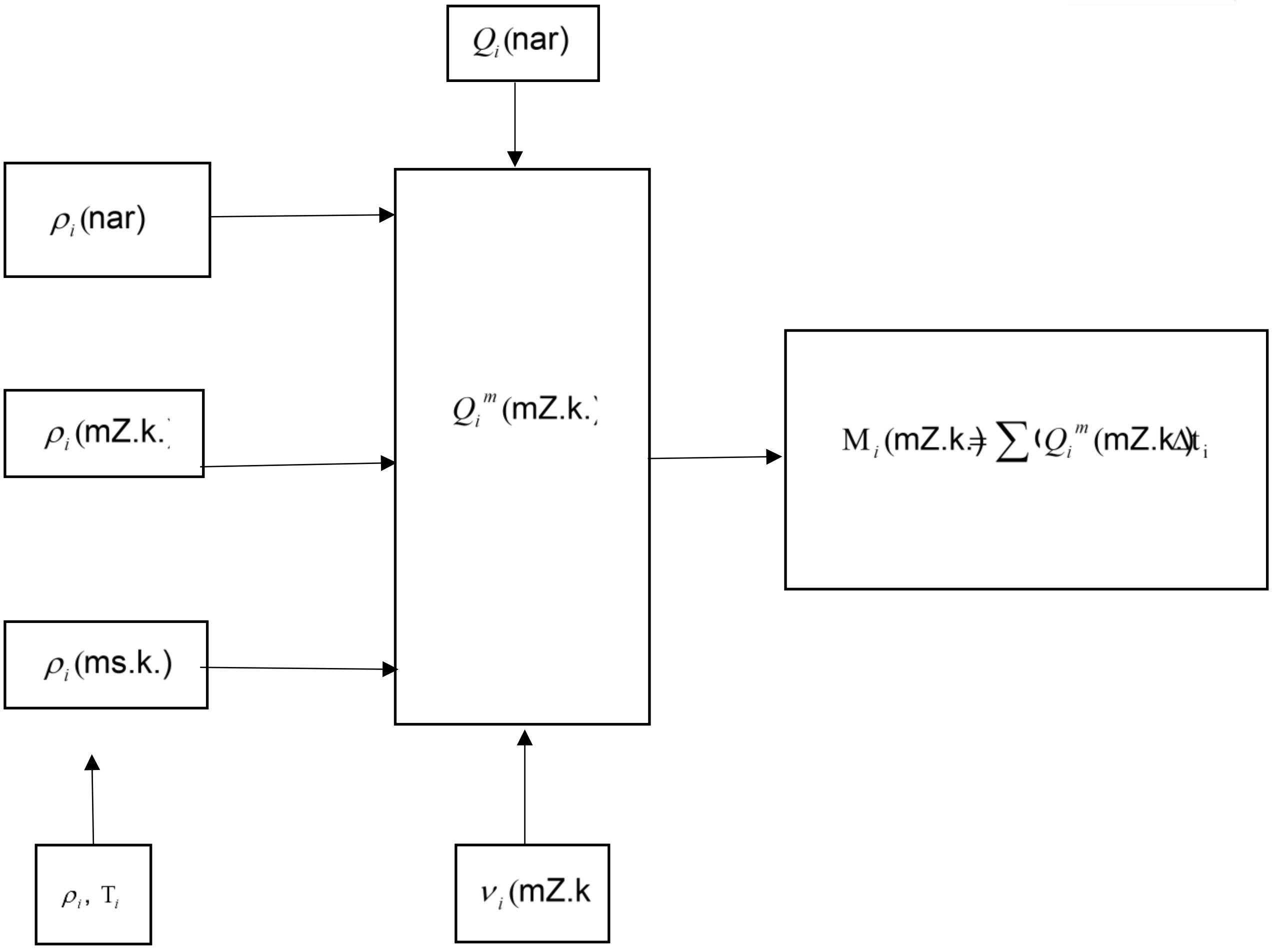

Fig. 2. The total number of masses of foreign bodies in the air intake equipment of aircraft gas turbine engines, Block diagram of the measuring device

The following problems need to be solved for the design and practical implementation of a device for measuring the total number of masses of foreign bodies in the air intake equipment of aircraft gas turbine engines:

Problem 1. Find and develop technical principles and methods and digital measuring instruments based on these methods (or modernize and use ready-made instruments if they are available) that can measure the flow of airborne equipment and its components within the above parameters. , In the conditions of dynamic processes of flight and landing.

Such necessary tools are:

- Measurements of mixture flow as well as heavy and light components in the flow;

- Volumetric flowmeter of mixture flow;
- Measure the speed of heavy components;

In addition, it is necessary to use the altimeter, the data of which must be taken into account to determine the density of the light component (or air) in the flow of the engine intake device, because the determinants of air density ρ - pressure p and temperature - T depend on altitude - h.

It is known that the change in ρ density of air according to the altitude h above sea level is expressed by the formula [3]

$$\rho = \frac{pM}{RT} = \frac{pM}{RT_0(1 - Lh/T_0)} = \frac{p_0 M}{RT_0}\left(1 - \frac{Lh}{T_0}\right)^{gM/RL-1},$$

Where **p0** is the standard atmospheric pressure at sea level, 101,325 kPa;

T0 - The standard air temperature is 15 K°;

R - Universal gas constant, 8,314 J / mol kelv;

M - Molar mass of air, 0.0289;

g - Free fall acceleration, 9.81 m / s2;

L - Temperature gradient, 0.0065 kV /

Below is a table from the same source, showing how atmospheric temperature, pressure, and air density change with altitude (0 to 10 km).

altitude **h**, m	temperature **T**, K°	pressure **p**, Kpaskal	Density ρ, kg / m3
0	288,150	101,325	1,225
250	286,525	98,876	1,196
500	284,900	95,461	1,167
750	283,276	92,635	1,139
1000	281,651	89,876	1,112
1500	278,402	84,560	1,058
2000	275,154	79,501	1,006
2500	271,906	74,692	0,957
3000	268,659	70,121	0,909
3500	265,413	65,780	0,863
4000	262,166	61,660	0,819
4500	258,921	57,752	0,777
5000	255,676	54,048	0,736
5500	252,431	50,540	0,697
6000	249,187	47,218	0,660
6500	245,943	44,074	0,624
7000	242,700	41,105	0,590
7500	239,457	38,300	0,557
8000	236,215	35,652	0,525
8500	232,974	33,154	0,496
9000	229,733	30,801	0,467
9500	226,492	28,825	0,440
10000	223,252	26,500	0,414

As can be seen from the table above, when the aircraft is flying at an altitude of 10 km above sea level, the air density can be reduced from 1,225 kg / m3 to 0.414 kg / m3, three times.

There are many physical principles and methods based on them for measuring the density of heavy and light components in a stream as well as for measuring the flow rate of the mixture and the velocity of the heavy components.

The problems posed in Task 1 can best be solved by the physical methods used in contactless and non-invasive control tools. Consider some of them.

A) Use of radioisotope gamma radiation

As is well known, the intensity of monochromatic and parallel rays of gamma radiation passing through a substance changes according to the following Lambert-Berry law.

$$l = l_0 \exp(-\mu d),$$

Where l0 is the initial intensity of the gamma-ray flux and μ is the linear absorption coefficient, depending on the type of substance and its ρ density, is the thickness of the d-substance in which the gamma-ray passed under partial absorption.

The above principle is used, for example, to determine the dissipient characteristic of the volumetric content of gas in a two-phase flow (water-gas) β = Q (gas) / (Q (gas) + Q (water)), where

$$\beta\gamma = 1 - \ln (I\ (gas)/I) / \ln (I(gas)/I(water)),$$

Where I is the intensity of the measured gamma radiation passing through the substance I, and Q is the volumetric consumption [4]. The authors of the latter designed a three-phase (gas-water-oil) flow parameters in the pipe to determine the parameters of the isotope gamma-density measurement, which used ammonium 241 (Am241) and cesium 137 (Cs137) radioisotopes.

It should be noted that the use of radioisotope gamma radiation to determine the parameters of the components in a multiphase flow in a pipe is better than others because its use does not change the dynamic and kinematic characteristics of the flow or the geometric dimensions and mechanical characteristics of the pipe. . Because of these properties, radioisotope tools are widely used for a variety of scientific research and technical tasks in a variety of industries and services, including aviation. One example of this is the radioisotope indicator RIO-3, which contains a radioisotope source - strontium 90 + yttrium 90 (90Sr / 90Y).

But the disadvantage of this method is that during the operation of radioisotope equipment it is necessary to strictly adhere to radiation safety measures, which primarily involves placing the radioisotope in a protective container made of high-density substances (lead, tungsten, etc.), which will inevitably increase the load. In addition, when equipping an aircraft with a radioisotope device, there is a possibility of radiation pollution in the event of an aircraft crash.

In addition, in some cases, when there are limitations on the volume and weight of the measuring instrument due to its technical requirements and operating conditions (such as aircraft constructions and weight minimization requirement when installing additional equipment), it becomes unreasonable to use this method if this requirement is not satisfied.

B) Use of ultrasound method

The flow of air in an air intake device, which is mixed with outside objects, is treated as a two-phase flow - a mixture of gas and solid phase. In practice, a similar flow of air containing solid particles takes place in pipes that transport cement, flour, fuel coal dust, and other similar substances through pneumotransport.

During the passage of acoustic oscillations in fluids, effects are generated, the parameters of which depend on the density and velocity of these substances.

At present, three methods are used to measure the flow rate in a pipe using ultrasonic oscillations.

1. A method based on the measurement of changes in the displacement characteristics of ultrasonic oscillations in the direction of flow and countercurrent. Fig. Figure 3 shows three variants of this method: temporal (when the time difference between the corresponding pulses of the ultrasonic oscillations is measured, Fig. 3a), phase (when the difference between the phases of the ultrasonic oscillations is measured, Fig. 3b) and frequency (when the frequency of the ultrasonic oscillations is measured). Difference, Fig. 3 c).

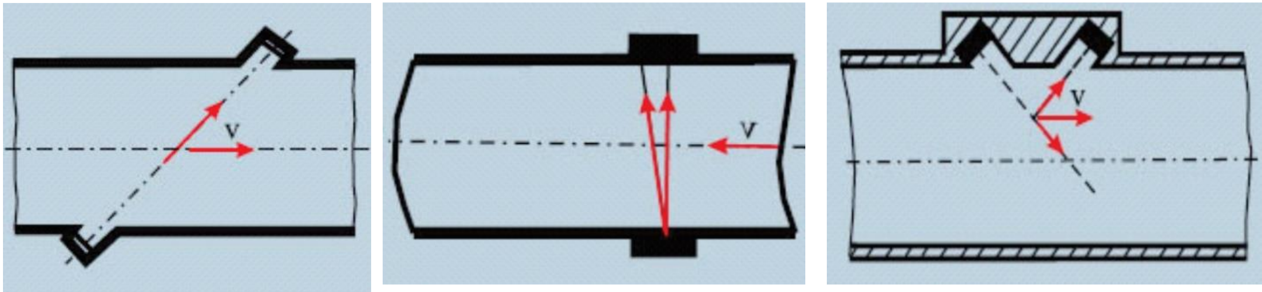

Fig. 3. Variants of the method of measuring the change in the characteristics of the movement of ultrasonic oscillations in the direction and in the flow: temporal a), phase b), frequency.

1. A method in which ultrasonic oscillations are directed perpendicular to the direction of flow and are measured from the initial state of the oscillations when the oscillations between these oscillations as they pass through the environment.
2. A method based on the Doppler effect.

Radiation and receiver elements made of piezoceramic materials are used to inject ultrasonic fluctuations into the flow, as well as to measure the parameters of the output fluctuations, the characteristics of which are of great importance for the selection to be used in the given specific conditions.

Devices based on the ultrasound method are varied according to both the primary converters as well as the measurement circuits and the conditions of use [1]. For example, high frequencies (0.1-10 MHz) are typically used to measure the flow rate of clean liquids, while in the case of contaminants, tens of kilohertz frequencies are used to prevent the scattering and absorption of acoustic oscillations by contaminants. It is essential that the wavelength be one order of magnitude greater than the diameter of the solid particles. Low frequencies are also used to measure gas flow.

Due to the variety of devices based on the ultrasound method, in this article we will not discuss the physical foundations of the construction of each type of device and the functional schemes of their operation. Let's just say that they can be used to measure the volumetric flow of airflow into an aircraft. As for the light and heavy components of the flow, as well as the total densities of the flow, their measurement will require the production of special emitting and receiving ceramic piezoelectric elements, as well as the processing of a measuring circuit.

Today, many countries around the world produce ultrasound screens for various purposes, which are used in the transportation of crude oil products by oil companies, in the transportation of various hazardous substances in chemical plants by special pipes, in the pneumatic transport of coal dust, and more. The leading manufacturers of ultrasonic density measurements and cost measurements are - ExAir Corporation, USA; Georg Fischer; Emerson et al.

C) use of radiofrequency (radar) method

The phase velocity of the radio wave propagation at the inlet of the air intake and the absorption coefficient are directly related to the composition of the propagation medium [2]. An interesting option from measuring devices is therefore the registration of objects without the radio frequency method.

The phase velocity of the radio wave propagation at the inlet of the air intake and the absorption coefficient are directly related to the composition of the propagation medium. In particular, the initial amplitude of a wave decreases with distance r by the following regularity:

$$\boldsymbol{A = \frac{A_0}{r} e^{-\frac{\omega \chi r}{c}}}$$

Where χ is the absorption rate and is calculated as follows:

$$\boldsymbol{\chi = \sqrt{\frac{1}{2}\varepsilon(\sqrt{1 + tg^2\delta} - 1)}}$$

ω - Is the angular frequency of the radio wave, c is the speed of light, tgδ is the tangency of the loss angle, ε is the electrical constant.

The phase of the radiated electromagnetic wave changes with the following regularity:

$$\boldsymbol{\Psi = \omega t - \frac{\omega n r}{c}}$$

Where n is the refractive index:

$$\mathbf{n = \sqrt{\frac{1}{2}\varepsilon(\sqrt{1 + tg^2\delta} + 1)}}$$

In our case we must assume that the propagation environment is of a dielectric nature and at this time tgδ << 1. The values of tgδ and ε depend on the frequency of the radiation, the temperature and the structure of the environment. These values should be determined experimentally. In this case, typical samples such as dust and sand particles, runway decay products, water and ice particles, etc. should be used as an environment.

Knowledge of the frequency dependence of the parameters of external particles allows to determine their composition by radiation of several frequencies. Dimensions of objects can be determined using high-frequency range radar methods:

- ✓ The development of modern technology has made it possible to utilize high-frequency radio frequencies (20-120 GHz) that were difficult to use in the past. We consider it expedient to use the technologies of radar systems in this range to solve the posed problem.

  Using this method it will be possible to determine the composition of substances, for example: rain, fog, ice debris, sand, volcanic ash, salts, etc. Sh. Since each type of molecule has specific absorption frequencies in the specified radio frequency range. Substances will be classified according to the absorbed frequencies. And the amount of energy absorbed determines mass and volume. Because the wavelength of the radiation is in the micrometer range, this allows the geometric dimensions of the particles to be measured.

D) Optical (laser) method

One of the most interesting options for creating a device for recording objects and measuring parameters in the air intake without an air intake is the use of an optical method, in which information is transmitted using fiber-optic means.

With the optical-fiber method it is possible to "see" the objects of observation, as well as to transmit the relevant information with reliable accuracy to the device for receiving and processing information. If the gas stream contains small particles with two beams of laser pointing at it. When the particle passes the first laser beam, it is scattered and hits the photodetector, which generates the corresponding electro-pulse signal. When the same particle passes through a second laser beam, it is also scattered and hits the photodetector, which generates a second electropulse signal. If we measure the time interval T between these two signals and know the current F through the distance and the distance L between the sources of the first and second laser beams, we can calculate both the flow velocity υ and the volumetric flow Qv with the classical formulas

$$\upsilon = L / T, \quad Q^{v} = \upsilon * F.$$

Laser flowmeters measure the velocity of a moving and flowing particle, which does not depend on the physical properties of the particle or the gas composition and composition. Therefore, laser measurement technology provides more accurate data than other methods when they cannot be used or are measured with large errors (at high temperatures, pressure and humidity, or during vibration and acoustic noise. Laser flowmeters can measure flow velocities of 0.1 m / s). From 100 m / s.

In addition to the methods discussed above, there are many other methods on the basis of which density and cost measurements of different types and purposes are created [1]. Most of them can be used in their current form or it is impossible or inappropriate to solve the problems posed in the article.

Problem 2. Find and determine the space and locations required for the placement and installation of experimental samples of measuring instruments in the air intake equipment of air turbine engines so as not to alter the aerodynamic characteristics of the aircraft.

In our opinion this can be solved by adding a pipe or other structural element of the same diameter to the inlet of the air intake device, on which it will be possible to further install the measuring instruments (see Fig. 4). The dimensions of the additional tube or other structural element shall be determined on the one hand by the technical conditions necessary for the installation of the handled equipment and on the other hand limited by the principle of inadmissibility of deterioration of the aerodynamic characteristics of the aircraft.

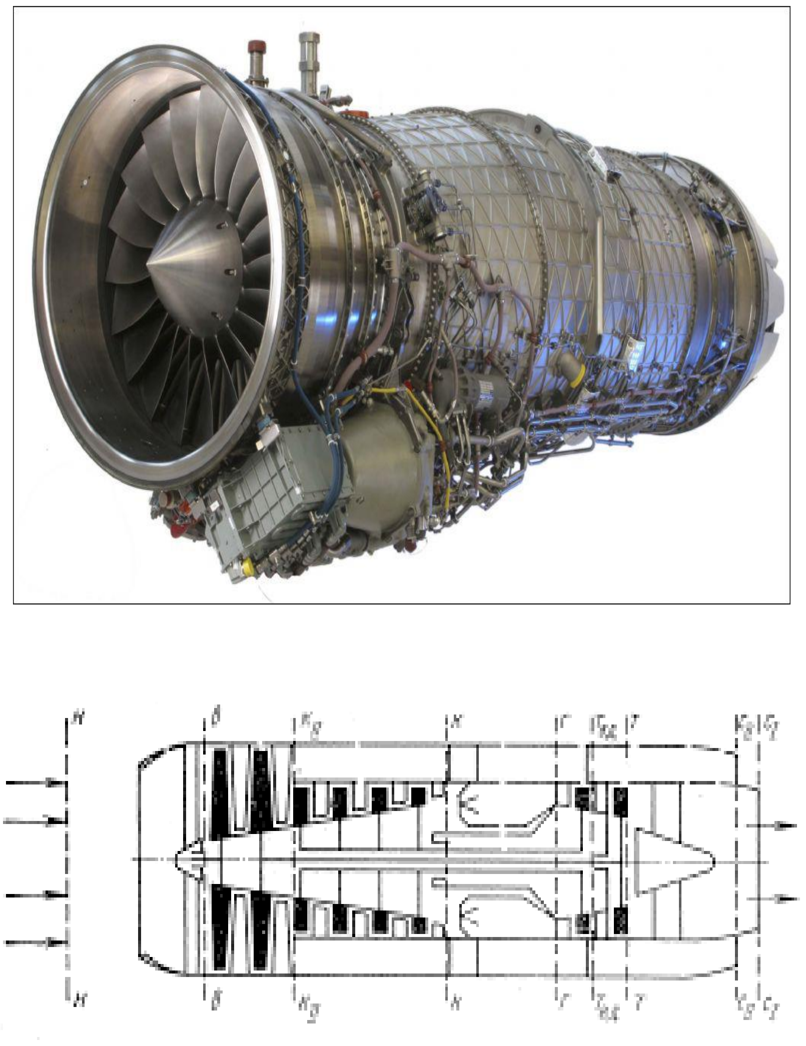

Fig. 4 Aircraft engine air intakes for one type of aircraft

As shown in Figs. Figure 4 shows that there is some space in the air intake device from its start to the fan where specially designed or existing devices can be arranged so that their placement does not alter the aerodynamic characteristics of the engine. As much as possible to install them, these are technical problems that will be solved taking into account the design features of a particular device.

Problem 3. To process the electronic circuit of the device for measuring the total number of masses of foreign bodies in the air intake device of aircraft turbine engines and to connect and supply the devices for measuring the flow and parameters of its components in the air intake device.

The practical implementation of the block diagram presented in Fig. 2 of the total number of masses of foreign bodies in the air intake equipment of aircraft turbine engines is a problem in the sense that each element of the processed measuring device must ensure their reliable operation in the aircraft. In the range of air temperature and humidity during operation of the equipment, it must withstand mechanical overloads and noise during flight, etc.

Conclusion

To create a device for measuring the total number of masses of foreign bodies in the air intake equipment of aircraft turbine engines, it is necessary to:

1. Selection of methods for automatically measuring the flow characteristics of the air entering the air intake device and the accompanying foreign particles, such as average flow density and velocity or volume flow, as well as the densities of the light and heavy components;
2. Processing of individual measuring instruments (velocity or volumetric flowmeters, flow and its heavy and light component densities) included in the total number of foreign body mass measuring devices included in the engine air intake device and receiving-processing units;
3. Development of a general electronic circuit of the device for measuring the total number of masses of foreign bodies in the air intake device of engines;
4. Processing of design and installation documentation to accommodate the device for measuring the total number of masses of foreign bodies in the air intake device, taking into account the design and technical capacity of the air intake device of each type of engine.

References:

[1] Кремлевский П. П. , Расходомеры и счетчики количества, Справочник, Лю отд-ниеб 1989, ISBN 5-217-00412-6];

[2] “Analysis of forein objects ingress into aircraft gasturbine engines and metods of their recording”, A. Maisuradze, G. Mushkudiani, D. Metreveli, G. Gedaminski, Internacional Scientific Journal “Air Transport”, #1, 2019)

[3] hmong.ru/wiki/Air_density

[4] Двухизотопный слектрометрический плотномер для диагностики трехфазных потоков нефт-вода-газ. Б. Н. Свешников, С. Н. Смирнов, А. Ю. Филиппов, Ю. П. Филиппов, ЭЧАЯ, 2021, Т. 18, N1

საფრენი აპარატების აირტურბინულ ძრავების ჰაერმიმღებ მოწყობილობაში მოხვედრილი უცხო ნაწილაკების რაოდენობის გაზომვის გზები და საშუალებები

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ანოტაცია

სტატიაში გაანალიზებულია საფრენი აპარატების აირტურბინულ ძრავების ჰაერმიმღებ მოწყობილობაში მოხვედრილი უცხო ნაწილაკების ფიზიკური და გეომეტრიული პარამეტრების ფრენის რეჟიმში გამზომი მოწყობილობის შექმნის პრობლემები და შემოთავაზებულია მისი გადაჭრის შესაძლო გზები, დამყარებული სხვადასხვა ფიზიკურ პრინციპებზე.

ჰაერმიმღებში შემავალი ნაკადი, რომელიც ჰაერთან ერთად შეიცავს მყარ სხეულებს, განხილულია როგორც მილში გამავალი ორფაზიანი ნაკადი (აირი/მყარი სხეულები) და შერჩეულია შესაბამისი მეთოდიკა ნაკადში მყარი ფაზის პარამეტრების გასაზომად ზემოთ აღნიშნულ პირობებში. დასახულია ღონისძიებები, რომლებიც საჭიროა საფრენი აპარატების აირტურბინულ ძრავების ჰაერმიმღებ მოწყობილობაში მოხვედრილი უცხო სხეულების მასების ჯამურ რაოდენობის გამზომი მოწყობილობის შესაქმნისათვის.

საკვანძო სიტყვები: აირტურბინული ძრავები, ჰაერმიმღები მოწყობილობა, ორფაზიანი ნაკადი, გამზომი მოწყობილობა, ნაკადში შემავალი მძიმე და მსუბუქი კომპონენტების კონცენტრაცია.