CURRENT DEVELOPMENT TREND IN AIRCRAFT POWERPLANTS

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The aircraft powerplants key question connected with the current state of art, perspectives of performance improvement, costs of research works, productions, consumptions of structural materials and exploitation problems together with utilization of worn-out propulsion aggregates has been presented. All these costs are not only the financial expenses but also the environmental pollution by toxins emitted to the atmosphere, waters and soil including the huge quantities of carbon dioxide.

1. INTRODUCTION

The aircraft powerplants only utilise the reaction exerted by escaping fluid as the source of motive power. This escaping fluid can be stream of air going through the turning propeller, helicopter rotor, fan of two-spool turbojet engine, flow duct of jet engine or the nozzle of rocket engine. The present state of using the piston and turbine engines as the propulsion for airplanes and helicopters is the result of periodical advantages of performance, costs and needs required by the constantly tactically and quantitative evolved armies previously being potential enemies during the cold war. The demand of great powers on the high-speed and far-reaching military aviation just after the Second World War called out the intensive development of turbojet engines. In that time also came into being the row of solutions having the significant influence on durability and reliability of engines. As the examples of such solutions can be: the open lubrication system of bearings for rotating turbines, flexible supports for aggregates of rotating compressors and turbines, automatic control system for acceleration and deceleration of engine, and many other rationalizations improving, at the end, the safety of flight.

2. CURRENT DEVELOPMENT STATE OF AIRCRAFT POWERPLANTS

Observed, the outright instant progress in all technical fields can yet more than once surprise our civilization, especially this is true in aviation and space technology. From this reason, the opinions introduced in this study relating to the aircraft power plants are not certainties, but only the experts' opinions based on the knowledge relating to current state of the art and the route to approach this state during the last ten years.

2.1. Turbine engines

Until now, the progress of aircraft power plants were, first of all, aimed on the quality of realization of separate component parts and assembling aggregates. Here, the quality is understood as repeatability of the material proprieties and dimension of parts assuring their interchangeability and interchangeability of aggregates build with these parts. As a result of this action the modulus come into being can be replaced directly on "the wing" of flying craft (without need to take over the engine from airframe). Since the early 1980s, the intensive growth of methods to diagnose and monitor the chosen parameters has been noticed. These methods give the possibility to estimate the current technical state of engine and forecast its the failure-free working time. The final effect of these action was, from one side, the doubtless growth of engine production costs but, from other side the marked drop of operation costs (among the others due to the elimination of necessity to disassemble aggregates and perform their control on stationary stands in fixed date ordered by producer). The essential advantage of this action is the possibility to keep the engine working till the limits of its technical possibilities together with the simultaneous assurance of flight safety.

At the end of the Second World War, the producer of first German jet engines mounted on combat airplanes gave the guarantee of 20 hours of failure-free operation. During the Korean War this period was prolonged to the range of 100 to 300 hours. In a lot of armies the modern jet engines of combat airplanes have the failure-free operation set on the level of 300 to 500 hours. As an opposite example, the engines of F16 airplanes can be used through 4 000 hours thanks to the possibilities to replace the highly active modules („hot part") of engine (Fig. 1).

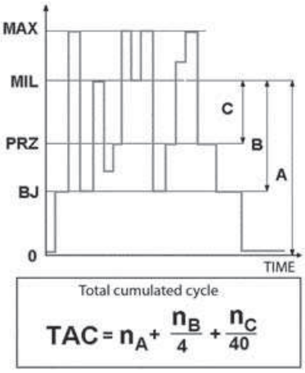
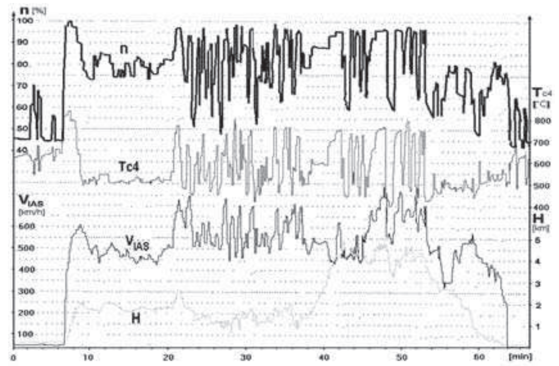


Fig. 1. The way to define the burdens loaded on the Pratt & Whitney F - 100 engines during operation (n - number of registered required changes of working ranges); BJ - idling range; PRZ - cross-country flight range; MIL - military range; MAX - maximum thrust range (with afterburner). Average of 2 to 2,5 cycle/hours of flight for F100-PW-220: - „cold part": 8600 cycles; - „hot part": 4300 cycles

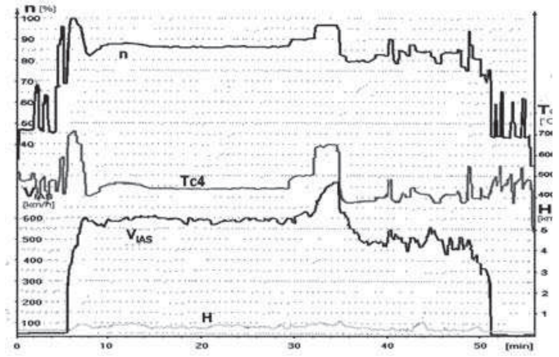
Similar differences were observed in transport civil aviation. For example, the D30 KU engines installed on the Ił-62M airplanes have the service life equal to 3500 hours, but on the Tu154 M airplanes the service life is 5000 hours. In the last case the performance is a little lover. However, engines of the CF-6 families installed on the Boeing 767 airplanes, used by our PLL LOT, achieve even 50000 hours due to the method of operation by tracking the technical state through monitoring the several dozen parameters of powerplant.

Relatively recently the problem of low-cycling fatigue of construction was taking into consideration. The definitions of full cycle of burden are different, but often in the case of turbine engines it is accepted that this cycle consist of: resting state in surroundings temperature, starting, idling, entry on the maximum range, descent to idling, shutdown and the chilling the engine to surroundings temperature. Reliability of such pattern of burden cycle does not wake special doubts in case of engines operated in transport aviation, and especially civil aviation. However, in the case of military aviation the doubts come to mind. During the raid flight the burden are similar to described above, but during the aerial fight the changes of engine burden are repeated many times in track of single flight so, the considerably more cycles than in raid have been occurred (Fig. 2). The accurate methodology to compute the really fatigue cycles taking by the engine requires the further research works.

In the last few years, it has returned to ideas of engine (called now the adaptive engine) introduced by the Rolls--Royce in 1950s. It is the modification of two-spool jet engine with the adjustable throttle valve between channels, feeding supply to the combustion chamber and afterburners and the adjustable escape nozzle. The construction of these engines makes possible to tune the fluid-flow channel according to changes of flight conditions (mainly speed) in such a way that the engine could work as the optimum powerplant. The changes of fluid-flow configuration according to the growth of flight speed lead to this that, during take-off and subsonic speed flight the engine works as double-flow one, in close to the sonic speed flight the engine uses the single-flow with possibility to use afterburner, and in case of the large ultrasonic flight it works as the stream engine.



a) Number of pre-arranged cycles = 15,35



b) Number of pre-arranged cycles = 3,12
Fig. 2. Examples of the registered cyclical burden on engine structures: at top – air-fight flight; at bottom - raid flight; parameters notation :VIAS - instrumental speed of flight, H - barometer height of flight, n - rotational speed of rotor, Tc4 - temperature of exhaust gas after turbine

Nowadays, the technology of production of the turbine rotor blades as casts in form of mono-crystals and applying the friction welding the shafts with bearing shields of rotors are commonly spread. The tuning of the minimum value of turbine top gap according to the flight conditions is applied in more and more engines of transport airplanes. It is particularly profitable in two-spool large thrust engines installed on intercontinental passenger airplanes. The realization is performed by the programmed cooling of the trunk of turbines by air taken from compressor. This is one of the ways to reduce the operational fuel consumption.

From over quarter of a century it is guided the investigations of counter-rotated fan-propellers (among others in General Electric). The encouragement for this activity are undoubtedly the results obtained on the Hercules airplanes, which engines drive four-blade fan-propellers. After introduction of the counter-rotating fan-propellers (Fig. 3) it is expected to get 10 per cent rise in propulsion efficiency. This is mainly due to the radical limitation of the whirled stream after a propeller. The permanently sharpened rules relating to ecology in range of airports forced to search the ways to reduce a noise emitted by propulsive aggregates (including fan-propellers) during take-off and landing of airplanes.

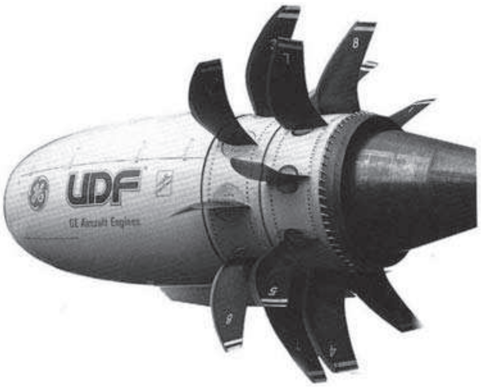


Fig. 3. Prototype unducted fan engine GE 36 UDF - modification of F-404 rotatory speed: 1700 rpm, diameter: 3.05 m, specific fuel consumption: 250 g/daN h (fuel economy: about 8%), turbine power: 10 900 kW

In the past, the favourable features of the counter-rotation in the fluid-flow machines were detected, however, mainly in aspect to reduce the gyroscopic effect during the airplane curvilinear flight. Mainly for that reason the counter-rotating propellers were applied in the counter-rotating, star-shaped engines during the First World War. Actually such solution is used in turbine engines of PW-100 families with counter--rotating rotors of centrifugal compressors and, installed on Tornado airplanes, the RB-199 jet engines with the counter rotated compressor rotors.

The experts of the Institute of Aviation in Warsaw worked out the construction of counter-rotating fluid-flow compressor in which besides the rotor there is the guide ring diffuser which is rotated in opposite direction. It gives the possibilities to increase the compression on the single stage of centrifugal compressor. During tests on the laboratory stands authors obtained the confirmation of their investigations and calculations. This solution was patented in Poland, Canada, USA and former Soviet Union. Above mentioned solution applied in the axial compressor should give similar effects as in centrifugal compressor (Fig. 4).

The new materials and automated technologies of production are permanently introduced into the construction of turbine engines. All of these assured the geometrical, resistant and rigidity repeatability of the produced units.

It is hoped that the non-contact magnetic bearing will be used in aircraft turbine engines to make the possibilities for direct automatic control of the direction and magnitude of aerodynamic lift. Undoubtedly, the electronic will enter more effectively to control the engine and aircraft (thrust management) by using the actually measured in the real time parameters connected with the engine and flight. In addition, these parameters will be used for engine diagnosis. It should be expected the significant structural changes (rather not in fluid flow arrangements) of jet engines designed for remotely controlled combat airplanes. It will be pilotless airplanes with high manoeuvrability, in which man's physiological features will not be limited by gravity load.

The growing costs of production and use of the aircraft turbine engines impose the requirement to get the largest durability at the high reliability to guarantee the full safety flight. Above mentioned reasons leads to the endless development of automated diagnostic systems with the signalling of approaching the wear stages when engine will be broken down.

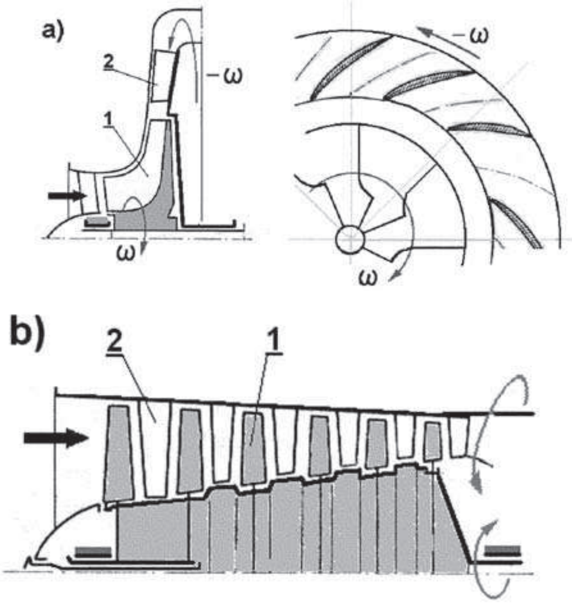


Fig. 4. Schematic diagram of counter rotated compressors: a) centrifugal; b) axial-flow; (1 – rotor, 2 – diffuser)

2.2. Piston engines

The perspectives of development of the aircraft piston engines look less optimistically, especially in comparison with observed development of car engines. In personal cars engine (at the beginning of 1980s in USA, and at the end of 1980s in Europe) production absolutely prevailed the spark ignition engines with low-pressure, electronically steered injection of stoichiometric petrol and ignition with elongated time of spark discharge. This way of fuelling and ignition makes possible the particularly profitable course of process of inflaming and burning charge especially when charge in cylinder is intensely rotated. (Fig. 5). Automated fuelling and ignition assured the high efficiency of burning process and the very low content of toxic component in exhaust gas expelled to atmosphere. The present-day engines of personal cars and large load capacity lorries (TIR type) are characterized not only by the low specific fuel consumption but also by the low level of noisiness, huge reliability and durability expressed in a mileage (long ago the mileage of personal cars was exceeded 100 000km, and in case of TIR type cars - 1000000km).

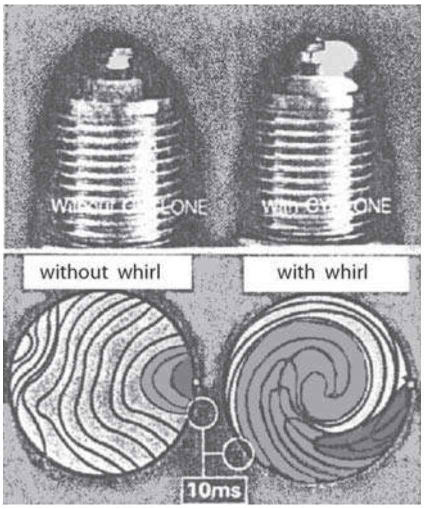


Fig. 5. Influence of charge whirl on flame spreading speed in engine cylinder

It should be expected that progress reached in traction engines will be successfully introduced to aviation by modernizing engines which, from many years, are used to power the different types of airplanes such as: disposable, tourist, rescue, agricultural, sport and so on. One with difficulties, to be overcome, is the regulations formed a long time ago. These regulations coming from a very important purposes which are the flight safety, are related not only to the pilots and passengers of flying craft but also to persons and their possessions on the ground surface over which these craft are flying.

However, the works are conducted on the modification of classic airplane powerplants such as engines with carburettor and adjustable airscrew pitch propellers. For example, at Aviation Institute in Warsaw, the steering of the Lycoming 0-360 engine, with the regulated airscrew pitch propeller, by four manually control lavers was successful replaced by the microprocessor control system using only a single manually control laver. The manual steering by four lavers does not allow the pilot to easily adjust the optimal parameters of pawerplant which are changed with flight conditions and manoeuvre type so the potential possibility of powerplant are not fully used. In the case when a pilot needs to use only one control level to set the required thrust and other three are automatically set to optimal value by microprocessor control system the all possibilities of powerplant can be fully utilised, don’t mention that the pilotage was made easier. This, fully build in Aviation Institute, single laver microprocessor control system came satisfactory through the full ground test with the real engine.

It is repeatedly signalled intention to use, in aviation, the self-ignition engines. The present-day designing knowledge, accessibility to various materials, methods and technological devices used in industry have been assuring the production of high quality parts and aggregates and making up the guarantee to produce the light, durable, unfailing, fuel-efficient engines which are friendly for environment. Present and future aviation can not give up from small power piston engines essential for airplanes with moderate speed and several passenger seats. It is forecast building a family of engine in push-pull arrangement of the opposed - cylinder engine with different number of equal cylinders and possibilities of self-supercharging. The composing of engines in such a way makes possible to choice the powerplant which will be the best for given airplane or helicopter operated in the foreseen area. The interest in engines with self ignition comes back to life over half-century after the end of the Second World War. At that time the production and uses of engines of family Jumo 205 was stopped in devastated German aviation. Nowadays, engines with self-ignition are started to be more attractive in aviation. It comes first of all from their large efficiency in a wide range of loading (its specific fuel consumption is, in average, about 25% smaller than engines with spark ignition) and possibilities to use the unified fuel that means the aviation kerosene which are easy to get at each airport. Engines with self-ignition can use a very wide range of mixture ratio (λ = 1,3 ... 15) in distinction to engines with spark ignition (λ = 0,7...1,3). From these features it is relatively easily to steer engines with self-ignition.

It should be expected that superficial filters or may be better the inertial dust cleaners will be inserted into air inlets of engine (similarly as from a long time ago, they were applied in helicopter turbine engines), and also the noise silencers will be placed in the escape exhaust gas systems.

The trial run has been already conducted to use the hybrid drive to power a pilotless flying object. These kinds of objects are particularly profitable for the long-lasting observation of definite area (for example a battle field) and are competitive with the satellite or reconnaissance airplanes which performed the same job. The propellers would be driven by electric motors supplied from the wing solar batteries and accumulators periodically charged by generators driven by the self-ignition combustion engine with the very high stage of supercharging or for example, from inertial accumulators of energy.

The rationality of producers of aircraft piston engines and theirs mutual competition will undoubtedly cause the transfer of huge experience relating fuel supply and computer control systems from car industry. The computer control system make easier to perform the objective diagnosis of current technical state of engines. In this field exists the hope for our polish aviation industry, till now there are (yet!) intellectual, designing and technological staff, and possibility of fabrication.

3. FUEL

So far in aviation, the turbine engines (turbojet, turboprop and bypass or ducted fan engines) consume the largest amount of fuel. The piston engines, although used in great number in sport, economic and disposable aviation, consume the considerably less fuels than turbine engines, but requirements for their failure-free work in the very diverse climatic and atmospheric conditions impose the necessity to keep the very subtle proprieties of these fuels. Lasting from almost a half of century, the rise and development of aviation owe, among others, a lot to a development of combustion piston engines. They were engines with spark ignition and carburettors, in which the petrol obtained from petroleum was used as fuel. The basic difficulties of using the spark ignition engines are its large cubic capacity of cylinder. It comes from the necessity to obtain the necessary power of engine at a small rotational speed of propeller. In principle, the cubic capacity of individual cylinder is in the range of 0,8 to 3,5 cubic decimetres. So, it can lead to the detonation burning despite two spark plugs placed in the opposite sides of cylinder head. In Brother Wright engine, which has the compression ratio equal to 4.4, available at that time the car petrol was used. According to present estimation, the octane number of that petrol was about 38. The necessity to increase the engine efficiency and keep their overall dimension as small as possible has been extorted: increase the compression ratio and rotational speed and supercharging. The above mentioned operations caused the necessity to compose petrol with the additive increasing their octane number (at present this number reached 130 units) and the continuous search to find a alternative fuels, for example alcohols and their mixtures with petrol. The most effective ant-detonation additive is lead tetraethyl. The lead toxicity has been known for ages, so a dozen years ago the lead additions were already withdrawn from car petrol and replaced by others and the ethanol in added larger quantities is applied.

In the interwar period it was tried to introduce to aviation the engines with self ignition according to their advantages such as: greater efficiency than in spark ignition engines and using the universally available fuel. Practically only Germany has been able to successfully construct, produce and use the two-stroke self-ignition engines in aviation.

The limited and depleted mineral resources such as the pit-coal and petroleum and the constantly sharpened, ecological requirements forced to search the methods to get the new liquid fuels for any combustion engines. The interest increases in hydrogen as the particularly ecological fuel. However, the small density of this fuel causes that a deck tanks should be four times greater than the ones for hydrocarbons fuel to be able to contain the same energy, and in addition they have to have the suitable thermal isolation and durability (see table and Fig. 6). It is quite obvious to insert into the classic fuels such as: petrol, diesel oils and aviation kerosene the significant quantitative components of ecological fuels of vegetable origin.

Tab. 1. Comparison of some properties of hydrogen and aviation kerosene used as fuel

	Aviation kerosene	Liquid hydrogen
Caloric value [kJ/kg]	42 800	119 890
Density [kg/m^3]	753	71
Energy from 1m^3 volume [MJ]	**32 228**	**8 512**
Fuel weight [kg] with energy of 100 GJ	**2336**	**834**

Fig. 6. The studio project of A - 320 airplane in case of engines fueling by the liquid hydrogen (extremely big fuel tank in fuselage)

The groundless restrictions were recently upraised in our country about the allegedly destructive effects of vegetable origin fuels on combustion engines. It was called out by politicians, unfortunately together with the titled scientific workers who fortunately are working in the fully different fields. So their opinion is completely inexplicable. At this point, it should be called to mind, that in 1989 it was the flight from Wasco in Texas to Paris on single-engine airplane which piston engine was fuelled by the pure ethanol. In the same time USA military aviation conducted 1000 hours ground tests of engines and 3000 hours flight tests of F-16 airplanes using the conventional aviation fuel (aviation kerosene) to which the significant quantity of Biodiesel 100 fuel were added. The positive results were obtained during these tests.

4. SUMMARY

In 2004 from 30 largest world airports were send away 1260 million passengers (leads Hartsfield airport in Atlanta with 83 million passengers). It means that in every moment about half a million people takes airplane trip.

The present of our civilization orders to regard not only the production costs of devices (for example engines), their use until to utilization, but also the quantity of carbon dioxide emitted to the atmosphere in this cycle. The burning of mineral fuels introduces, in irreversible way, the carbon dioxide to atmosphere in contrast to fuels of vegetable origin. So for the future, the earthly atmosphere can not be treated as the infinitely great ocean of clear air.

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AKTUALNE KIERUNKI ROZWOJU NAPĘDÓW LOTNICZYCH

Przedstawiono problematykę napędów lotniczych dotyczącą stanu aktualnego i perspektyw poprawy osiągów z uwzględnieniem kosztów badań, produkcji, zużycia tworzyw konstrukcyjnych, eksploatacji, aż do utylizacji „wypracowanych” zespołów napędowych. Koszty te, to nie tylko nakłady finansowe, ale też „obciążanie” środowiska toksynami odprowadzanymi do atmosfery, wód i gleby – w tym ogromnymi ilościami dwutlenku węgla.

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АКТУАЛЬНЫЕ НАПРАВЛЕНИЯ РАЗВИТИЯ АВИАЦИОННЫХ ПРИВОДОВ

Представлена проблематика авиационных приводов касающаяся актуального состояния и перспектив улучшения характеристик с учетом расходов на исследования, производство, износа конструкционных материалов, эксплуатации до утилизации „выработанных” силовых установок. Эти расходы, это не только финансовые затраты, но и „нагрузка” среды токсинами отводимыми в атмосферу, в воду и почву – в том числе большими количествами двускиси углерода.