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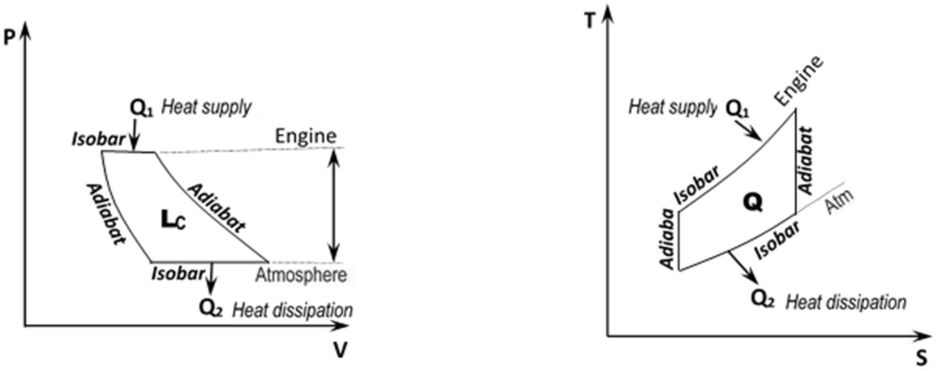
GRAPHIC SUPPORT FOR THE OPERATION OF AIRCRAFT POWER UNITS

Introduction

Most modern aviation designs use gas turbine internal combustion engines, the characteristic feature of which is continuous combustion (unlike piston engines, where the fuel is ignited in each cycle). The basic principles of heat engine calculations are given in thermodynamics. Almost all modern gas turbine engines operate according to the Brayton cycle. (Fig. 1).



Adiabat – process line without heat exchange Isobar – process line with constant pressure

Fig. 1. Brighton Cycle: L_C – cycle work; P – pressure; Q – heat; S – entropy; T – temperature; V – volume;

In general, the operation of engines is determined by the size of the area outlined by the lines of processes occurring in the engine, and efficiency (efficiency) depends on the difference in parameters inside and outside the engine.

To obtain the maximum area, various processes can be specified.

Since we cannot influence external conditions (the atmosphere), there is only one way left: achieving the maximum permissible parameter values inside the engines, taking into account a number of conditions:

– for maximum combustion efficiency, optimal combinations of mass flow rates of air and fuel are needed, taking into account the calorific value of the latter;

– air flow with a rigid engine design is ensured by its compression ratio;

– an increase in air temperature during compression forces fuel consumption to be limited due to the strength capabilities of engine element materials.

Calculation methods for turbochargers imply the presence of fixed conditions: flight speeds and rotor rotation. In reality, these conditions are constantly changing (flight altitude and trajectory, mode set by the crew, changes in flight mass when fuel is consumed, altitude and seasonal changes in atmospheric temperature, and much more). Any deviations in calculations, setting flight modes, etc. worsen the efficiency and economy of the engine as a whole. The task of designers is to ensure stable operation of engines in a selected range of conditions with acceptable efficiency, assigning some control functions to built-in automatic systems.

A typical design includes sets of design and operational documentation (the presence of a finished product is not necessary). For it, a Certification Basis and Tables for determining compliance with the adopted Aviation Rules (Norms or Airworthiness Criteria) are compiled. In the process of certification inspections and tests, design improvements are made and operational documents on the application and limitations of modes, which are the basis for maintaining airworthiness, are clarified.

Additionally, the following may be attached: technological maps, developer bulletins, airworthiness directives of aviation administration bodies. As a result, the information is placed in text form in different documents, which makes it difficult for operators to have a comprehensive presentation and sequence of actions. In aviation, there are two groups of operational documents: for ground personnel and for crews (Fig. 2).

SERVICE REGULATIONS

Frequency of work
Maintenance airworthiness

FLIGHT MANUAL OPERATION

Restrictions
Systems and procedures
Modes, characteristics

MANUAL OPERATION

➢System descriptions
➢Tolerances
➢Technologies

PRODUCTION GUIDE FLIGHTS

Sections of the Flight Manual Operation in relation to conditions airlines

Fig. 2. Types of operational documentation

Formulation of the problem

The combination of the engine and related devices is called the power plant. (Fig. 3).

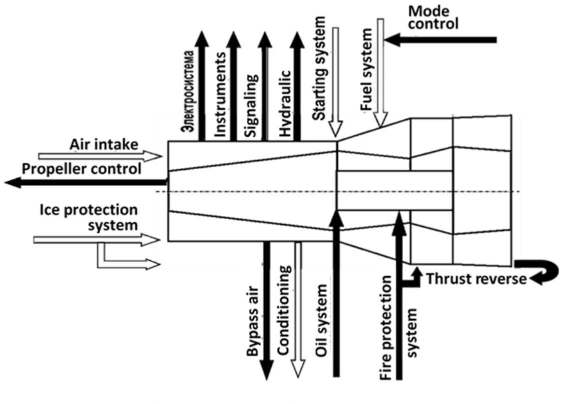


Fig. 3. Powerplant structure

The number of systems and subsystems that provide operation and control of modes, depending on the purpose and design (excluding fully autonomous and automatic ones), usually reaches 15 or more. In general, for each type of power plant, several multi-volume documents with pages periodically updated and clarified may be attached. Their contents (sections) usually correspond to accepted national or international rules [1].

Analysis of recent research and publications

In preparing the article, documents attached to different types of aircraft were analyzed, such as: modifications of the An-12, An-24, An-26, An-32 (A/B/P), Yak-40, Yak-42 aircraft, Mi-6 helicopters and others, as well as engines: AI-20D 5 series, AI-24, AI-25, D-25V, D-36, AV-68DM propeller, R68DS-K propeller regulator and others. Due to the accepted rules, in the various documents reviewed, the necessary data (working, expected and critical values of control parameters), response points (on/off) of individual functions, duration restrictions, etc. are scattered over 60 or more pages. Finding or remembering them takes considerable time; many data in specific situations are often unnecessary and useless. A similar problem is present in the development of algorithms for automatic analysis of engine condition signs based on data from parameter recording systems both in flight and during ground checks. It seems advisable to switch to summarizing data using a graphical method. Based on this, the main emphasis is on the representation of physical processes, so the scales in the illustrations are very arbitrary – everyone can build and clarify their own similar dependencies.

In scientific works [2–8] systems, methods, technologies and means of control and diagnostics of aviation power plants are considered, which are used to assess their technical condition and its management in the processes of maintenance and flight-technical operation by means of constant control and analysis of parametric information of direct measurements during the entire period of regular use as intended.

The work [2] proposed the justification of the need to apply a comprehensive approach to the current in-depth assessment of the technical condition of modern aircraft engines and functional systems that ensure their operation.

In works [3–5], the issue of creating automated systems to support the operation of aircraft engines was considered and the basic principles of forming information flows were proposed to solve the problems of increasing the reliability and efficiency of operation o aircraft engines.

In works [6-7], issues of increasing the efficiency of diagnostics of gas turbine engines and the diagnostic informativeness of parameters of the work process are considered

The authors [8–9] considered the possibility of solving the problem of diagnosing the technical condition of helicopter aircraft engines using

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different architectures of neural networks and the method of least squares, which ensure high reliability of recognizing defects, including double defects, in various engine nodes.

However, not enough attention has been paid to the issue of developing calculation-graphic information methods for the analysis of power plant parameters and choosing optimal ways of presenting them for aviation personnel and supporting the adoption of adequate operational decisions.

Purpose of research

1. Based on the analysis of operational documents and statistical processing of parametric information, identify the main properties and processes for gas turbine engines for various applications in aviation.
2. Find sequences common to all gas turbine engines – patterns of processes and procedures inherent in all types of engines for most stages of operation.
3. For a full cycle of work, develop the most convenient unified method applicable to different types of power plants for constructing compact representtations of all information in a generalized form.
4. Develop recommendations for monitoring, adjusting characteristics and making decisions on the prospects for further operation.

Main material

With all the variety of designs, it is possible to identify common processes inherent in all types of engines. For example:

- starting and spinning up the rotor to minimum stable modes (“earthly idle”);
- manual control of operating modes with lower limits in flight (“flight idle”);
- automatic adjustment of fuel consumption according to flight conditions (altitude, speed, air temperature, angle of attack, etc.);
- air bleeds for air conditioning, anti-icing systems, etc.;
- slowing down forward and reverse acceleration characteristics to prevent surge;
- shutdown by cutting off the fuel supply;
- inertial “run-down of the rotors” until a complete stop.

Descriptions of most of these stages are given in operational documents for ground and flight personnel, as noted, in text form. Additionally, included: statistical analyzes of data obtained from ground and flight tests, materials from software analysis of flight information, results of some investigations of aircraft accidents.

Processes, conditions and limitations when starting engines

Spinning up the gas generator rotor

A necessary condition for the operation of heat engines is the proportions of the mixture components acceptable for combustion: air and fuel. The source of the air component is the gas generator compressor. The fuel supply is provided by pumps driven from its rotor. This means that the launch should begin with promotion using starters. There are different types of them: electric, pneumatic and even powder. The whole process consists of three successive stages:

- promotion by starter (stage 1 is controlled by the timing mechanism of the starter panel, is practically not adjustable and mainly depends on the properties of the starter)
- joint promotion by the starter and combustion of the gas mixture (stage 2 begins when the time set for stage 1 is reached, ends at the configured rotation speed or pressure in the liquid system, the fuel supply is regulated in proportion to the rotor speed);
- promotion by the gas mixture combustion (Stage 3 is characterized by a rapid increase in gas temperature at the beginning, followed by a decrease towards the end of the startup process. The intensity of promotion and limitation of gas temperature are regulated. The rotation speed of the gas generator rotor is adjusted in the <Ground Idle> mode).

The startup processes according to the parameter recorders look as shown in Fig. 5.

The processes that occur during startup are not always displayed in the form of indications on the display, instrument readings, or records of parameter values in the recorder drives. From the point of view of the “minimum sufficiency” condition, this is not necessary. General recommendations on the lists of parameters recorded and displayed on dashboards are given in the relevant parts of the ICAO Annex [10].

Graphical representation of the startup process

On Fig. 4 shows a fragment of the analysis of engine starts when processing data recorded.

A simplified analysis comes down to recording the maximum “overshoot” of gas temperatures, estimating the start time of each engine and triggering the systems using binary signals in the graph window (System alarms) or using display simulators in a separate strip (System activation display).

Note: The colors of the simulators are assigned to the names of the events and usually do not correspond to the colors of the real indicators.

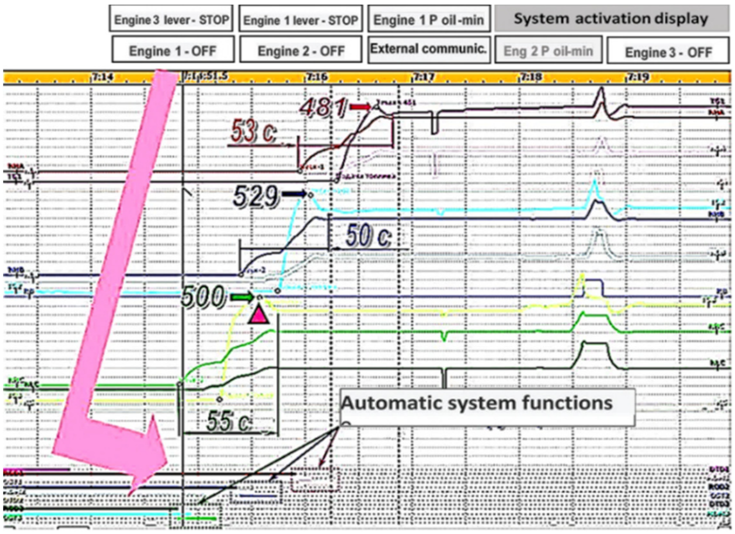


Fig. 4. Analysis of engine starts

There is no unambiguous correlation of parameters for assessing the condition:

– engine 1: temperature = 481°C, time = 53 s – the “coldest”;

– engine 2: temperature = 529°C, time = 50 s – the “hottest” and “fastest”;

– engine 3: temperature = 500°C, time = 55 s – the “slowest”.

It is convenient to present a more detailed representation of the startup process in the coordinates <time> – <rotation speed>, as shown in Fig. 5 (measurement units are arbitrary).

The diagram contains: the sequence of processes, the expected values of parameters at moments determined by the clock or rotor speed, switching the attention of the crew, probable problems, recommended actions and elements of performance settings.

If possible, the diagram can be supplemented with graphs of other parameters with their scales (for example, the temperature of exhaust gases), comments on tolerances for a number of parameters (for example, for vibration levels), marks on system switching (for example, starters), checks of values during switching (<Board >-<Ground>), time limits for startup stages, and similar data.

The names of units and control elements, control values of parameters usually vary for different types, but the sequence of events and the application of corresponding comments can be accepted as unified and used in the preparation of operational and automated analysis algorithms. Next to the markings of the ranges of monitored events, indications of control elements are recommended for adjusting the characteristic in case of discrepancy.

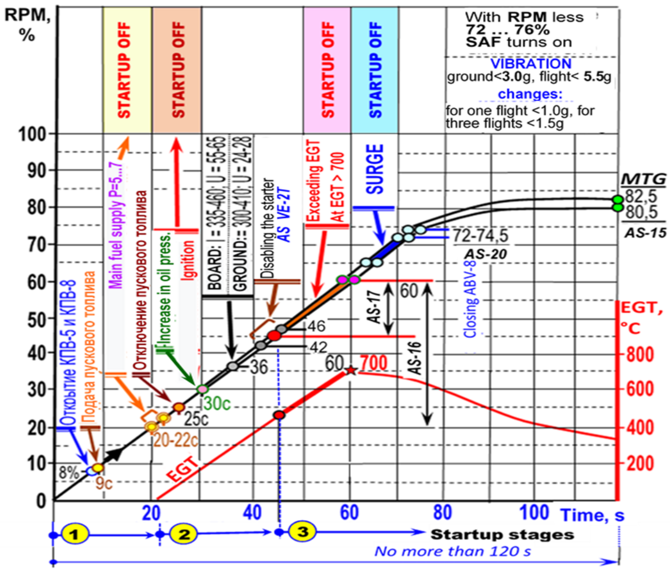


Fig. 5. Sample startup diagram: ABV-8 – air bypass valve behind the 8th compressor stage; AS-# – adjustment screw with its designation; EGT – exhaust gas temperature; MTG – mode "Small Terrestrial gas"; P_{fuel} – fuel pressure in front of the injectors; RPM – rotor speed; SAF – system of automatic propeller feathering

Modes, characteristics and limitations

In most aircraft designs, a single-factor manual change by the crew of the engine operating mode is performed. The remaining tasks of managing fuel consumption are solved by specialized automatic systems.

The modes are selected either based on the specific conditions of the flight stages (take-off, landing, failure of one or more engines, the presence of obstacles on the trajectory), or for reasons of flight efficiency.

Methods for setting modes may vary:

– by the position of the manual control levers,

– by indicating fuel consumption,

– according to the specified flight speed.

Sometimes, by decision of the crew, additional options for increasing thrust (power) are used. Depending on the purpose, some ranges of modes are given names (see Fig. 6 in the coordinates <position of the fuel tap lever> – <parameter values>).

An example from the practice of Tu-154 family: Based on research by the State Scientific Research Institute of Civil Aviation at the state level, flight speeds for the entire fleet were reduced from 0.86 M to 0.82 M in order to save fuel.

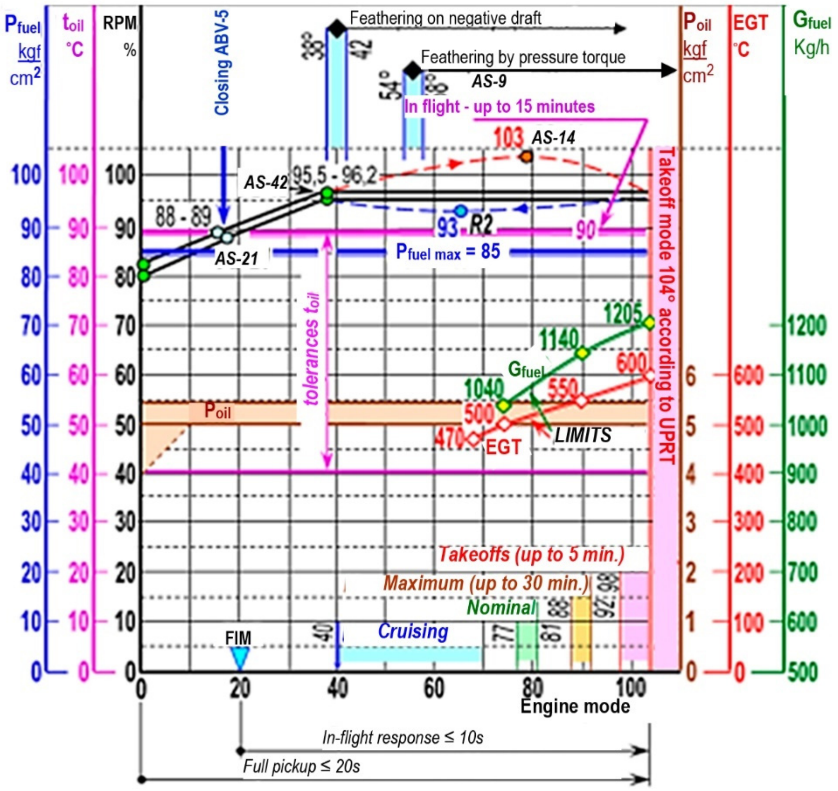


Fig. 6. Turboprop engine modes: ABV-5 – air bypass behind the 5th compressor stage; *AS-#* – adjustment screw with its designation; EGT – exhaust gas temperature; G_{fuel} – hourly fuel consumption; FIM – "Flight idle" mode; P_{fuel} – fuel pressure in front of the injectors; P_{oil} – pressure in the oil system at the engine inlet; RPM – rotor speed; SAF – system of automatic propeller feathering; T_{oil} – engine oil temperature; torque – propeller shaft torque; UPRT – fuel valve lever position indicator

A feature of turboprop engines: maintaining constant rotor speeds (RPM) in all modes, after reaching a certain specified value (in Fig. ≈ 95.5...96.2 in percent RPM). To ensure uniform filling, the scales of some parameters may be shifted.

Description of modes

MPV – minimum parameter values, starting from which the engine operates stably, regardless of any external conditions;

MPVF – minimum parameter values at which the aircraft is capable of stable flight;

Transitional modes: the entire range of modes from MPV to the maximum permissible. The time of changing modes (increase or decrease) is called direct (reverse) pickup; With a rapid change in modes, gas-dynamic problems are possible: temperature surges, unstable combustion, longitudinal pulsations of flow in compressors (“surge”). To reduce the rate of change, special elements are used (in the figure, for example, throttle *R*2);

Equilibrium modes – fulfillment of the condition in the range: RPM = const (in the figure – starting from УПРТ ≈ 40°);

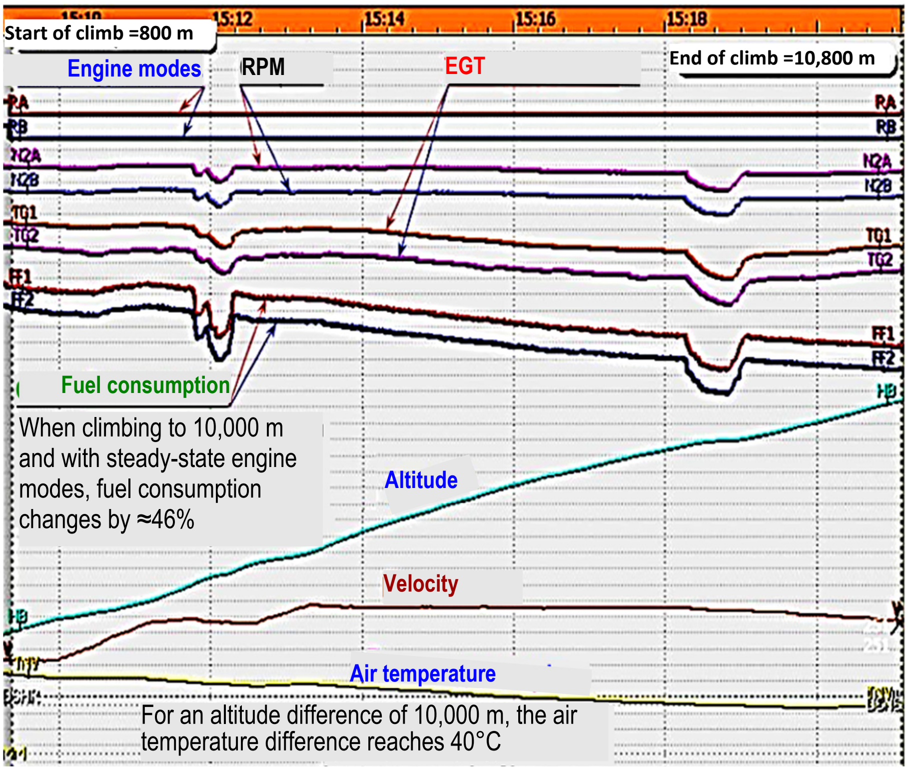
Cruising modes – a term that requires clarification.

“Cruising” in its original sense meant “sailing along the shore.” The goals could be different: as far as possible (maximum range) or as LONG as possible (maximum duration).

Based on the conditions of mandatory engine operation, without which flight is impossible, a distinction is made between minimum hourly and kilometer fuel consumption modes.

Minimum hourly flow rates are achieved at high altitudes (so-called “ceilings”), as shown in Fig. 7, and are limited from below by the ability of flight stability.

Note: There are known cases of accidents due to “falling into a tailspin on ceilings.”



When climbing to 10,000 m and with steady-state engine modes, fuel consumption changes by ≈46%

For an altitude difference of 10,000 m, the air temperature difference reaches 40°C

Fig. 7. Changes in engine parameters during climb

Kilometer (route) costs are determined by the relationship $q_{km} = q_{hour} / V$, kg/km. Here it is very important to fix the concept of speed V.

The task of transport, including aviation, is to move given distances. A special feature of aviation is the need for sufficient speeds of air flows. In the general case, such speeds have two components: the actual movement of the aircraft relative to the atmosphere and the oncoming projection of the wind speed vector. Economy is thus determined by the maximum speed Vrg (relative to the ground). Modern navigation tools provide such an opportunity.

As shown in Fig. 8, the minimum fuel consumption qkm depends on many variables during the flight: mass M, oncoming wind components, modes set by the crew (Modes), atmospheric characteristics at flight points, and others.

In such conditions, a significant part of the functions of maintaining optimal engine modes is assigned to automation: correctors for height, speed, temperature and other units of fuel supply systems. From the above it follows that the concepts of Cruising modes can be conditionally attributed to the range of maximum duration, and Nominal modes - to the maximum range.

Maximum modes are used in emergency situations to continue flight in the event of serious malfunctions. Prevention of failures due to thermal fatigue of the material is achieved by limiting the duration of these modes.

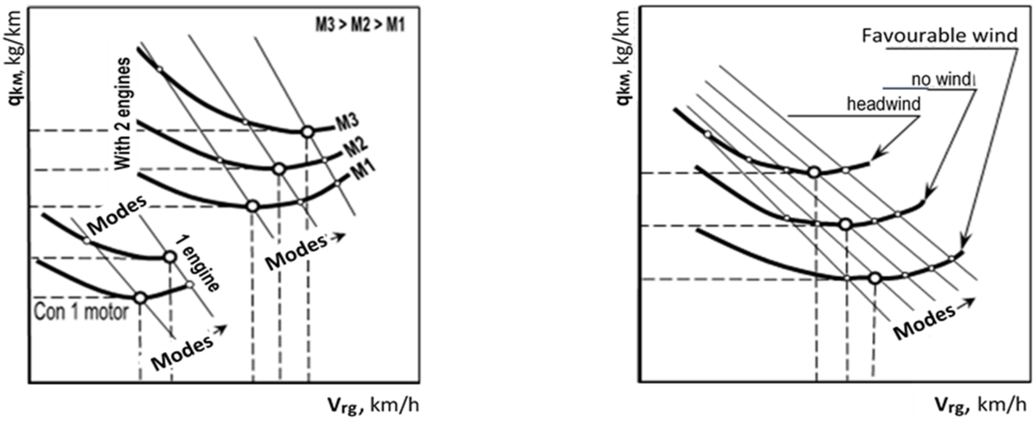
Takeoff modes are more intense in terms of mechanical and thermal loads. They are selected based on specific conditions:

– flight configuration of the aircraft (weight, balance, etc.),

– atmospheric conditions (air pressure and temperature, wind speed and direction),

– characteristics of the runway (adequacy of length, presence of obstacles on the take-off trajectory, possibilities for safe continuation of take-off in emergency situations.

The modes required for takeoff are calculated in advance by the crew using the diagrams in the Flight Manuals.



Effect of flight mass

Wind influence

Fig. 8. Factors influencing the efficiency of flight modes

The calculations include power reserves in case of engine failures during takeoff. The operating time in these modes is strictly limited.

Some civil aviation designs provide for Emergency Mode and Afterburner Mode. After using such modes, further use of the engine requires special studies.

Depending on the given conditions and the qualifications of the crew, different methods of starting takeoff are used:

– normal (“from the brakes” at the executive start);

– “spurt start”, shown in Fig. 9. Its feature: an increase in engine modes during the take-off run (21 ... 27 seconds on the recorder scale). According to the laws of mechanics, variable force (thrust) somewhat deforms the acceleration characteristic, but the operating conditions of the gas generator improve: at lower speeds – lower modes.

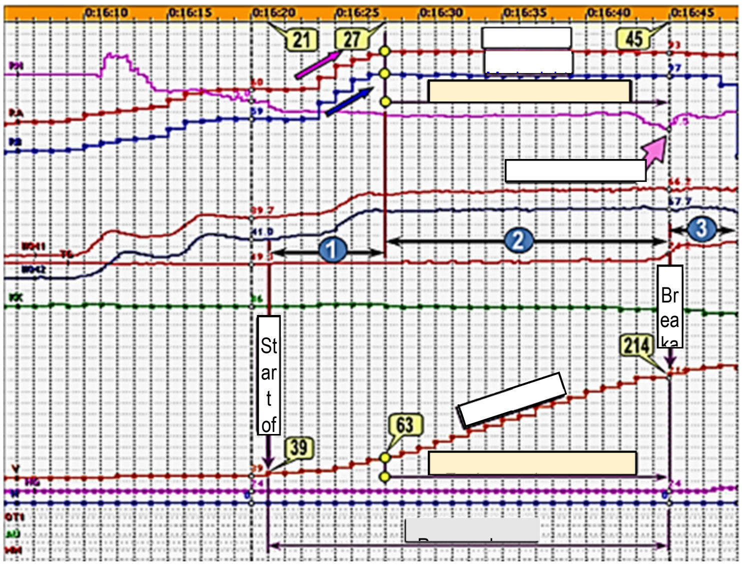


Fig. 9. Take-off run in the “spurt-start” option

Sets of parameter values: current time and speed, engine modes make it possible to statistically evaluate the condition of the engines and take-off weights based on accelerations.

Notes: 1. Without knowledge of individual characteristics, conclusions may be erroneous. Poor airframe aerodynamics can be perceived as a sign of deteriorating engines and vice versa.

2. The resulting power usually does not correspond to the mode set manually, since fuel consumption is adjusted automatically according to external conditions (see, for example, Fig. 7).

A correlation between power and hourly fuel consumption (Gt in Fig. 10) may be acceptable for assessments.

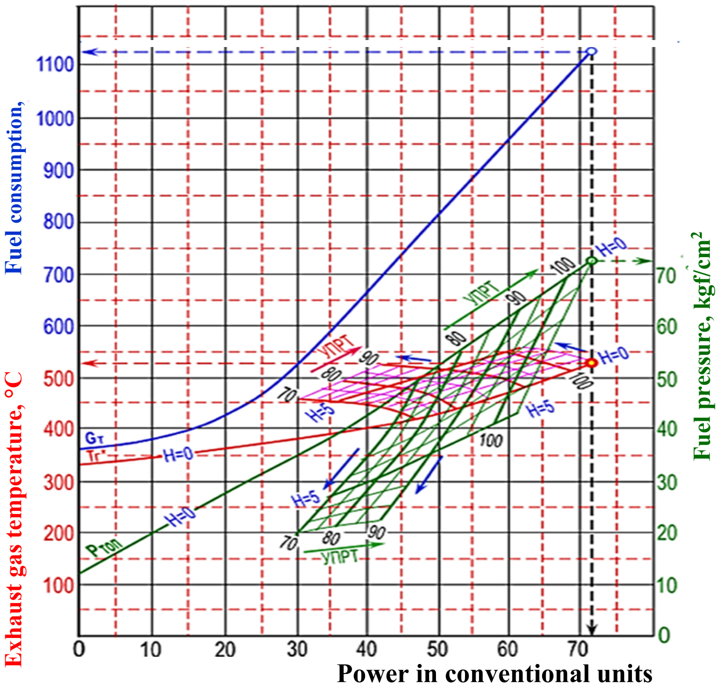


Fig. 10. Summary diagram of workflow parameters in work mode: $G_{\text{т}}$ – fuel consumption during ground checks; H= – parameter values at flight altitudes in km; UPRT – mode set by the crew; $P_{\text{топ}}$ – fuel pressure during ground checks; $T_{\text{г}}^{*}$ – temperature behind turbine during ground checks

The reason for the “stratification of characteristics” in the above figure is the influence of only two factors: flight mode and altitude. In general, for families of power plants with correctly configured characteristics, the reduction in fuel consumption has a linear relationship, similar to that shown in Fig. eleven.

Notes: 1. A sign of incorrect characteristics (the so-called “kink”) manifests itself in the form of launch problems at some high-altitude airfields with normal launches at others.

2. The launch setting for all conditions is carried out after the flow characteristic has been “straightened”; the technologies are given in the attached operational documents. The optimal characteristic is determined by average statistical values.

3. Before making a decision to make adjustments, you should analyze the possible results for limitations (tolerances) for each parameter, especially the work process (Fig. 12).

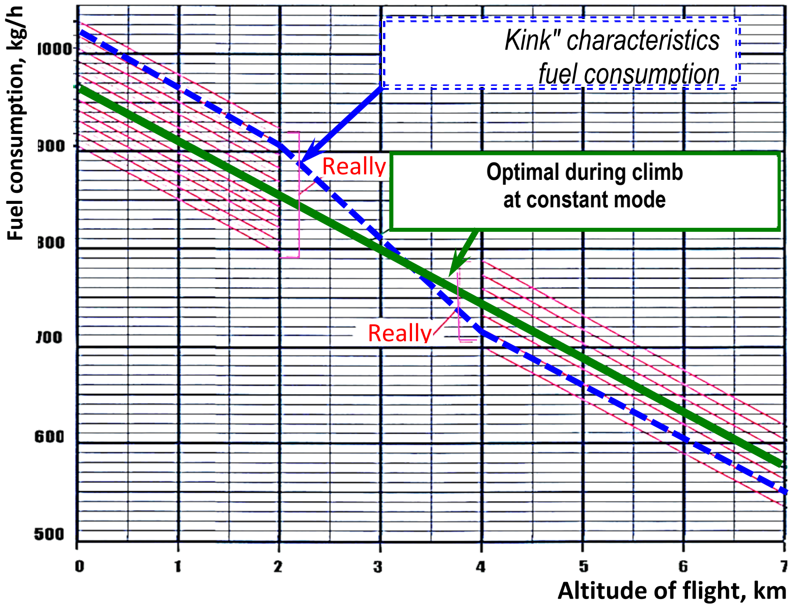


Fig. 11. Fuel flow characteristics

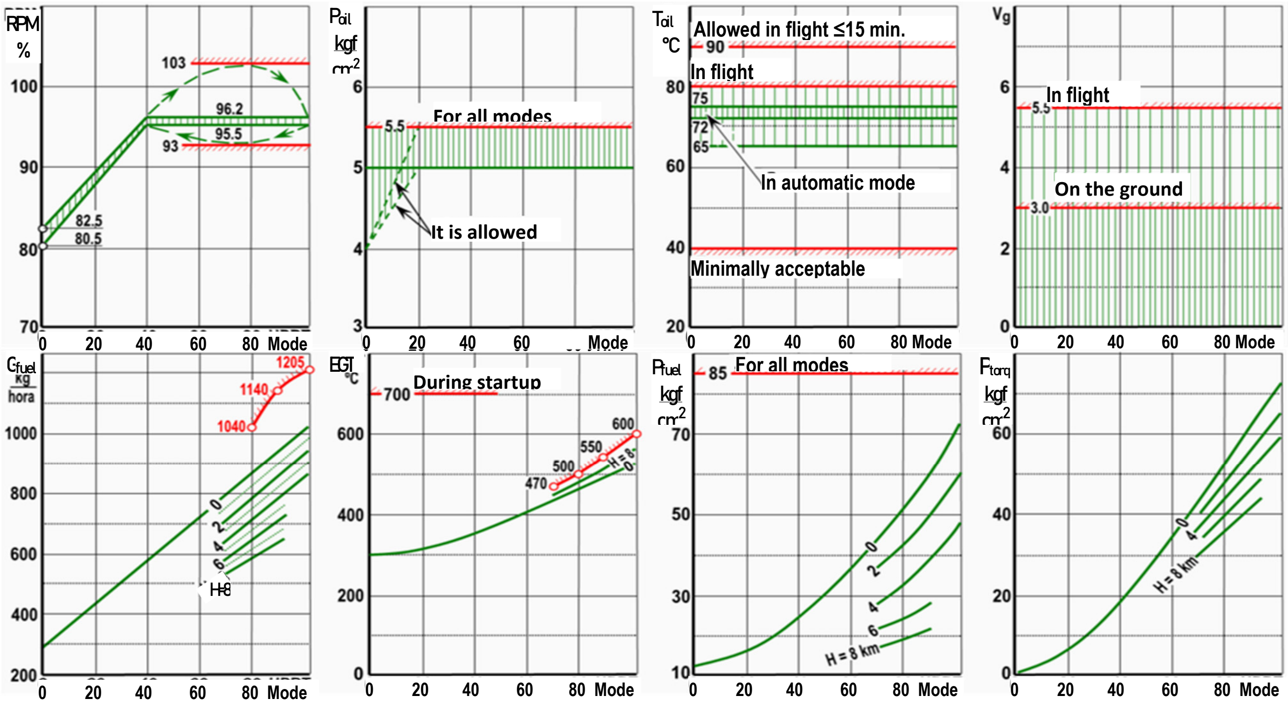


Fig. 12. Real values and tolerances of parameters

Tolerances (shown in Fig. 12 with the necessary comments) are established by manufacturers (Developer and Manufacturer) based on bench and flight tests, calculations, modeling, operating experience, etc. They provide some reserves for parameter values for different conditions and for possible (non-hazardous) deterioration of the product's condition.

In some cases, subject to flight safety conditions, there may be no restrictions (upper or lower).

Changes in approvals, and with them – warranty obligations, are formalized in the prescribed manner with the relevant documents and with the necessary notes in the technical documentation (passports, forms, regulations, manuals).

Control of modes and their indication

Mechanical schemes for setting modes

In most designs, manual control of fuel consumption is implemented individually for each engine, as shown in Fig. 13. The crew sets the position of the control lever (throttle lever), checking its position against the readings of the UPRT indicator.

The thrust lever, as a rule, has safety stops for ground and flight idle throttle, as well as the maximum permissible mode (Fig. 14).

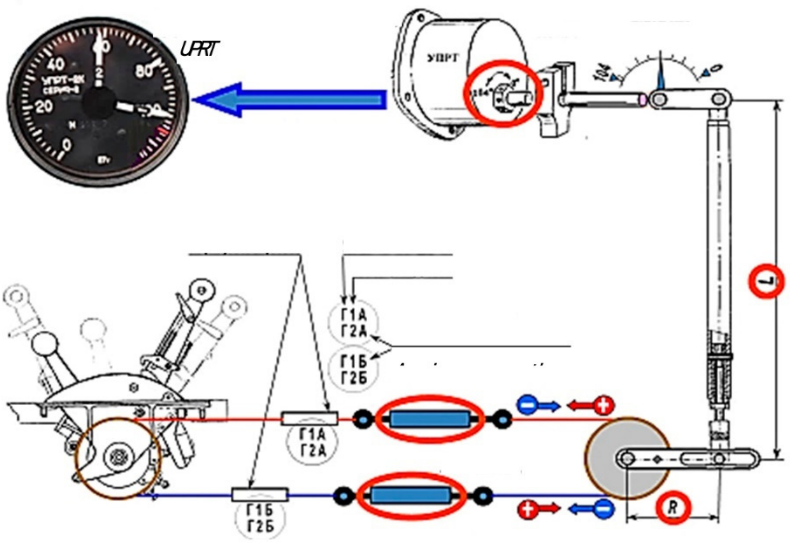
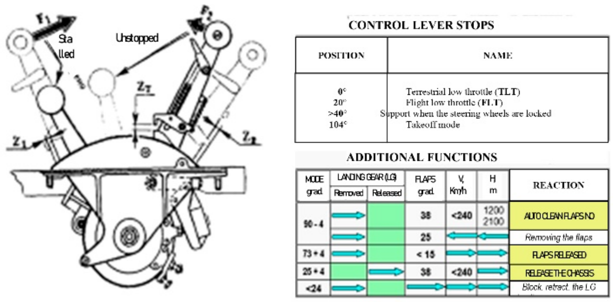


Fig. 13. Setting the mode display



CONTROL LEVER STOPS

POSITION	NAME
0°	Terrestrial low throttle (TLT)
20°	Flight low throttle (FLT)
>40°	Support when the steering wheels are locked
104°	Takeoff mode

ADDITIONAL FUNCTIONS

MODE grad	LANDING GEAR (LG)		FLAPS grad	V, Km/h	H m	REACTION
	Removed	Released				
90 - 4	→	🟩	38	<240	1200 2100	AUTO CLEAN FLAPS NO
	→	🟩	25	←	←	Removing the flaps
73 • 4	→	🟩	< 15	→	→	FLAPS RELEASED
25 • 4	🟩	→	38	<240	→	RELEASE THE CHASSIS
<24	→	🟩	→	→	→	Block. retract. the LG

Fig. 14. Thruster functions corrector amplifier; AM – Actuating mechanism; SV – solenoid valve; MB – Matching block; TCA – temperature controller amplifier; CB – Compensation block; TP – throttle position; HC – Height corrector; TSE – tachometer; T-80 – thermocouple <ПРТ> limit temperature controller

The mechanical transmission includes cable wiring, rods and levers for setting positions, control ranges, etc. The tension devices of the cable wiring coordinate the positions of the thrust levers themselves with the KTA dial, the linear dimensions L and R - the “span” of mode changes.

The UPRT indication is determined by the relative position of the KTA fuel dispenser dial and the synchro-sensor roller.

Microswitches (in Fig. 14 – at the bottom of the RUD block) connect light and sound alarms, issue executive commands, switch or limit these commands depending on the priority in a given mode (Fig. 15).

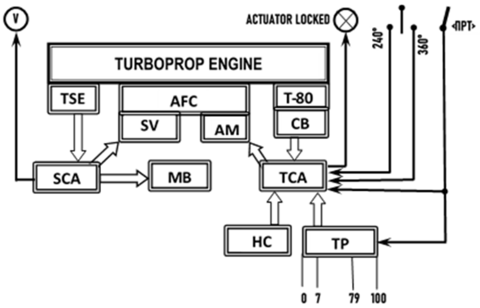


Fig. 15. Switching priorities according to the specified modes: AFC – Automatic fuel consumption; SCA - speed

Characteristic settings using adjusting screws

Mechanical adjustable systems make it possible to establish, with a certain degree of accuracy, the mutually corresponding positions of the command device (CD) and the dispenser actuator. This in no way affects the automatic correctors of the dispensers themselves, whose task is to slow down the acceleration processes (forward and reverse acceleration), monitor flight conditions, control anti-surge systems, connect various subsystems, etc. Most of the automation elements are built inside the dispensers and their settings are made with screws. One of the design examples is shown in Fig. 16.

Note: Designations and assignments of screws are relative. They apply only to specific structural products. Technologies for adjustment work are given in the product operating manuals.

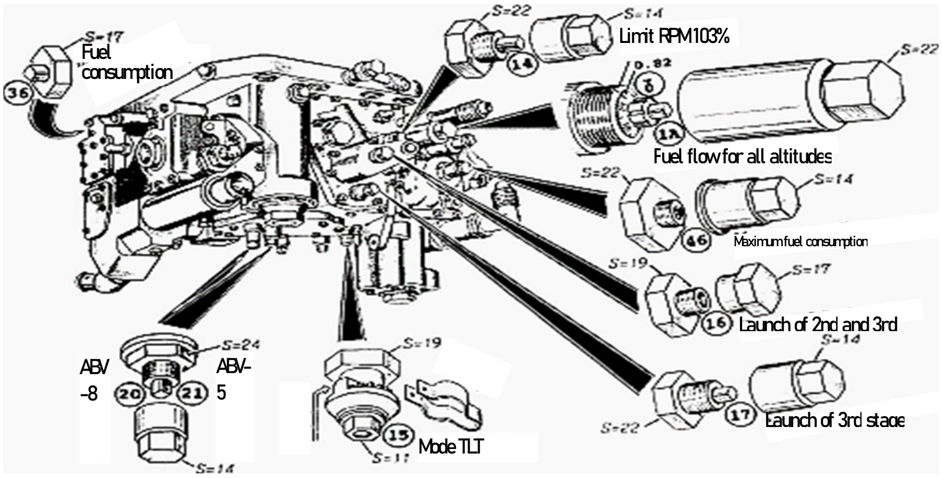


Fig. 16. Fuel metering screws

Processes, conditions and limitations when engines stop

One of the safety conditions: guaranteeing operation in the event of serious failures of several systems (power supply, etc.) contradicts the shutdown principle. For this stage, multi-functional blocks are created, connected to independent command systems (electro-mechanical, hydraulic...).

The apparent simplicity of stopping the engine in some cases leads to unclear technologies in the operational documentation, and this, under certain circumstances, can cause serious consequences. General recommendations for any type can be as follows:

1. Before stopping, in order to avoid thermal deformations, it is recommended to “cool” the engines in the TLT ZMG mode for some time. Failure to comply with this condition may lead to “rotor jamming”.
2. Stop is implemented by shutting off the fuel supply and proceeds as shown in Fig. 17.

Note: Parameter values are conditional.

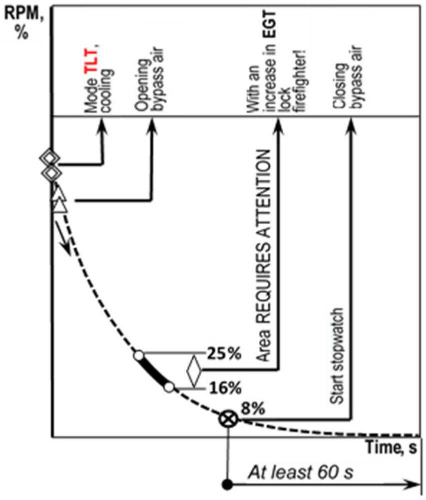


Fig. 17. Stopping the engine

To prevent surge in off-design modes, at the beginning of a drop in RPM, air bypass devices from the compressor are automatically opened.

– Possible malfunctions:

– leakage of fuel shutoff,

– loss of power to the stop solenoid valve,

– termination of launch, etc.

– The engine “freezes” in arbitrary modes (25÷16 %). In this case, the combustion process may enter the uncontrollable stage.

– Dangerous development with rising gas temperatures is blocked by shutting off the fire hydrant.

– At lower RPMs (8 %), the air bypass system returns to the closed position.

– The accompanying factor that influences the RPM deceleration is disabled. The following remain:

– aerodynamic resistance of the flow part of the gas generator and mechanical losses due to friction.

– The mechanical component is indirectly assessed by the time until the rotor stops completely.

Until the rotor completely stops, the stopping device cannot be returned to the original position!

When performing emergency non-standard shutdowns, for example by feathering a propeller, fuel volumes may accumulate in the combustion chamber with the problem of untimely ignition during the next start and subsequent temperature rises.

Before starting the engine after questionable stops or long preparatory operations, it is mandatory to “blow out” the flow parts in the “cold scrolling” mode

Violation of the sequence of shutdown operations, leakage of the throttle valve during long-term storage, inattentiveness of the crew, violation of technology, and de-energization of the on-board network before completion of the stop can cause a state of uncontrolled burning.

Watch the parameters, be ready to cut off the fire valve!

Multi-operation settings

Ground checks (“races”) of the engine make it possible to verify the functionality of the systems and the compliance of the parameter values with the established characteristics and limitations. However, the factors that influence the operation of automatic systems for adjusting fuel consumption, and therefore all parameters of the work process, on changes in external conditions (barometric pressure of the atmosphere, air temperature, flight speed) remain unknown. It is not always correct to draw conclusions and make decisions when the maximum permissible value is reached by any one parameter. For a comprehensive analysis, values of three groups of parameters are needed: flight conditions, established modes, and - values of work process parameters.

Sources of information can be special protocols, recorders' records, or photographs (Fig. 18).

The recommended shooting frequency is every 1000 m of climb with constant engine modes.

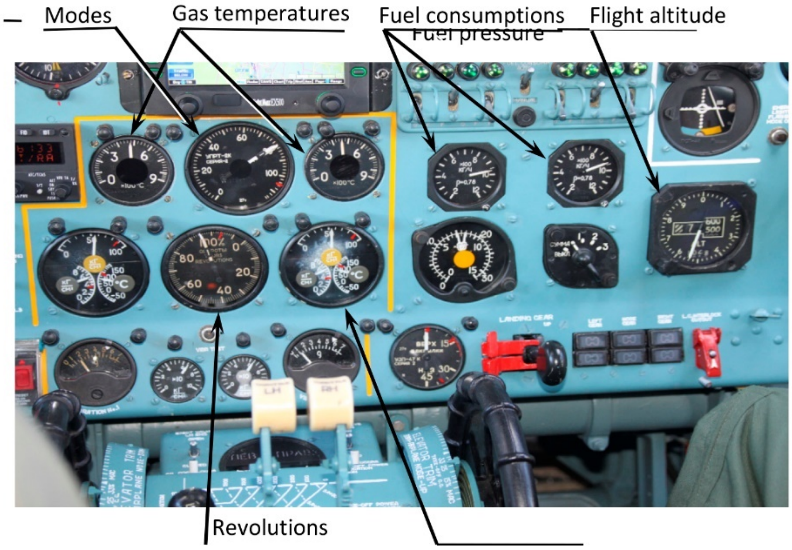


Fig. 18. Workflow parameters workflow options

Optimization of flow characteristics

According to the sources, it is possible to plot the flow characteristics during the climb and compare them with the optimal ones (Fig. 11). If deviations are detected, perform adjustments as shown in Fig. 19):

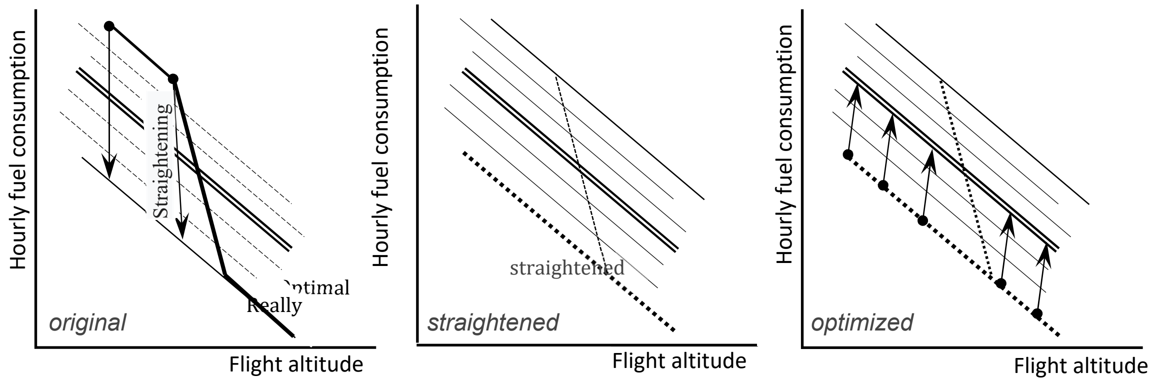


Fig. 19. Correction of the “kink” in the flow characteristic

The “kink” in the characteristic is straightened with the screw of the altitude-speed corrector, after which the characteristic is adjusted to the optimal values for fuel pressure. This technology may have graduated scales for each adjustment screw.

AFTER this operation, the launch characteristics are adjusted as necessary.

Launch settings

The cause of launch problems at different airfield altitudes is the deformation of the flow characteristics discussed above. Typically, it should have a linear relationship with flight altitude. If this condition is met, the nature of the starts (sluggish, hot, etc.) will be the same for any of them.

The final adjustment of the launch intensity is performed with the same screws, but the magnitude of the settings and their directions depend on the height ranges relative to the optimal flow characteristics. For example, for low altitudes it should be reduced, and for high altitudes it should be increased (see Fig. 20).

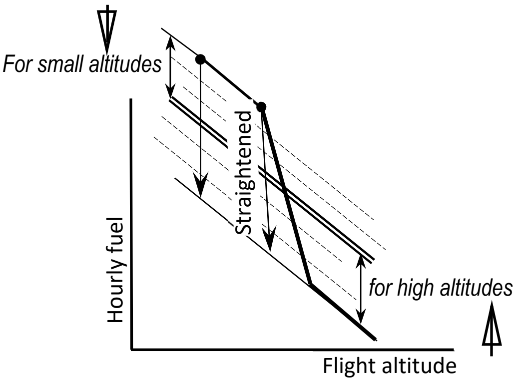


Fig. 20. Correction of launches

As noted in section 1.1, the launch consists of three stages. In normal mode, the following conditions must be met:

– the rotor rotation speed increases linearly,

– during acceleration in the second and third stages, gas temperatures do not exceed specified limits,

– the total startup time does not exceed that specified for this type of product.

The purpose of the setting is to automatically reach the control temperature values. On the diagram (Fig. 21) they are marked with asterisks with the values set for control. Optimality is achieved by adjusting the slopes of the lines: common for hot and sluggish (steps (2) and (3). When changing the intensity at step (3), adjustment is carried out with a separate screw.

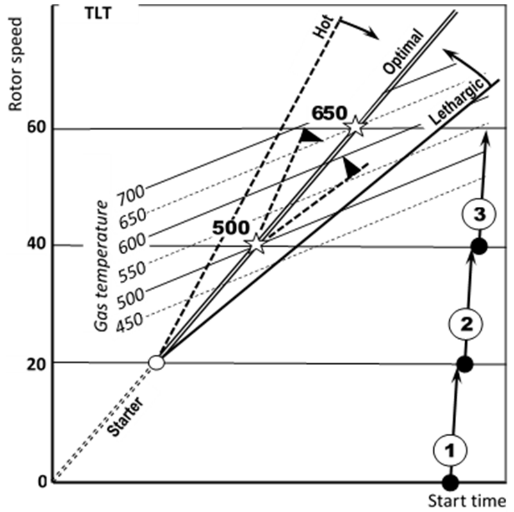


Fig. 21. Launch setup procedure

The launch should take place without “freezes” (waiting for the transition to the next stage), without exceeding temperatures.

At stage (3), after reaching the maximum, a decrease in TVG begins.

As a result, the process corresponds to the diagram shown in section 1 in Fig. 6.

In a number of cases, based on a combination of parameters, a conclusion is made that the technical condition of the engine is deteriorating (TVG is too high, power is too low, etc.).

Before making a decision, you should make sure that the settings are correct and the information received is reliable. Some recommendations for additional checks are given below.

Synchronization of parameters

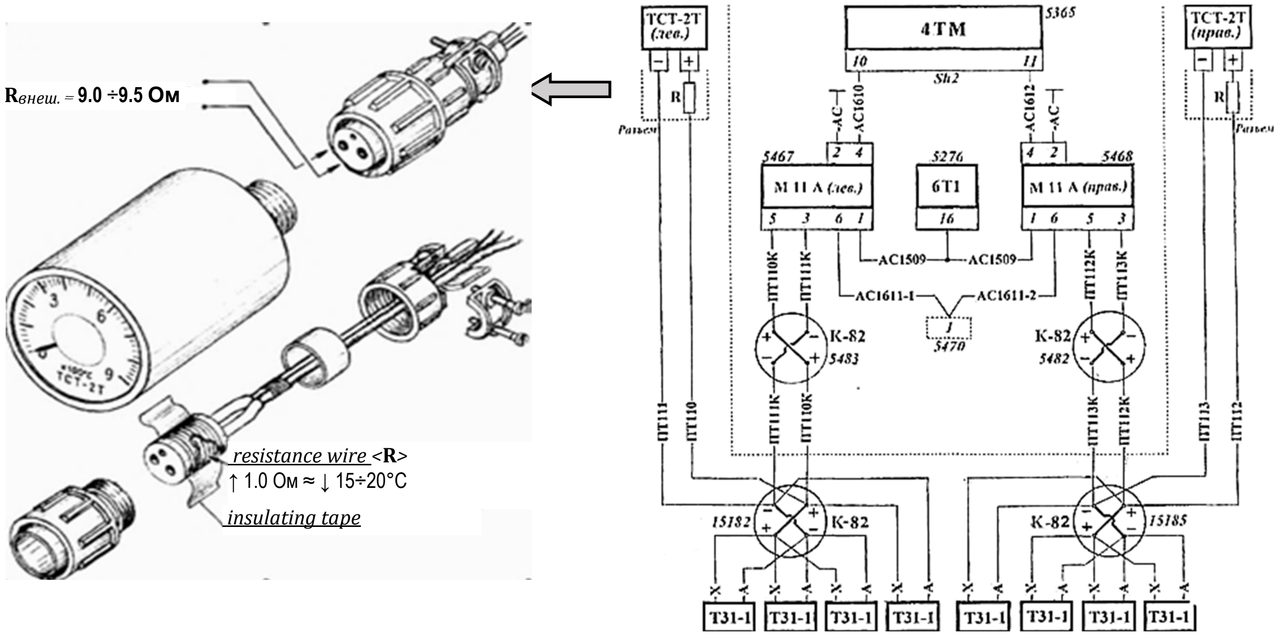
Depending on the situation, the test can be carried out on the ground or in flight. In the second case, for safety, it is recommended to increase the engine speed with reduced parameters.

Thrusters are set to the position of equal hourly flow rates (see Fig. 18), after which the equality of other parameters is checked: fuel pressure in front of the injectors, gas temperatures, power (thrust), etc. If all the readings are the same, EXCEPT for the throttle positions, there are no comments on the engines - you need to adjust the flow characteristics, startup processes, etc., as described above. It is recommended to perform a similar synchronization check procedure during a flyby after replacing engines.

Confidence of parameters

The components of measurement circuits are usually electrical circuits: sensor-transmitter-wiring-device. Each of them (including material, wiring length, etc.) creates summable (accumulated) errors. Thus, indicators are, in fact, devices that display SOME quantities, converted into electrical signals or into binary codes. Consequently, conclusions about the condition of engines, made on the basis of recommended parameter values [11] are always approximate and, moreover, abstract in nature [12].

To reduce errors, compensating elements are sometimes included in measurement circuits (for example, compensating pads or trimming resistances in gas temperature measurement circuits), as shown in Fig. 22.



4 TM, 6 T1 – parameter recorder blocks
<A> , - <X> – thermocouple material (<*alumel* > – < *chromel* >)
К-82 – compensation block
М 11-А – encoder
R – trimmer resistance
Т31-1 – thermocouple type
ТСТ-2Т – device type

Fig. 22. Compensation for measurement and recording errors

Absolute measurement accuracy is usually not needed.

Sometimes, States create special standardized laboratories. In some cases, separate verifications of the external circuits of measurement systems and the design characteristics of indicators (devices) are carried out. Periodic verification of the settings of measurement elements is carried out using developed specific control and measuring equipment at intervals and according to the technologies given in the operational documents. An example of the latter option is shown in Fig. 23. The scatter of characteristics in the diagram was revealed during laboratory testing of a group of similar devices.

It means that, under all equal conditions, actual instrument readings may differ within the range of ±10°C.

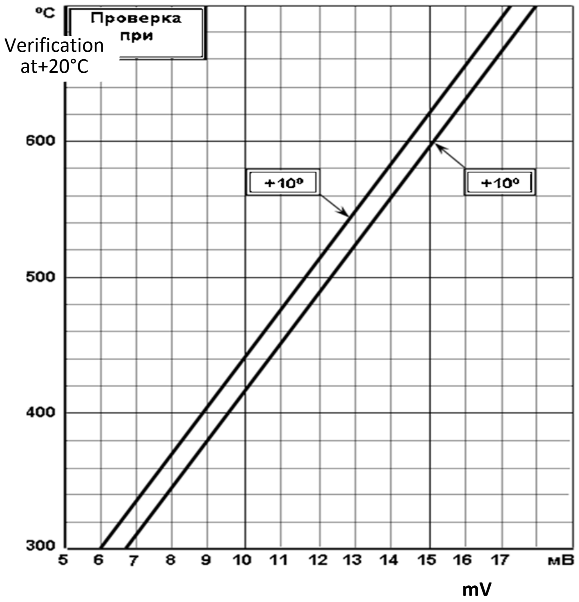


Fig. 23. Characteristics of EGT indicators

The external temperature and the resistance of the external circuit contribute their errors. Adjusting the internal resistance (in Fig. 22 – in the connection connector) helps if the characteristics are approximately parallel. Otherwise, kits with similar characteristics are selected for the aircraft.

The following materials are usually used in thermoscouples: chromel, copel, and alumel. Since the chemical compositions of alloys are always different, during calibration, components are assigned groups indicating the ranges of displayed measurements and the compatibility of the components of the measuring system.

Case studies

1. A new set of thermocouples was installed on the newly installed engine. When setting up the launch, the blades collapsed as a result of overheating, and the turbine failed.

Reason: mismatch between groups of sensors (thermocouples) and the device. Taking the low readings as true, we increased the temperature.

2. During a ground check in one of the intermediate modes, the power indication abruptly goes to “0”, restoring in other modes. There are no changes to the sound environment or other parameters. The situation repeats itself during takeoff.

Reason: Design flaw in the pressure sensor, the engine is working.

3. When taking off from a large (busy) airport, the fire alarm went off. The crew took emergency measures to return. Messages added: “The roll is great.” “Lower the landing gear”, “Lower the flaps”... All this – against the backdrop of a light and sound fire alarm!

The landing was made on a runway without landing gear, the plane was destroyed, and the airport was closed.

REASON: Structural mass defect: crack in the air intake pipe from which the group of fire detectors was blown (in Fig. 24, highlighted with circles) – False Activation. The engine is fine, the consequences are serious.

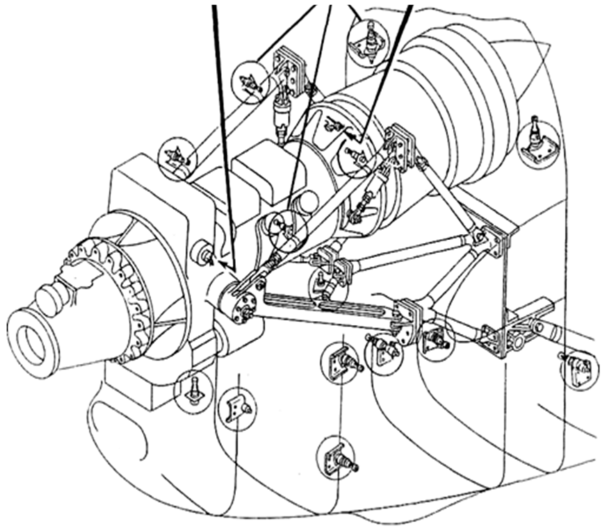


Fig. 24. Placement of fire alarm detectors in the engine nacelle

Applicability of the method

The common practice in aviation of editing and republishing individual pages of operational documents requires all specialists to familiarize themselves with and remember the changes made in different places. This approach forces constant revision of the contents of many volumes and does not guarantee the consolidation of updated data. The method of compact graphical representation of a set of data is also used in air navigation [13], an example of one of the fragments is shown in Fig. 25. It combines characteristic objects, their coordinates, references to the magnetic pole in a given area, data on ground-based means of coordinating communications and trajectories (glide path, missed approach, etc.). Such diagrams cover the entire surface of the planet and are published on all six official languages adopted by ICAO rules. This example can be attributed to flight operations.

The proposed method of graphically presenting the stages of work in a concise, generalized form allows you to move away from the practice of memorization. Some unification of diagrams (similar to pages [13] simplifies the search and makes it possible to quickly analyze parametric data.

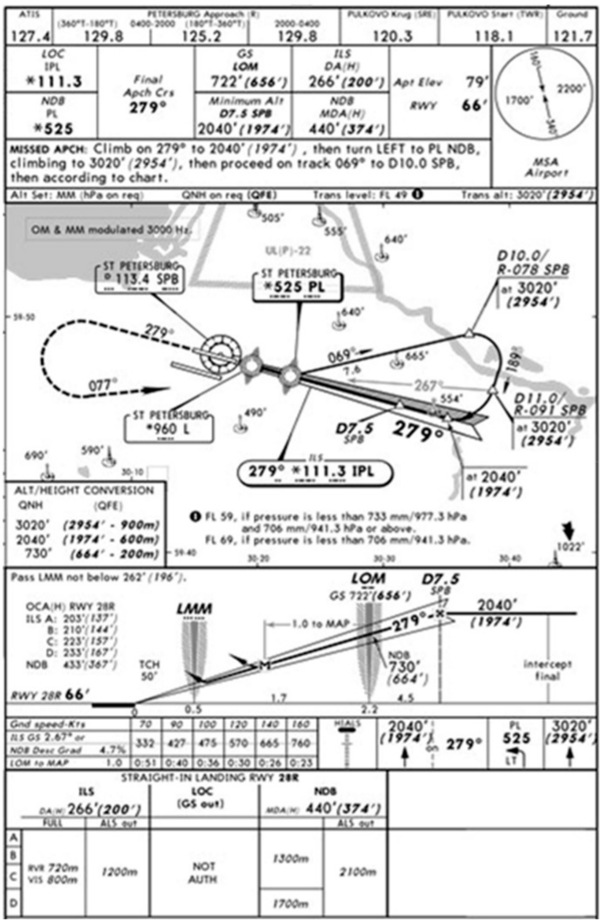


Fig. 25. Fragment of approach procedure options

Evaluation of the method

The presented material was tested and refined under operating and testing conditions (ground, flight and bench) of several types of aircraft. Sets of Jeppesen schemes with step-by-step parameter diagrams proposed in this work can be included in Flight Operations Manuals, which airlines develop taking into account the specifics of their work (technique, regional conditions, standard, alternate, emergency airline routes, etc.).

Examples of applying the method of checking engine characteristics using the described diagrams are shown in Fig. 26 (during checks on the ground) and Fig. 27 (during climb).

The expected values are highlighted in green, and the actual values of the parameters of the left and right engines, respectively, in red and blue.

The results confirm ease of use, clarity, efficiency and the ability to quickly make decisions on corrective actions to restore performance.

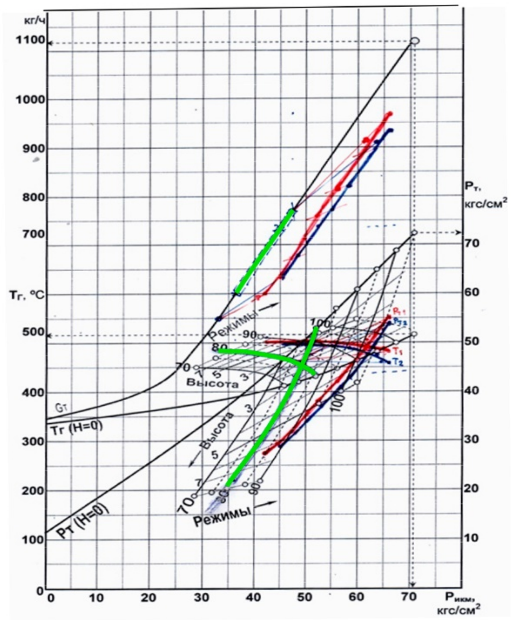


Fig. 26. Graphical assessment of engine performance (ground checks)

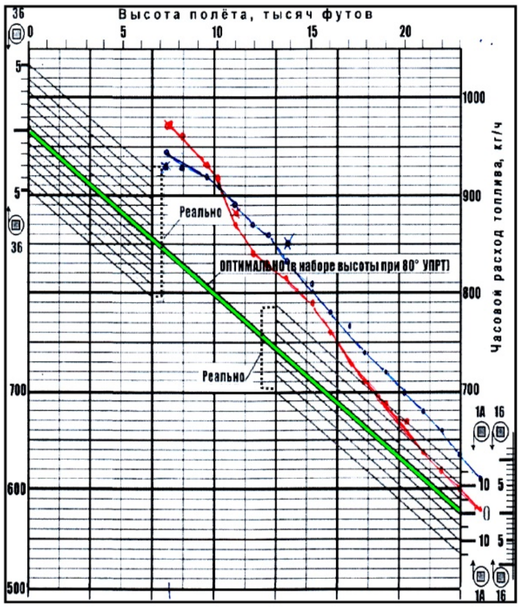


Fig. 27. Engine consumption characteristics

Conclusions

In the vast majority of cases, the assessment of technical condition is based on readings of anlog parameter values. Since it is almost impossible to produce absolutely identical components of measuring circuits, error systems, accuracy classes, etc. are introduced. Absolute measurement accuracy is usually not needed. As a rule, trends in changes ("trends") in the fields of tolerances, errors, groups and accuracy classes specified in the documentation are analyzed. The tolerances themselves take into account possible statistical errors inherent in the entire range of measurement systems.

The arsenal of technological capabilities in aviation is constantly expanding. At the same time, diagnostic methods are being improved, replenishing the databases with statistical data [14, 15].

Analysis systems built into the structures of aircraft are capable of recommending procedures for maintaining airworthiness with the proper levels of reliability and safety; the technical level of avionics allows them to be called up on display screens in the cockpit upon request and monitor the processes.

Increasingly, the work of the crew is reduced to activating automatic self-adjusting systems. Programming capabilities allow you to automate the control of most of the described processes, reconfigure characteristics, including the selection of the most economical modes.

The problematic issue remains the contradiction between proactive actions and their validity: the legal relationship of responsibility in decision making, since they establish financial costs in the event of aviation accidents.

Using examples of power plants with turboprop engines, approaches to the development and application of step-by-step unified graphical generalizations of processes and control parameter values, combined with indications of characteristics setting elements, are proposed.

The methods have been tested under operating conditions, having confirmed their convenience and effectiveness at different stages of operation, and can be recommended for inclusion in Flight Operations Manuals created by airlines in relation to the range of operating conditions of their aircraft fleet.

When writing the article, we used information from operational documents attached to different types of aircraft, statistical analysis of data obtained during ground and flight tests, materials from software analysis of flight information, and the results of some investigations of aircraft accidents.

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ГРАФІЧНИЙ СУПРОВІД ЕКСПЛУАТАЦІЇ АВІАЦІЙНИХ СИЛОВИХ УСТАНОВОК

Основне завдання експлуатантів – підтримка льотної придатності авіаційної техніки шляхом виконання технологій, викладених у комплектах документів, що додаються до типових виробів.

Двигуни - основне джерело енергії для виконання польотів практично завжди працюють у сукупності з багатьма системами, кожна з яких, у свою чергу, супроводжується інструкціями та посібниками із забезпечення працездатності. Відповідно до прийнятої практики більшість роз'єднаної інформації наводиться в них у текстовому вигляді. Це змушує запам'ятовувати необхідні дані або постійно шукати їх у десятках оновлюваних і замінюваних сторінок наведених технологій, або створювати власні зручні прийоми, що дозволяють проводити параметричні аналізи та виробляти рішення щодо керуючих впливів для коригування технічного стану.

На прикладах силових установок з турбогвинтовими двигунами пропонуються підходи до розробки та застосування поетапних уніфікованих графічних узагальнень процесів та контрольних значень параметрів, поєднаних із вказівками елементів налаштування характеристик.

У статті для повного циклу роботи запропоновано найбільш зручний, застосовний до різних типів силових установок, уніфікований метод побудови компактних представлень усієї інформації в узагальненому вигляді. Розроблено рекомендації щодо контролю, налаштувань характеристик та прийняття рішень щодо перспектив подальшої експлуатації.

Методики апробовані в умовах експлуатації, підтвердивши їх зручність та ефективність на різних стадіях роботи, можуть рекомендуватися для включення до Посібника з виробництва польотів, що створюються авіакомпаніями стосовно діапазонів умов роботи свого парку літальних апаратів.

Ключові слова: авіаційна силова установка, експлуатація, параметрична інформація, діагностика

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GRAPHIC SUPPORT FOR THE OPERATION OF AIRCRAFT POWER UNITS

The main task of operators is to maintain the airworthiness of aircraft by implementing the technologies outlined in the sets of documents attached to standard products.

Engines, the main source of energy for flight, usually work in conjunction with many systems, each of which, in turn, is accompanied by instructions and manuals to ensure operability. In accordance with accepted practice, most of the disaggregated information is provided in text form. These forces you to remember the necessary data or constantly search for it in dozens of updated and replaced pages of the provided technologies, or create your own convenient techniques that allow you to conduct parametric analyzes and develop decisions on control actions to correct the technical condition.

Using examples of power plants with turboprop engines, approaches to the development and application of step-by-step unified graphical generalizations of processes and control parameter values, combined with indications of characteristics setting elements, are proposed.

For the full cycle of work, the article proposes the most convenient, applicable to different types of power plants, unified method for constructing compact representations of all information in a generalized form. Recommendations have been developed for monitoring, adjusting characteristics and making decisions on the prospects for further operation.

The methods have been tested under operating conditions, having confirmed their convenience and effectiveness at different stages of operation, and can be recommended for inclusion in Flight Operations Manuals created by airlines in relation to the range of operating conditions of their aircraft fleet.

Keywords: aviation power plant, operation, parametric information, diagnostics.

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