# DEVELOPMENT OF THE AIRCRAFT POWER PLANTS - CHALLENGES

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***Abstract***

*On the background of a current level of the aircraft power plants modernities presented here is the trial settlement of the possible directions of their further development - resultant from the current and future economic, military, sports needs. The general direction of development of all types of aeronautical propulsion systems, and also of these produced a long time ago and exploited for many years, is their permanent „upgrade" in the new equipment and of methodic of the current technical state checking for the purpose of the indispensable flights safety assurance, the prolongation of the failure-free exploitation time - but also the maintenance of the economic concurrency requirements. Recently, a categorical form receives the requirement of the noise limitation of aviation power plants and the limitation for emission of toxic elements in exhaust. In the piston engines, the direction of developments are aimed on the design of compression ignition engines, fuelled with standardized aircraft jet fuel. Their additional valour is their smaller fuel expenditure, about 30% less with respect to their spark ignition equivalents. Particularly important is the task of decrease the quantities of fuel used up, the limitation of number of produced engines through raising their efficiency and durability, limitation of noisiness of engines alone and driven: propellers, ventilators and the lifting rotors of helicopters, the limitation of thrust, required to the flight of the airplanes and the helicopters. One turned attention on ecological requirements, which force the application of mineral fuels completed by biofuels.*

***Keywords:*** *transport, combustion engines, internal combustion aircraft engine*

## 1. Introduction

Development of aviation from the moment of its creation is subordinated from performance of power plants producing thrust required to the flight, but particularly their reliability, small mass and expenditure of energy. These demands can be met (thus far) only with use of internal-combustion engines: piston and turbine powering propellers and the lifting rotors of helicopters, and the producing thrust directly - turbine jet engines and rocket engines. Specialized types of power plants already achieved the very high level of perfection and rather there is no hope to expect certain jumping revelations in this issue - how this once took place. The choice of power plant type will depend from aerodynamic attributes and assumed aircraft flight performances - that is explained on Fig. 1.

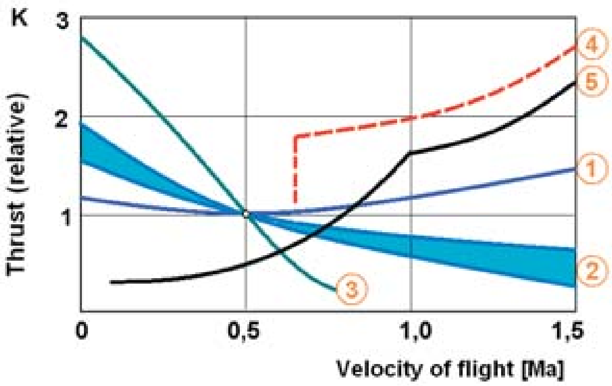


*Fig. 1. The dependence of required thrust K (5) and (comparatively) the thrust of different power plants from the flight speed of aircraft: (1) jet-propelled single flow; (2) jet-propelled twin flow; (3) propeller; (4) jet-propelled with afterburner*

Already introduced during 1st. World War beside liquid cooled engines with cylinders in row, the air-cooled engines with radial cylinders (also rotary and bi-rotor engines), but in the pre war period and during the 2nd. World War rotary charge compressors and turbochargers and the direct gasoline injection to cylinders were introduced. Radically step progress at this time was caused by design, production inurnment and war application of the combat aircraft with the jet-propelled turbine engines and rocket engines. Post-war years are marked by development of turbine engines adapted to the needs of a definite kind of aviation - from single spool jet-propelled and propeller engines to the jet-propelled multi spool engines with afterburners and continuous adaptation of bypass ratio to the flight conditions and at the same time total halting of piston engines development on the „pre-war" level. On this period also space performance of rocket engines belongs - particularly of the liquid fuel engines.

## 2. Present state

The piston engines are mainly used for propulsion of the „small" aviation aircraft: general, tourist, enterprise and the like and motogliders and motoparagliders - also in military to reconnaissance and transport flights. The range of shaft power in engines utilized here is huge: from several to several hundreds kilowatts. Prevailing are engines build with accordance to the „pre-war design philosophy": air-cooled, with twin valve heads, carburetted fuel supply, two magnetos and multiple lever manual control. In the small and medium power range they are structured as 2, 4, 6 cylinder „boxer" configuration whether even 8 cylinder configuration. In the big power range they are used as before (and are also produced by us, in our country) supercharged engines in the single row radial, 7 or 9 cylinder configurations. The shy tries step out for the introduction of a low-pressure fuel injection, which permits to receive of some greater shaft power and decreases unitary fuel consumption.

However power from the unity of the cylinders volume capacities of contemporarily used engines is scarcely approaching to the half of this parameter values for the engines of the last war combat aircraft (BMW-801, DB-600, Jumo-213, Allison-1710, WK-107, AM-42- about 50 HP/dm$^3$, only Rolls-Royce Merlin engine achieved near 65 HP/dm$^3$). Is this confusing for generally leading aviation technology, particularly in the comparison with performance of the mass produced personal vehicle engines, in which this coefficient have value of 50-100 HP/dm$^3$ with the much more smaller unitary fuel consumption and the exhaust toxicities. In the automobile engines the fuel does not contains tetra-ethyl lead (as anti-knock medium), thanks to this it is possible to use in the injection system the oxygen content sensor in exhaust („lambda pick-up") permitting to provide stoichiometric composition of combustible mixture in the whole range of engine loads. This also enables the use of catalyst converters for exhaust cleaning.

The engines and propellers originate from the rather accidental selection of wares accessible on the market (and cheap), able to be adapted relatively easily to the needs of this kind of aviation.

Recently to „mini airplanes" utilized to perform a close reconnaissance or as targets for small arms fire and anti-aircraft artillery training, the electric propeller propulsion is used with the current supply from light and highly effective onboard storage batteries, also sometimes with the supporting solar batteries mounted on the aircraft wings. The jet turbine and propeller turbine engines - after the first trial and search for optimum solutions period - since a long time ago obtained already the stable enough forms of flow channels and rotary assemblies of air compressors and turbines.

On Fig. 2 the schemas of characteristic designs of aeronautical turbine engines are juxtaposed. Merely Fig. 2a presents the schema of the oldest, in the past serially manufactured Jumo-004 engine, the designers of which already 60 years ago noticed the need for the control of the sectional area of the exhaust nozzle in dependence on the engine performance range and on the aircraft flight conditions.

In the power plant assemblies of fast combat aircraft consolidated itself the twin flow engine type with the small bypass ratio of $m_z/m_w \approx 0.3\text{-}1.0$ and with the flow mixer and effective afterburner with the 50-70% thrust increase.

However, in the fast intercontinental passenger airplanes are generally utilized bypass turbofan jet engines with the large bypass ratio reaching actually the value of $m_z/m_w \sim 5.0$ and greater, endowed with the efficient thrust reverser (reversing about 50-70% of maximum thrust). The engines of this type have at disposal thrust of 25 000-30 000 daN, with the airflow intensity in the range of 600-800 kg/s and the unity fuel consumption (scarcely) 400-300 g/daNh. They are characterized by great reliability and durability which enables maintenance less performance even in the period of 20-30 thousand hours (also thanks to the continuously perfected diagnostic systems).

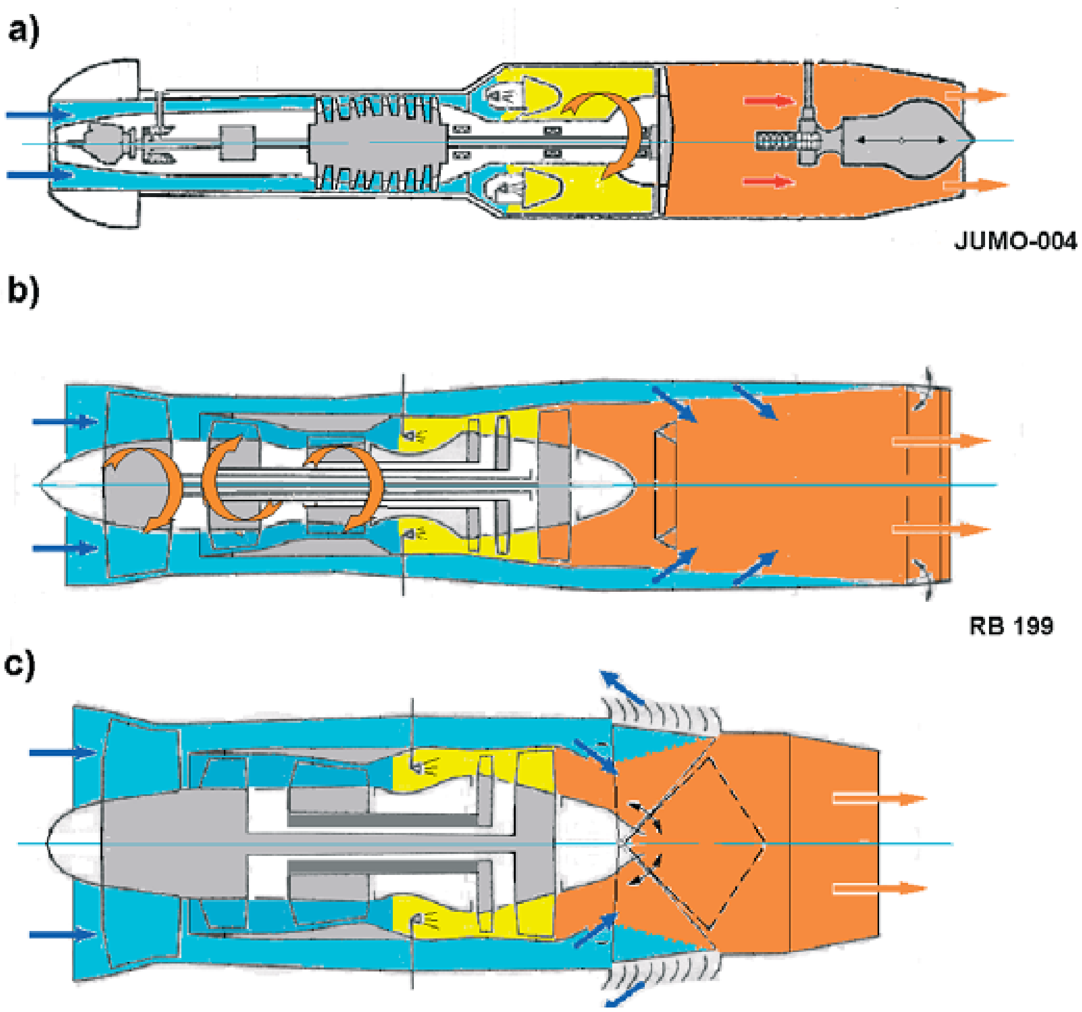


*Fig. 2. The flow diagrams of jet-propelled engines: a) single flow single spool, b) twin flow three spool with afterburner, c) twin flow fanjet with thrust reverser*

To power the propeller driven passenger and military troops transport planes with the large cargo capacity and moderate flight speeds, the high power turbine engines are used in the power range of several thousand kilowatts, single spool axis-symmetrical design line, easily fitted in the wing gondolas. The largest such unit is the Soviet engine K-13 (presently NK-12 with power of 15000 HP) moving two contra-rotating eight bladed propellers, designed by Ferdinand Brandner design team, invited to the USSR from the occupied Germany after the 2nd World War.

In the lower power range the broad application had found the engines with the free power turbine and primary transmission, permitting power delivery to the helicopter lifting rotor transmission or to the propeller transmission. Such design rule, showed schematically on Fig. 3 permits to manufacture high perfection engines with the relatively low costs.

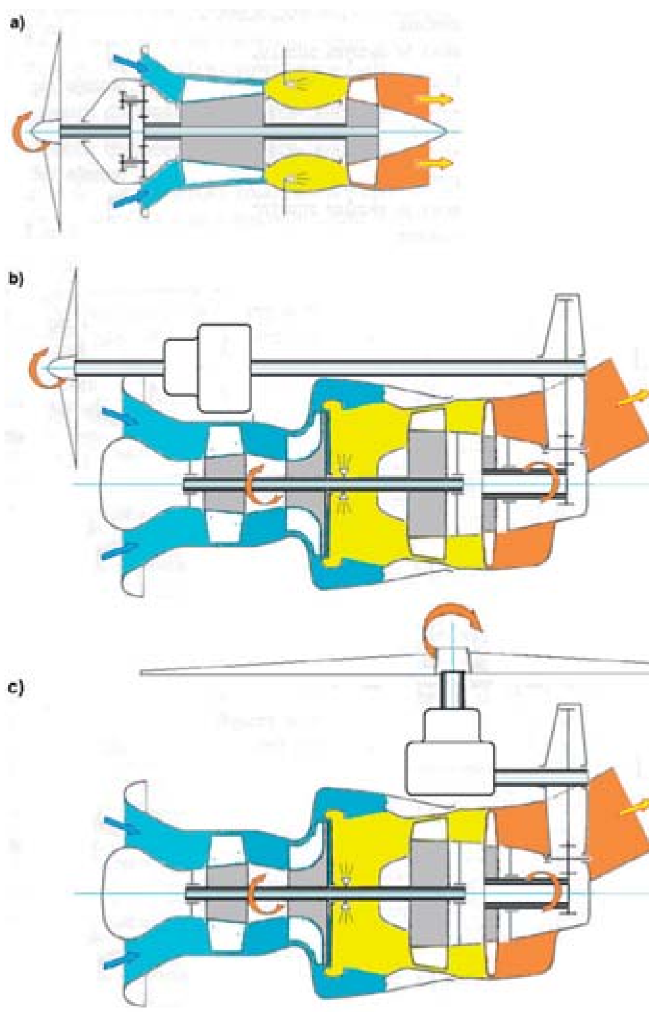


*Fig. 3. The schemas of turbine engines: a - propeller single spool engine, b - propeller engine with the free power turbine; c - helicopter engine with the free power turbine*

The turbine engines unitary fuel consumption approaches the value attainable by piston engines (250-220) g/HPh. In the moderate power engines, principally appropriated to powering of the helicopters, widespread is the design of air compressors with several axial stages and with final radial stage (Pratt&Whitney, Allison, General Electric and Turbomeca firms excel in this) that assures the obtainment of the high values of compression with the compressor limited length. Essential for the durability of the helicopter engine design change was introduced by General Electric Company in the form of integrated axial-radial inertial inlet air cleaner, schema of which is submitted on Fig.4. Such design assures the high efficiency of air cleaning with the minimized: flow resistance, mass and outline dimensions of engine assembly.

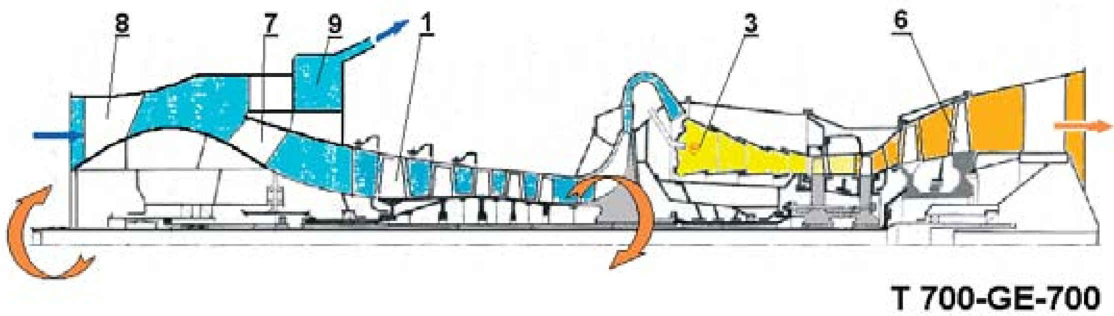


*Fig. 4. The helicopter engine with inlet air cleaner airflow schematics: 1 - air-compressor; 3 - combustion chamber; 6 - power turbine; 7 - directing vanes; 8 - the disc of stationary vanes for rotating the airstream; 9 - the air dust particles collector*

The rocket propulsion in aviation is presently utilized during takeoff of overloaded combat aircraft from short airstrips or landings field. They are, according to our knowledge, engines with the solid propellants, which can be suspended on aircraft fuselage before takeoff in the particularly difficult conditions. Rocket engines on much more effective - liquid propellants are in the application area for the global range missiles and the in-space activities. In these applications the particularly essential meaning has self ignition ability in the moment of the contact of hypergolic components: fuel with oxidant in the combustion chamber of the rocket engine. This feature in of post-war years was superbly widened on the most effective fuels (as hydrogen, alcohol, aviation naphtha) and their oxidants (liquid oxygen eventually fortified with ozone) through the introduction of appropriate additives to the fuels. The modern world armies are equipped with the missiles powered by rocket propulsion with the solid propellants (always ready to immediate use) applied as antitank weapon or single soldier antiaircraft weapon, as aircraft weapon, anti-aircraft (anti-missile), and in so-called rocket artillery missiles of „Katyusha" whether „Nebelwelfer" types. In some armies ramjet engines are utilized as marching engines of armour-piercing missiles and in missiles for shelling of permanent ground enforcements.

## 3. Principal directions of development

The general direction of development of all types of aeronautical propulsion systems, and also of these produced a long time ago and exploited for many years, is their permanent „upgrade" in the new equipment and of methodic of the current technical state checking for the purpose of the indispensable flights safety assurance, the prolongation of the failure-free exploitation time - but also the maintenance of the economic concurrency requirements. Recently, a categorical form receives the requirement of the noise limitation of aviation power plants and the limitation for emission of toxic elements in exhaust. Differentiated design of aviation power plants is not easing the speedy realization of these requirements, however the results of the persistent trend to minimization of the fuel expenditure clearly can be seen. In commercial aviation one wants to achieve this through the shortening of power plant working time by planning exactly the course of flight („gate-to-gate" system) from the passengers on boarding moment to „unloading" them on the destination airport.

In the piston engines, the direction of developments can be clearly seen, aimed on the design of compression ignition engines, fuelled with standardized fuel (aircraft naphtha) available on every civilian and military airport in the world. Their additional valour is their smaller fuel expenditure, about 30% less with respect to their spark ignition equivalents. Engines with spark ignition will be undoubtedly modified through introduction of the low-pressure (but can be also the high-pressure) fuel injection with the automatic control of the mixture composition by „lambda" pickup and electronic control of timing and duration of spark discharge on ignition plugs, but also introducing rotating charge within cylinders. Undoubtedly, turbo charging will spread to the engines of both groups. This will permit „to overtake" technical level already achieved and implemented generally in the car vehicle power plants.

In the airplane turbine engines the design forms (until to so-called „adaptive" jet engines) became worked out in the formation period of the „Cold War" threats in the world. Particularly significant contribution for the development of engines design was carried by British firms, and particularly Rolls-Royce firm, and in the manufacturing process for parts and assemblies (modules) - by the American firms like: General Electric, Pratt and Whitney or Allison. To the Americans belongs the start of modular design, enabling the exchange of assemblies „on site" and the practical implementation and exactness of diagnostic methods, but also the recognition of the low cycle wear occurrence in structures and the rules for designating the permissible number of cycles. On Fig.5 is presented the calculation method of the number of fatigue cycles transferred through the engine and through its principal assemblies, decisive for necessary exchanges (on the example of the F-16 aircraft engine).

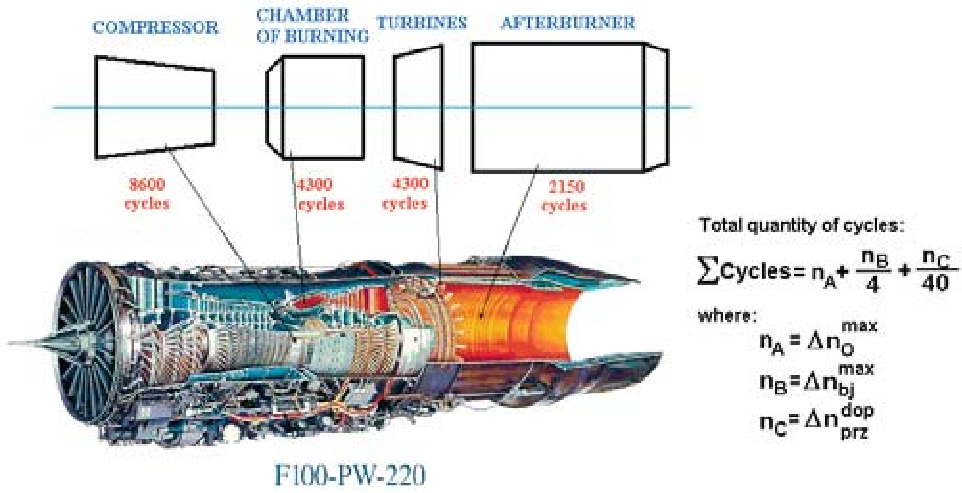


*Fig. 5. The schematics of the jet engine modules exchange in dependence on the number of transferred fatigue cycles*

In the long range reconnaissance aircraft the engines must fulfil the requirements of the high manoeuvrability (in the threat time on enemy territory) and the long range and limited possibility of spotting them from earth. Hence, they must have the possibility for the high thrust output in an instant delivery (afterburner, convergent - divergent nozzle), to be economic and silent (large bypass ratio and the ejector nozzle).

In transport planes power plants performing flights on the different altitudes and speeds are sought the possibilities for the limitation of the fuel expenditure through the broad changes in bypass ratio and the adjustability of output nozzle, at the same time assuring for lowering of noise emission in the wide range of engine performance. The schematic of engine designed with accordance to foregoing demands is presented on Fig. 6.

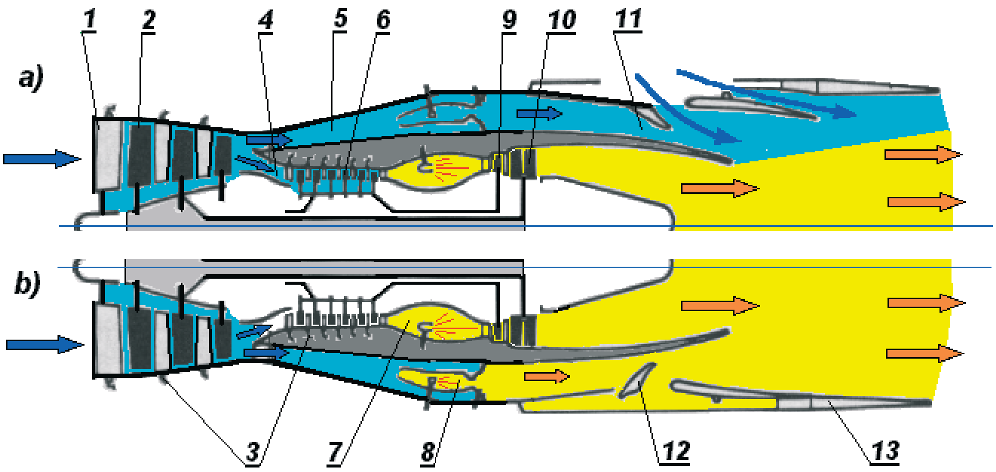


*Fig. 6. Flow schematics of a adaptive jet engine with the variable bypass control VSCE (system enabling selection from two bypass variants with the changes of the combustion chambers placement): a) configuration to subsonic flight (large bypass ratio); b) configuration to supersonic flight (small bypass ratio and afterburning); 1 - inlet control vanes; 2 - fan; 3 - movable control vanes of air compressor; 4 - internal channel; 5 - outer channel; 6 - the high pressure air compressor; 7 - combustion chamber (main); 8 - the combustion chamber of outer channel; 9 - high pressure turbine; 10 - low pressure turbine; 11 - mechanism for cross section regulation of outer channel; 12 - inlet flaps to nozzle control; 13 - multi flap controlled exhaust nozzle*

In the high manoeuvrability combat aircraft (particularly in the next unmanned and remotely controlled) adjustable exhaust nozzles are spreading, allowing for so-called thrust vectoring, necessary for example, to perform a controlled aerobatic figure „cobra" (thanks to which is easily possible to become coursing from the coursed). The appropriate schemas of nozzle mechanization are shown on Fig. 7.

Essential design changes in construction of turbine engines can be expected, along with miniaturization to aviation needs the electromagnetic bearings for rotary air compressors and turbines (replacement „of classical" rolling bearings by electromagnetic bearings). Hitherto, existing successes of this method of magnetic „pillow" generation between the structural parts, for example in the railway system, bring the hope for inurnment of them also in aviation.

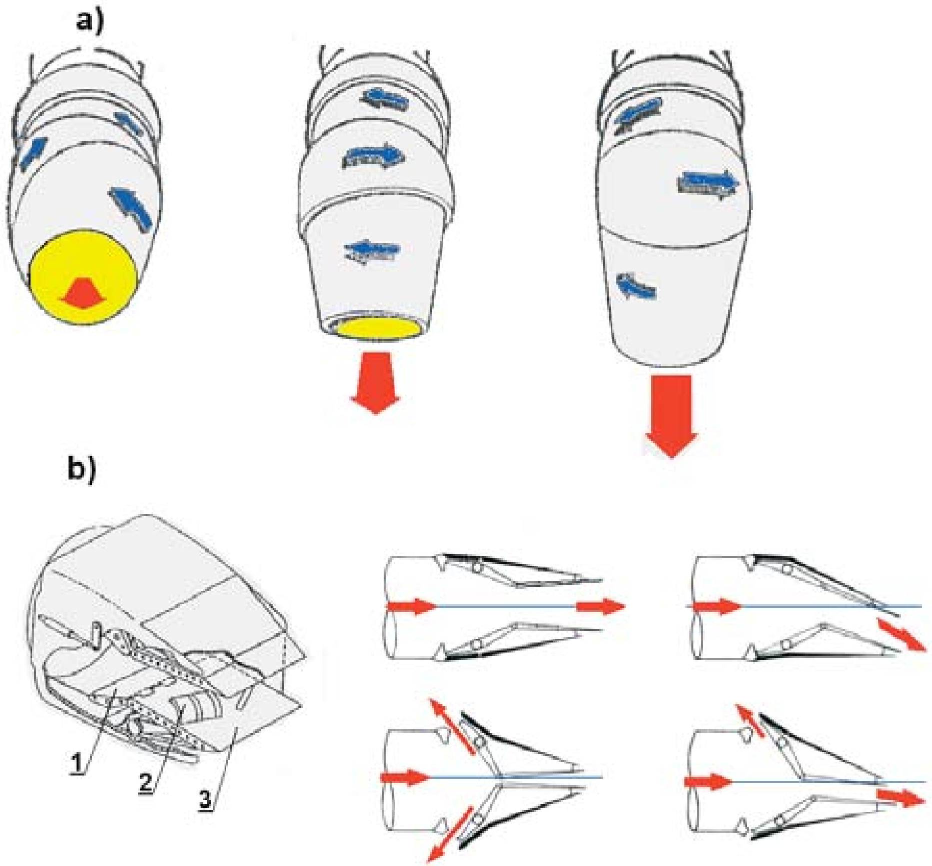


*Fig. 7. The schemas of adjustable exhaust nozzles for jet engines which enable the thrust vectoring*

Such method of bearing of rotary assemblies gives the occasion of a forthcoming implementation of birotational compressors in turbine engines. Schematics and the working principle of the air compressor of this type are shown and explained on Fig. 8.

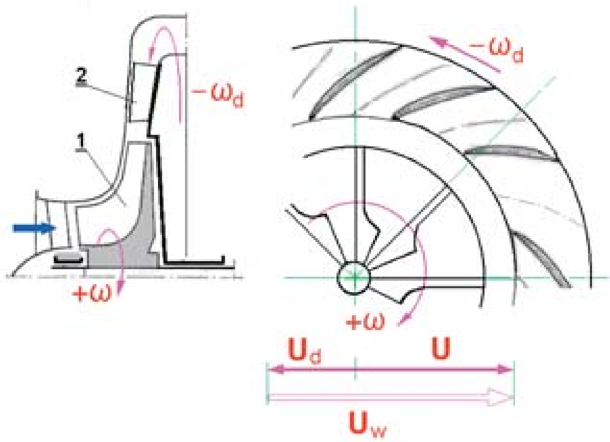


*Fig.8. The schematics of radial birotational air compressor and its working principle*

Initial research was performed in the Institute of Aviation (already since a long, a dozen or so years ago), which is owner of the patent proviso. Birotational air compressors will permit on the obtainment of near three time's larger compression ratio than classical compressors with analogous outline dimensions and a similar efficiency.

There are already accessible data's of the turbine power plant design - a surely already last of combat aircraft with the pilot on the deck, the possibility of a vertical landing and shortened takeoff. During the execution of these flight phases the power plant assembly determines three flow (!) turbine jet engine, and exhaust or air jets, flowing out from each of the three channels give all in all required lifting thrust. The schema of working principle and design sketch of this assembly is submitted on Fig. 9.

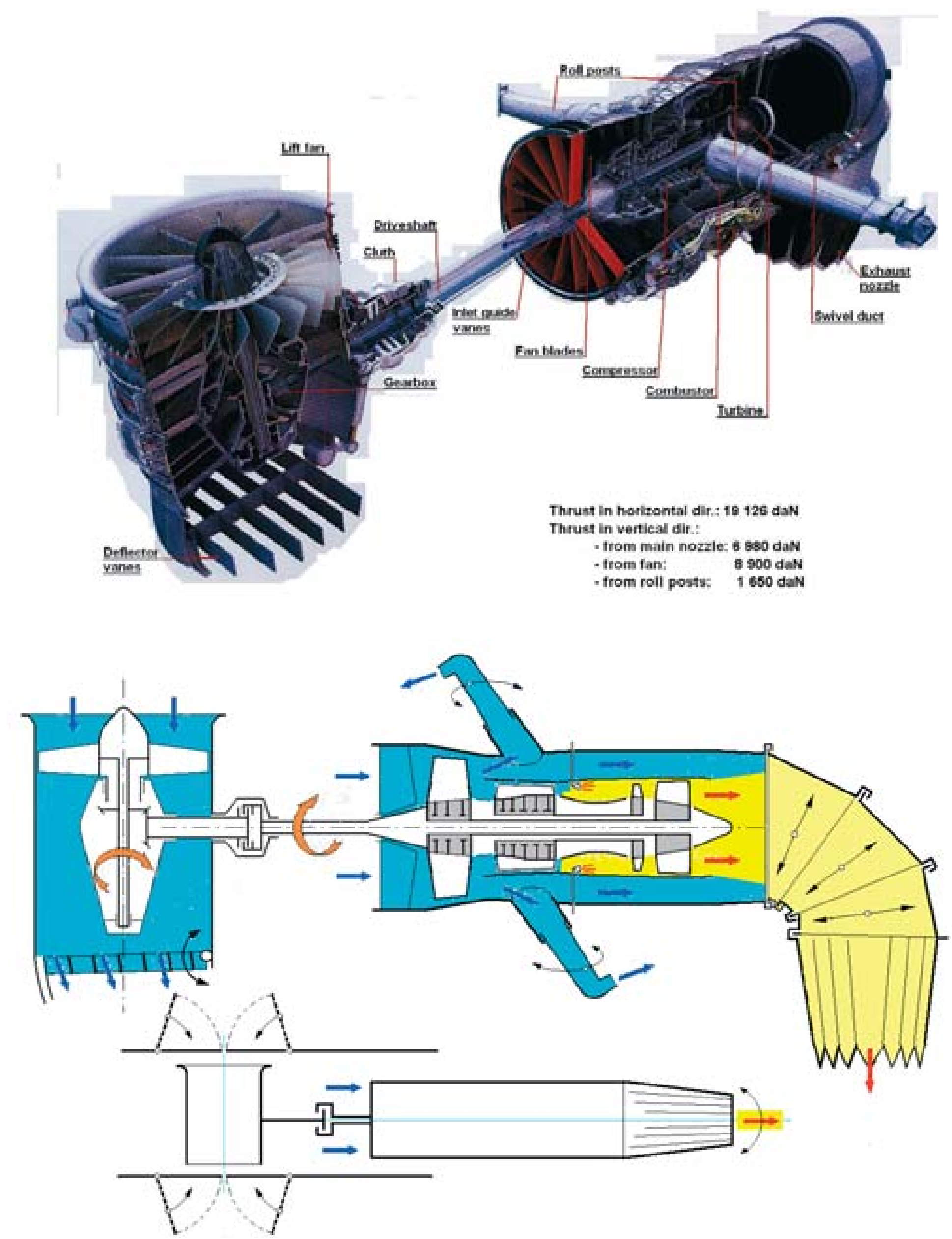


*Fig. 9. Pratt &Whitney F-135 power plant assembly of F-35 B aircraft*

In the cruise conditions the clutch between turbine of the low pressure rotor and the lift fan is straggled and afterburner flaps are closed, in order to limit turbines power to drive the rotors of basic (two) flow channels. Remaining after the turbines assemblies exhaust energy is exchanged in nozzle on marching thrust. The application of such powered aircraft to combat aviation can radically change the idea of construction of front-line airstrips and navy ships - aircraft carriers.

For a long time the trials were made for application of so-called renewable fuels with the special turn of attention on the verification of the adversaries proviso with respect to the constancy, reliability and safety of flights with usage of fuels of this type. Hitherto existing professional researches (and „half-professional" of Brazilian users) refer principally to piston engines - turbine engines can be multi-fuelled „naturally". In consideration of the necessity of limitations for the quantities of „greenhouse gases" introduced to the atmosphere, it would be necessary to spread the knowledge relative of the properties of fuels under the angle of comparisons of the quantities of energy obtained with emission of the $CO_2$ unit mass. It is shown for example, that for the crude oil fuels, 1 kg carbon dioxide originates with the creation (through the fuel combustion) of about 720 kJ energy, and for ethanol this index is more profitable and equals 960 kJ energy, and for methanol close to 1200 kJ energy /$kg_{CO2}$.

Wide spreading the renewable ecological fuels in every internal combustion engine is already ruthless requirement for our civilization… and the huge task for the present and future engineer's community of various specialties.

## 4. Challenges

The presentation of these issues is not devoid subjectivism from the position of our occupation or specialist narrow knowledge, but is supported by discernment on research potential of national laboratories and manufacturers and the quantitative state of experienced aeronautical engineers personnel. Hence also, one was limited to the issues possible to perform presently in our country - but essential for more distant engines development. Particularly important is the task of decrease the quantities of fuel used up, the limitation of number of produced engines through raising their efficiency and durability, limitation of noisiness of engines alone and driven: propellers, ventilators and the lifting rotors of helicopters, the limitation of thrust, required to the flight of the airplanes and the helicopters. Becomes important (with respect to each unit and each part used) minimization of energy required to their creation, their usage till the final utilization. Here we are limited exclusively to the engines issues and the research potential of our scientific centres.

***In the piston engines area:***

- The undertaking of the optimization tasks for the engines with various number of cylinders cooperation with the turbocharger - that is explained on Fig. 10 (Institute of Aeronautics, Warsaw University of Technology - MEiL, the Military University of Technology, the Polish Navy Academy),
- Optimization of the charge rotation speed in cylinders, according to engine rotational speed and on the degree of engine load (Institute of Aviation),
- The more detailed version of the fatigue calculations of crankshafts, connecting rods and pistons (Institute of Aviation, Warsaw University of Technology - MEiL, the Military University of Technology),
- Optimization of the biological and mineral fuels mixtures composition for different flight and climatic conditions (Institute of Aviation, Air Force Institute of Technology),
- The working out inlet air inertial dust separators and the noise silencers (Military University of Technology, the Institute of Aviation) also to helicopter and propeller turbine engines.

***In the turbine engines area:***

- The more detailed version of the numeral value low cycle wear of structures in the different ranges and frequencies of their occurrence, dependant from the conditions of flight, performing engine acceleration and deceleration (Institute of Aviation, Warsaw University of Technology - MEiL, Rzeszow University of Technology),

- Realization of investigations and the more detailed version of the computational methods for birotational compressors in the whole range of their performance (Institute of Aviation, Rzeszow University of Technology),
- The undertaking of research on the development of the piston and jet engines noise silencers,
- The usefulness opinion on the utilization of ejectors (Institute of Aviation, Warsaw University of Technology - MEiL),
- The continuation of research on the turbine blades cooling, also in the aspect of minimization of the tip clearance (Institute of Aviation),
- The undertaking of works on construction of electromagnetic bearings for rotary assemblies of turbine engines (Institute of Aviation, Bialystok University of Technology),
- The continuation of research of vortexes in inlets of the turbine engines and of methods, limiting the possibility of their formation (Institute of Aviation, Air Force Institute of Technology, Rzeszow University of Technology),
- The continuation of development of the current technical state diagnostics methods of aviation power plants, particularly through the choice of the parameters - carriers of diagnostic information.

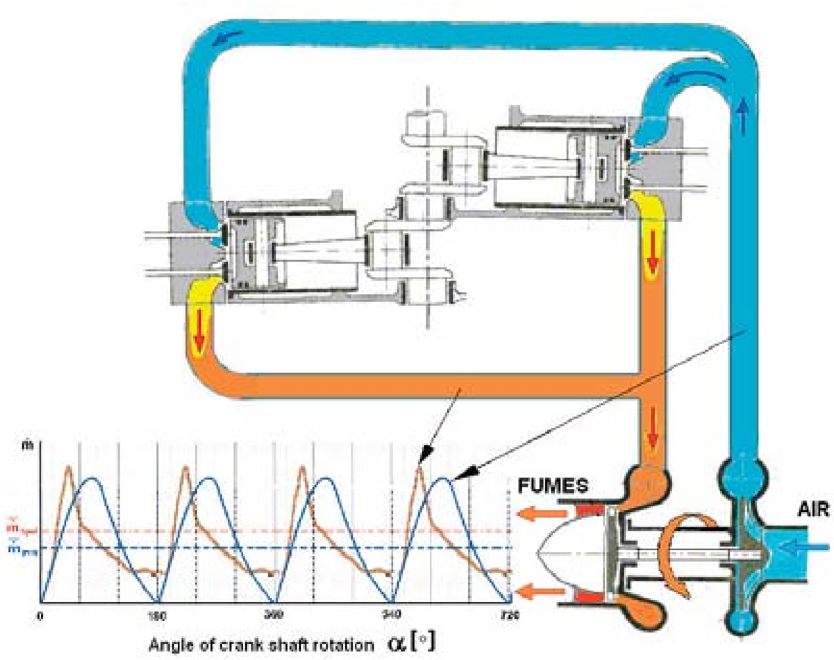


*Fig. 10. The schema of piston engine cooperation with the turbocharger*

***In the rocket engines area:***

- The undertaking of tasks for design and building of water rocket engines to power the equipment of immediate (close) recognition of battlefield (Institute of Aviation).

Each from mentioned tasks contains in itself the cognitive load sufficient for the conquering of succeeding scientific degrees by our younger colleagues - engineers, whom they will want to join to present generations of the aviation hobbyists.

This is particularly important task in consideration of enlarging generation gap among aeronautical engineers.

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