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НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
НАВЧАЛЬНО-НАУКОВИЙ АЕРОКОСМІЧНИЙ ІНСТИТУТ
Кафедра авіаційних двигунів

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
д-р техн.наук, проф.
_____________Терещенко Y. М.
"__________"__________2020 р.

КВАЛІФІКАЦІЙНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)
ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ МАГІСТРА
ЗА ОСВІТНЬО-ПРОФЕСІЙНОЮ ПРОГРАМОЮ
«ТЕХНІЧНЕ ОБСЛУГОВУВАННЯ ТА РЕМОНТ ПОВІТРЯНИХ СУДЕН І АВІАДВИГУНІВ»

Тема: «Методи підвищення паливної ефективності двоконтурних газотурбінних двигунів для дальномагістральних літаків»

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КИЇВ 2021

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
EDUCATIONAL AND RESERCH AEROSPACE INSTITUTE
AEROENGINE DEPARTMENT

PERMISSION FOR DEFENCE
Head of the Department
Doctor of Sciences (Engineering), prof.
______________Tereshchenko Y. M.
“_______”______________2021

MASTER DEGREE THESIS
ON THE EDUCATIONAL PROFESSIONAL PROGRAM "MAINTENANCE AND REPAIR OF AIRCRAFT AND AIRCRAFT ENGINE"
(EXPLANOTARY NOTE)

Theme: “Methods of Fuel Efficiency Increase of Turbofan Engines for Long-haul Airplanes”

Performed by:______________________________________Tkachuk Y. O.

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Labor precaution:

Ph.D. (Biology), assoc. prof_____________________________Kovalenko V.V.

Environmental protection:
Ph.D. (Engineering), Assoc. Prof._________________________Sayenko T.V.

Standards Inspector _________________________/______________________/

Kyiv 2021

NATIONAL AVIATION UNIVERSITY

Institute: *The Aerospace Faculty*
Faculty: *The Aircraft Faculty*
Department: *Aeroengines Department*
Educational and Qualifications degree: *Master*
The specialty: 272 Maintenance and Repair of Aircraft and Aeroengines

APPROVED BY

Head of the Department
________ Yu. Tereshchenko
“____”_____________2021

Graduation Diploma Work Assignment

Student’s name: TKACHUK YEVHENII OLEKSANDROVYCH

1. The Work (Thesis) topic: *Methods of Fuel Efficiency Increase of Turbofan Engines for Long-haul Airplanes.*

Approved by the Rector’s order of 04 “October”, 2021 № 2137/ст.

2. The Graduation Project to be performed: *October 25-2021—December 22-2021.*

3. Initial data for the project: *TFE should be designed for standard atmospheric conditions: T amb=288 K, P amb = 101.3 kPa, Tg_t=1575K.*
4. The contents of the explanatory note (the list of problems to be considered): *diploma work assignment; patent review, analysis of methods for improvement of fuel efficiency, analyses of aviation impact on the environment, analysis of labor precaution.*

5. The list of mandatory graphic materials*: schematic diagram of turbofan engine, graphics for special part of diploma work, Microsoft office Power Point, KOMPAC Autocad, should be used to provide graphic support and presentation.*

6. Schedule of Graduation Work Performing

Stages of Graduation Work Completion	Stages Completion Dates	Remarks
Literature review of materials concerning the project	28.09.21-13.10. 21	
Patent review of the problem raised in the project	14.10-21-24.10.21	
Investigation of methods for fuel efficiency improvement	25.10.21-07.11.21	
Development of calculations based on selected method for improvement of fuel efficiency	08.11.21-20.11.19	
Confirmation of improved fuel efficiency via thermodynamic and gas dynamic calculation, economical benefits	21.11.21-30.11.21	
Labor precaution	01.12.21-12.12.21	
Environmental protection	01.12.21-12.12.21	
Arrangement of graphical part of diploma work	12.12.21-18.12.21	
Preparation of explanatory note	14.12.21-20.12.21	

7. Advisers on individual sections of the work (Thesis):

Section	Adviser	Date, Signature	
		Assignment Delivered	Assignment Accepted
Labor precaution	Kovalenko V. V.		
Environmental protection	Sayenko T. V.		

8. Assignment issue date ____________________________________
Graduate Project Supervisor *I.I. GVOZDETSKYI* ____________________
(supervisor signature)

Assignment is accepted for performing:
Graduate student *Y. O. TKACHUK* ____________________
(graduate student's signature) (Date)

CONTENTS

ABSTRACT

The explanatory note on the qualification work “Methods of fuel efficiency increase of turbofan engines for long-haul airplanes”. … pages, … figures, … tables, 51 used sources.

TURBOFAN ENGINE, FUEL EFFICIENCY, AVIATION ENGINE, ENGINE PERFORMANCE IMPROVEMENT, OPTIMAL ENGINE DESIGN, ACTIVE CLEARANCE CONTROL, TURBINE COOLING, AIR TRAFFIC MANAGEMENT, AVIATION ENGINE EMISSION.

Research object – unified turbofan engine based on prototype ПС-90A and the improvement its fuel efficiency.

Research subject – analysis of publications, literature sources, a review of the patents, statistical data about overall fleet of airplanes fuel consumption, development of thermodynamic calculation and gas-dynamic calculation of the main engine parameters, obtaining the results in fuel efficiency improvement based on implemented methods.

The aim of the qualification work is to analyze the factors affecting on the engine fuel efficiency and provide possible ways for the improvement.

LIST OF ABBREVIATIONS, DESIGNATIONS, SYMBOLS

In this part short list of abbreviations and designations is given, which are used in calculations of qualification work and also main terms, which are used in text of explanatory note.

c	Jet velocity
c_p	Constant pressure specific heat, kJ/(kg-K)
$\bar{c}_p$	Average constant pressure specific heat, kJ/(kg-K)
c_{v}	Constant volume specific heat, kJ/(kg-K)
$\bar{c}_p$	Average constant volume specific heat, kJ/(kg-K)
C	Specific fuel consumption
d, D	Diameter, m
G	Mass air (gas) flow rate
H_u	Net calorific value of fuel, J/kg
HPC	High-pressure compressor
HPT	High-pressure turbine
k	Specific heat ratio, C_p/C_v
l_0	Quantity of air, theoretically required for complete combustion one kg of fuel, kg air/kg fuel
L	Work
LPC	Low-pressure compressor
LPT	Low-pressure turbine
m	Bypass ratio
M	Mach number
ND	Nozzle diaphragm

INTRODUCTION

Air transport is a major driver of the nation's economic and social development. This plant covers all operations involving the transport of goods and people by air. Air transport connects people, countries and cultures around the world. In addition, it opens up the market for international players, thus greatly supporting trade and tourism.

Air transport has played a significant role in the development of trade, communications, trade and tourism worldwide. Despite the massive expansion, air transport faces serious challenges such as high fuel consumption, fuel prices, air traffic growth, competition, economic crisis, greenhouse gas emissions, safety, design and operational challenges.

The fuel consumption is considered to be a major problem facing the air transport industry. Due to high oil prices and increasing competition, fuel consumption is rapidly becoming an important issue in the air transport industry. The rapid growth of the global economy last years also boosted oil demand, which in turn boosted its value.

The aviation sector accounts for about 5.8 % of total oil consumption worldwide. Aviation fuel consumption today corresponds to between 2 and 3 % of total fossil fuel use worldwide, more than 80 % of which is used by civil aviation. It is predicted that traffic will grow 5 % per year to 2026 and fuel demand 3 % per year. Fig. 1. shows the rate of fuel consumption since 2005.

Fuel consumption is one of the most important measures of direct operating costs in an air traffic control area. Fuel is the main and most volatile of operating costs, managing this issue is a growing challenge for the aviation sector. Airbus estimates that in 2003, fuel was about 28% of the total operating costs of a typical A320 family operator. But in the near future it may be more than 45% of all aircraft operating costs. The country's economy is largely dependent on oil prices. Increased fuel consumption affects airlines in two ways; direct impact on operating costs and reducing air and air travel needs.

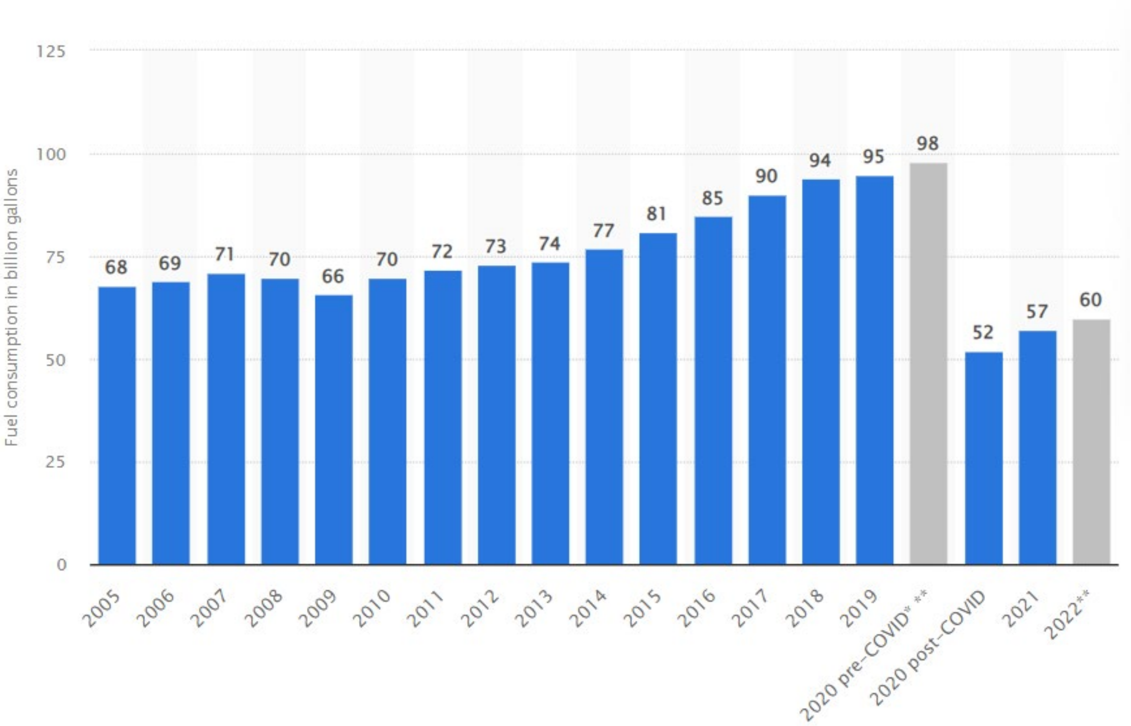

Fig. 1. World fuel consumption of commercial airplanes between 2005 and 2022

1. METHODS FOR ENGINE FUEL CONSUMPTION REDUCTION

The four main approaches for the fuel consumption optimization (FCO) are known [1] as shown in Fig. 1.1.

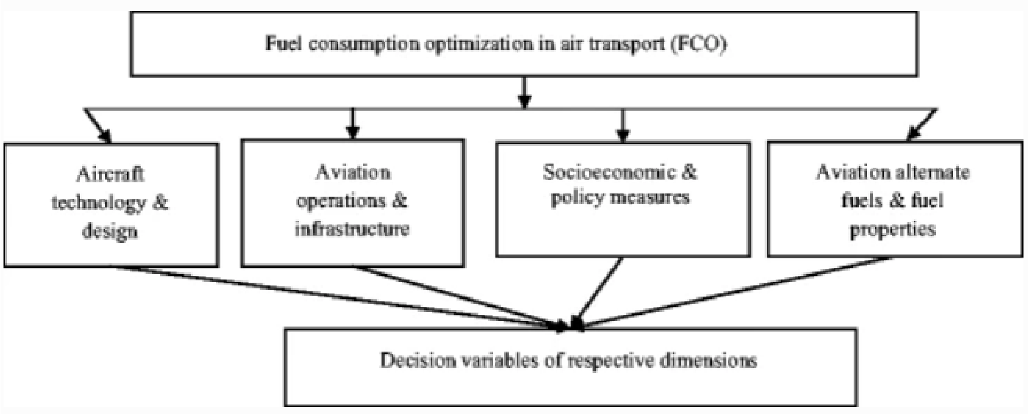

Fig. 1.1. Fuel consumption optimization in air transport

Aircraft technology and design

Today, airlines are operating in an increasingly competitive environment due to the globalization of air congestion, so a prerequisite for the commercial success of airlines is to reduce direct operating costs, which largely depend on the technology and design features of the aircraft used. Technological progress is accelerating, and we can effectively reap the benefits of this technological revolution to reduce fuel consumption by commercial aircraft. In addition, the use of fuel for air transport can be reduced through various options, such as improving the quality of aircraft, improving operations, using alternative fuels, socio-economic measures, improving infrastructure, but most of the benefits have so far been gained to fix.

Aviation operations and infrastructure

The amount of fuel the aircraft uses during its operation from take-off and pre-flight, to flight, proximity and take-off depends on a number of factors. Many factors can affect airlines with proper planning and business strategies. Current methods are not always good in terms of fuel consumption, so improvements need to be made. Operational improvement can be attributed to operational efficiency, which is a combination of ground and air efficiency. In general, the actual performance of an aircraft can be determined by how the aircraft operates with operational constraints in mind, and efficient operation methods are those in which real fuel combustion is at least in theory.

Improvement to AIR Transport Management (ATM) positively influences on flight delays, departure delays and scheduled flights, as well as the efficiency of stopping fuel consumption using cost-effective methods. Moreover, a good terminal design can also reduce fuel consumption. There are several ways in which airports, airlines and ATM providers can improve air traffic control systems to reduce fuel and smoke. These include improving air use, air control and operation, and improving air use and air management, including the use of air flexibility, road improvements, the use of new tools and programs to find the most efficient way and reduce distances. between the planes.

Socioeconomic & policy measures

Air flights are the fastest growing segment of the economy. This offers a number of socio-economic benefits. There are many socio-economic and political factors affecting the company's fuel efficiency. If these issues are controlled carefully, you can save a significant amount of fuel. Public awareness of the impact of aviation emissions on climate change also plays an important role in reducing fuel consumption. In addition, education and awareness are social activities that are very important for air traffic, and there will be many airline customers who never thought air pollution was an environmental problem. Flight impact information should be widely available so that airlines have the basic information they need to understand changing flight conditions. Conscious choice is an important part of transportation needs and the impact of environmental policy. In addition, economic/political measures to reduce fuel consumption include the trade in smoke, aviation fuel taxes and carbon taxes. In addition, there are some restrictions on aviation operations, training, service and booking, planning and routes, schedules, airports and personnel, and these restrictions should be removed to reduce fuel consumption.

Aviation alternative fuels & fuel properties

Alternative aviation fuel can also play an important role in improving aviation fuel consumption. Since the energy crisis of the 1970s, all airlines, aviation departments, engine companies and other government agencies have been working to improve the use of alternative fuels. Efficient alternative fuels can stabilize fuel price fluctuations and reduce dependence on crude oil. Existing alternative fuel replacement does not require aircraft modification and can be used for an existing aviation system consisting of an existing distribution and refueling infrastructure. In addition, the study examined the potential of alternative fuels for aviation: conventional jet fuel from petroleum resources, synthetic jet fuel, biodiesel and biogas, ethanol and butanol, liquefied natural gas and hydrogen. Measurement of technical potential with lighting: high energy density. Special high energy, high flash point, low cooling temperature and vapor pressure, high thermal stability.

In this qualification work the **aircraft technology and design** approach will be used to for the research of the problem for turbofan engine thrust specific fuel consumption reduction with based on the methods illustrated on the Fig. 1.2.

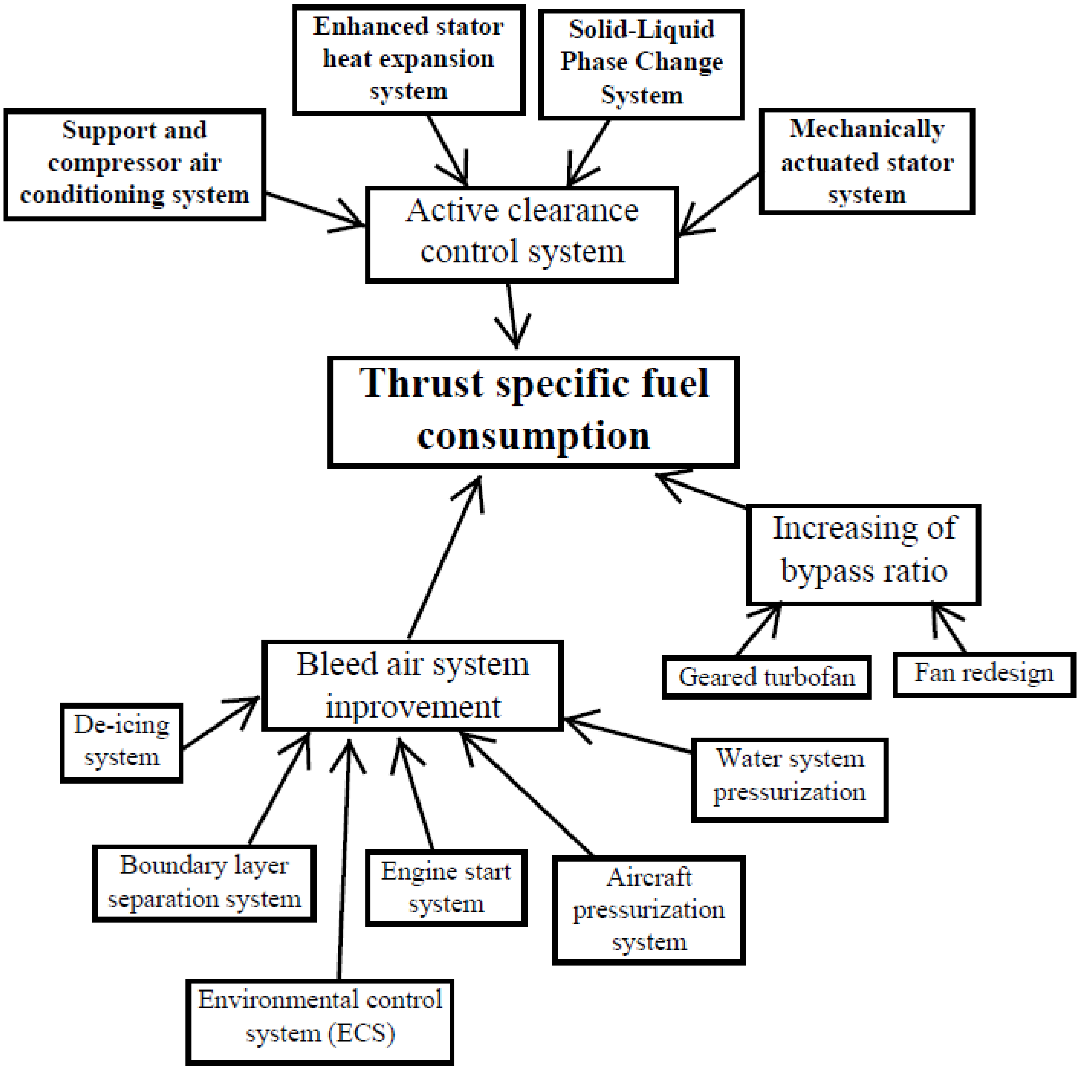

Fig. 1.2. Thrust specific fuel consumption improvement methods

1.1. Active tip clearance control method

Active Clearance Control (ACC) is a technique used in gas turbines to improve fuel efficiency. This is achieved by dynamically controlling the end gap of the turbine.

During normal cruising, the engine is subjected to many stresses such as extreme heat and centrifugal force. This causes certain components to expand and changes the clearance between the turbine housing and the tops of the rotating turbine blades. The amount of air that seeps around the edge of the blades without passing through them is critical to engine performance and fuel economy. For this reason, blade tip sealing has played an important role in aircraft engine design since the late 1960s. The ACC system dynamically adjusts the high pressure turbine (HPT) blade clearance. This can be accomplished in a number of ways [3]. Fig. 1.1.1. provided below is the visualization of the clearance changes between blade tip and engine shroud.

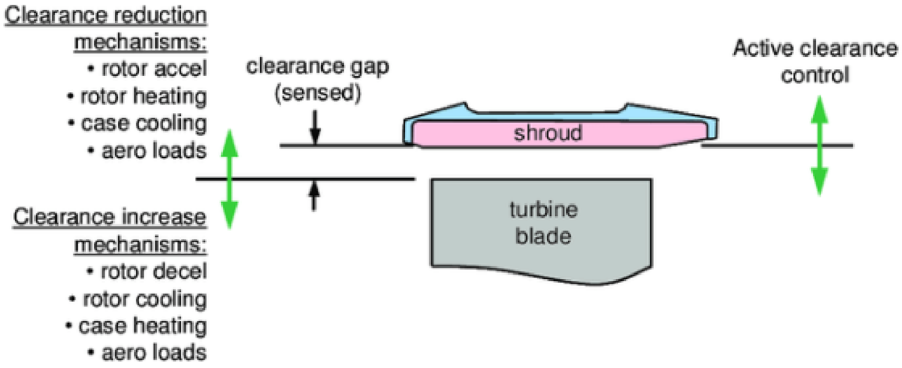

Fig. 1.1.1. Active clearance control visualization

HPT (High Pressure Turbine) blade tip clearance has a significant impact on combustion and emissions. Blade tip sealing has been a challenge since the development of the gas turbine engine. This is due to the fact that the gap between the tops of the blades and the surrounding casing (casing) tends to change, primarily due to changes in thermal and mechanical loads on the rotating (turbine wheel) and stationary (stator, turbine casing) structures. The use of ACC offers significant advantages in terms of fuel consumption, range and payload for long-range aircraft [4]. The active clearance control comprises the several systems. HPT cleaning control systems can be divided into indirect and dynamic, active controlled by hydromechanical control or FADEC (full authority digital engine control). The systems can also be classified as thermal or mechanical.

Support and compressor air conditioning system

The heating system uses the temperature difference between the fan / air compressor and the air flow to control the radiation displacement of the covers. The design of such a system is shown in Figure 1.1.2. As shown, HPT ACC (from fan/compressor) is used to control the deflection of cotton wool radiation. The appearance of such a system is shown in Figure 1.1.3.

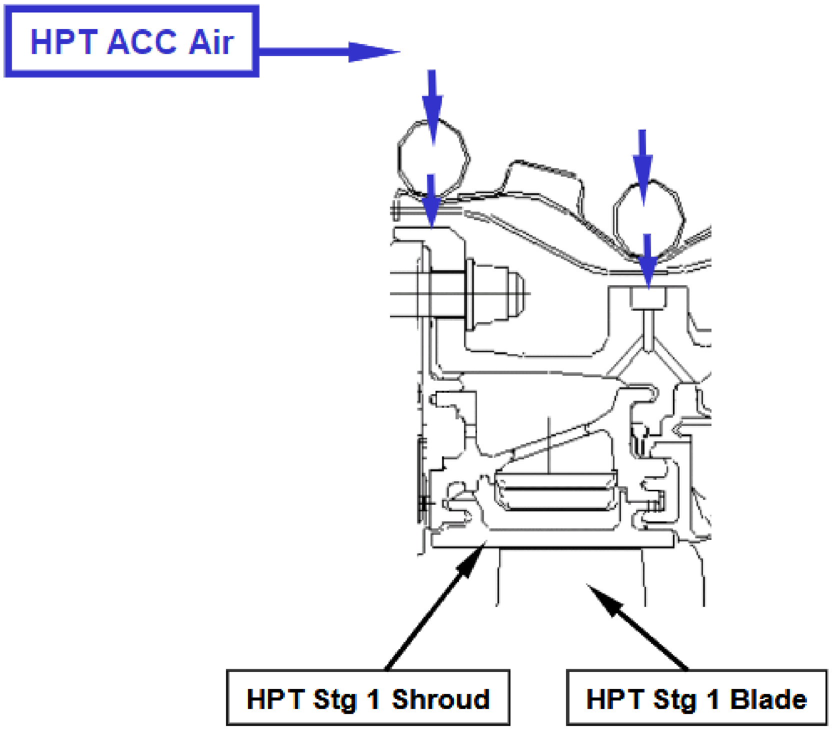

Fig. 1.1.2. Thermal based HPT ACC system schematic

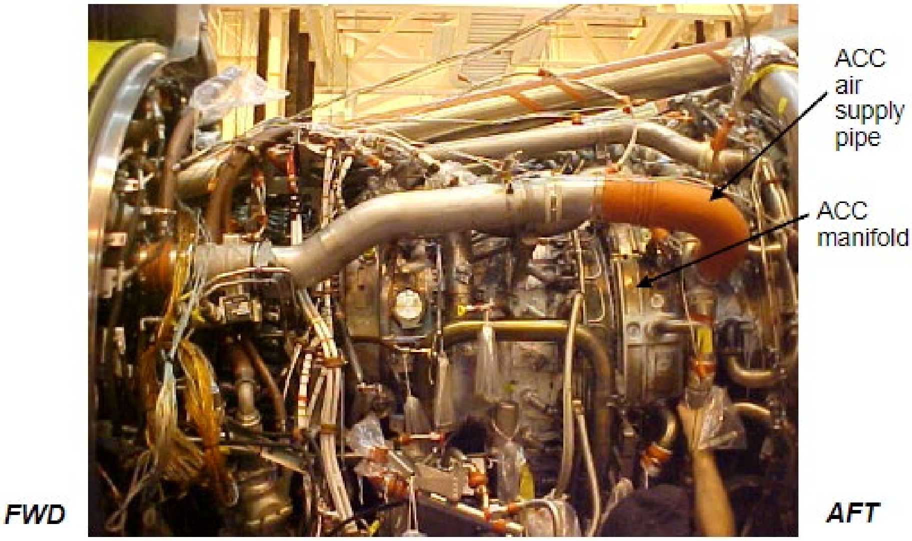

Fig 1.1.3. Thermal based HPT ACC system hardware

Enhanced stator heat expansion system

This system uses modified cover support made of a low α material (heat expansion joint), which reduces the work gap. This system is able to provide additional closure of the damaged engine length.

Solid-Liquid Phase Change System

It is an indirect system with no moving parts. The idea of this system is to use the phase change factor (PCM) material to control the constant time on the stator. Because additional heat is required to melt / cure the PCM, and because the temperature does not change as the phase changes, the stator time increases continuously during both acceleration and deceleration.

The advantages of this system are:

- Provides uniform stator temperature 360°;
- There is no change in any of the existing routes;
- Ability to integrate other systems.

Mechanically actuated stator system

The concept behind this system is to control HPT blade tip clearance by controlling the shroud position by means of mechanical actuators. Together with clearance sensors, this system can:

- Provide on demand clearance control;
- Have a significant clearance closure capability;
- Manage stator ovalization;
- Work equally effectively on both new and deteriorated engines;

- Provide rotor reburst protection.

Conclusion: active clearance control system has significant role in engine fuel efficiency improvement. Controlling the clearance increases the efficiency, reduces flow rate and engine development time. A clearance of tip cleaning varies under different operating conditions (eg start, idle, full power, shut-down) due to different radial forces and different thermal expansion and heat transfer.

1.2. Bleed air system improvement

1.2.1. General description

Bleed air is often extracted from a jet engine's compressor for various applications during aircraft flight. These applications include fuel tank pressurization, environmental control system use, anti-icing systems, aerodynamic blowing, and driving compressors and suction pumps. This extraction of bleed air introduces a performance penalty on the engine. Bleed usually causes thrust to decrease, specific fuel consumption to increase, and engine turbine temperatures to increase. All of these parameters have a strong effect on aircraft performance [5].

In many modern aircraft engines it is crucial to control the flow of air from the compressor. This is called "air production". The air extraction system of aircraft has a variety of purposes, including (but not limited to) cooling fan fans, creating air pressure in the room and bathroom water tanks, and heating various parts of the aircraft to prevent frostbite. However, the use of inflated air reduces the efficiency of the engine. In an effort to increase engine efficiency, Boeing has introduced an electric system without pouring air into its 787 Dreamliner. Boeing claims that this new wireless system has several advantages, including improved fuel consumption, reduced maintenance costs, increased reliability and less weight. This report aims to highlight the differences between the two systems and to discuss material advantages and disadvantages of each.

1.2.2. Bleed air system components improvement

Most turbofan engines have a bleed air system. This design takes advantage of low air temperature (200-250 degrees C). Air can be released from any part of the compressor, and its location depends on a special machine. In some cases, air is released from several compressor stages due to differences in pressure characteristics and gas temperature during the flow of each stage [7]. This air is then delivered to different areas of the aircraft through an interconnected network of tubes, regulators and valves. As mentioned earlier, this high pressure air has a variety of applications, which are described in detail below.

Aircraft pressurization

Perhaps the most important use of bleeding air is to provide pressure to the air components of the aircraft. As the plane increases in flight altitude, the surrounding environment changes dramatically. The atmospheric pressure on the ship drops to about 20% at sea level, thus, it becomes necessary to compensate for the pressure in the cabin and flight deck.

Environmental control system

In addition to providing pressure in many areas of the fuselage, it is also necessary for this compressed medium to be supplied to the passenger compartments to receive portions of fresh air. The pressurized air entering these rooms should be presented at a "comfortable" temperature. Given that this air is taken from the compressor stage when it is hot (200–250 degrees C), an air conditioning system is required [7]. This is usually achieved by passing some of this air through the air conditioning units of the aircraft. This air temperature can be controlled by mixing it with unheated air [7].

A one of approach for environmental control system bleed air improvement will be presented in a “Patent Review Analysis” section.

Turbine cooling

Due to the increase in temperature at the fan inlet in an attempt to increase the thermodynamic efficiency of the motors, cooling of the fan motors became necessary. Most modern motors have temperatures above the bright spot of the fan motors. This fact has led to new ways to cool the shoulders to prevent high tension and shoulder length. Many engines used bloody air supplied through small channels inside the fan coils to cool them. This air usually comes out of the fire near the front edge to create a film of cold air around the fireplace.

This question will be further discussed as separate method for thrust specific fuel consumption improvement.

De-icing system

Warm and high-pressure air can also be provided in areas of the aircraft where ice formation is a concern. Ventilation can be used to heat the engine compartment to prevent ice from forming, separating and entering the engine. Also, this warm air can be used to prevent the growth of snow on the front edges of the wings.

Engine start system

Air pumps are also sometimes used to start one of the aircraft engines. This air is supplied to the starter fan engine, which provides the flow needed to start the engine. This can also be achieved through an electric or water system; however, the start of air fans is often smaller and simpler in one of these systems.

Water system pressurization

In addition to pressurizing the cabin of the aircraft, bleed air is also used to pressurize the plane’s water system. This method provides a robust way of supplying potable water to the lavatories and the galley. Using bleed air for this purpose eliminates the need for a hydraulic pump and therefore eliminates a failure mode as well.

In addition to high air pressure, exhaust air is also used to increase the water system pressure on the aircraft. This method provides a reliable way to provide drinking water to galleys and lavatories. The use of bleed air for this purpose eliminates the need for a hydraulic pump and therefore also eliminates the failure process.

Boundary layer separation

Although not commonly used on commercial aircraft, bleed air can be used to improve the aerodynamic flow characteristics over a wing or into an engine inlet. This system injects the high pressure air just before the leading edge of the wing flap, which delays the boundary layer separation. This can lower the stall speed due to reduced drag, which can decrease the landing speed of the aircraft [8]. It should be noted that this system is more often used in high-performance aircraft.

Conclusion: a bleed air system is one the main factor that negatively affect thrust specific fuel consumption. All the bleed air systems components can be improved in order to minimize the fuel consumption.

1.3. Turbine cooling improvement as a part of bleed air improvement system

The technology of cooling gas turbine components, primarily via internal convective flows of single-phase gases and external surface film cooling with air, has developed over the years into very complex geometries involving many differing surfaces, architectures, and fluid-surface interactions. The fundamental aim of this technology area is to obtain the highest overall cooling effectiveness with the lowest possible penalty on the thermodynamic cycle performance. As a thermodynamic Brayton cycle, the efficiency of the gas turbine engine can be raised substantially by increasing the firing temperature of the turbine. Modern gas turbine systems are fired at temperatures far in excess of the material melting temperature limits. This is made possible by the aggressive cooling of the hot gas path components using a portion of the compressor discharge air, as depicted in Fig. 1.3.1. The use of 15–25% of this compressed air to cool the high-pressure portions of the turbine presents a severe penalty on the thermodynamic efficiency unless the firing temperature is sufficiently high for the gains to outweigh the losses. In all properly operating cooled turbine systems, the efficiency gain is significant enough to justify the added complexity and cost of the cooling technologies employed.

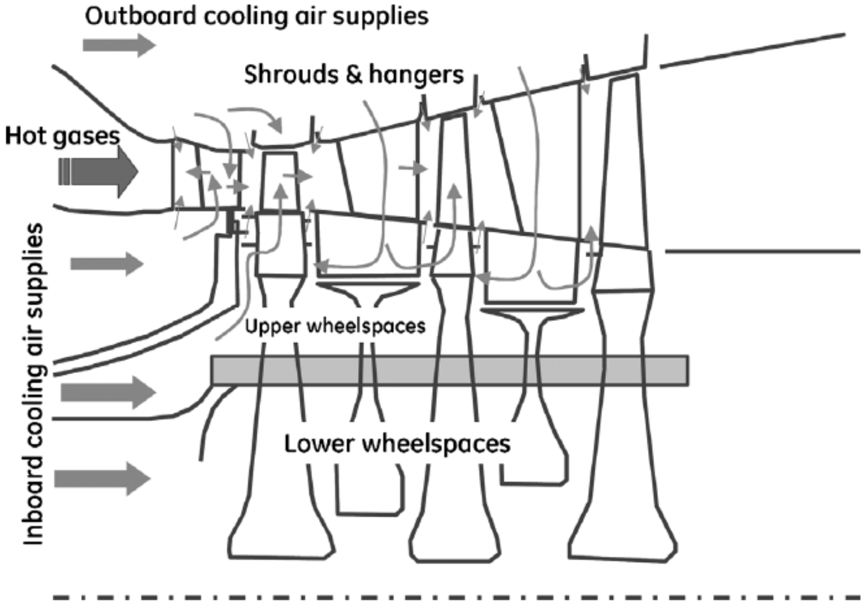

Fig. 1.1.3. Typical scheme of turbine cooling

Actively or passively cooled regions in power generating gas turbines include the stationary vanes or nozzles and the rotating blades or buckets of the high-pressure stages, the shrouds bounding the rotating blades, and the combustor liners and flame holding segments (fuel nozzles, splash plates). All such engines additionally cool the interfaces and secondary flow regions around the immediate hot gas path.

1.3.1. Turbulated channel cooling

One of the most common means for improving heat transfer coefficients between elements in turbine section internal cooling passages, the use of turbulators are used, also known as rib roughеners. Turbulators in the form of trip strips placed transverse to the bulk flow direction were one of the first improvements made to the cooling of blades, and hence many investigations have been made into the heat transfer and friction characteristics. With the advancements in materials and manufacturing technologies of the last decade, a drastically larger realm of surface enhancement techniques has become cost effective for use in the cooling of turbine airfoils. Turbulators may now be of varying shapes, orientations, segmentations, and sizes, essentially providing a continuous spectrum of possible geometries for achieving flow-surface interactions that serve to enhance local and global heat transfer coefficients. The bulk of researchers concentrated on turbulators of relative height e/D <0.2, but greater than that relative roughness typically associated with uniform surface roughness [9].

The general findings of all such research has been that surface averaged heat transfer coefficients within stationary, turbulated passages may be enhanced by factors from 1.8 to 2.8, while the friction factors or required pumping power are increased by factors of 3–10. Many parameters have been investigated in turbulated passages (angle to the bulk flow, P/e, e/D, shaping, taper, etc.), and many more in serpentine circuits, but the range of effects has remained much the same over the years.

1.3.2. Latticework (vortex) cooling

Lattice cooling, also known as vortex cooling or limited vertical cooling of pipes, using high temperature gas turbine components. Cooling cables can easily be described as a radiation cooling channel. The name itself defines the geometry, consisting of the basic structural unit, "network cooling" using coplanar cutting channels. As shown, each upper and lower sections of the global channel or cooling region have a number of low directions directed at a certain angle β relative to the direction of radiation (for example, radial is used, but not limited). The upper and lower walls can be considered as sides of air pressure and suction, e.g [10].

The two channel sections tend to overlap or intersect depending on the cable design. When cooling passes through a mesh conductor n, such as a blade root section, half usually occurs in the upper and lower channels of the channel, with little or no stirring between the lower channel - the upper and lower. The main advantages of this technology include a strong structure for die-casting with ceramic structure, general levels of improvement of thermal connection compared to the turbulent coils, overall with greater strength of blades.

The scheme of vortex cooling inside the turbine blade is provided in the Fig. 1.3.2. below:

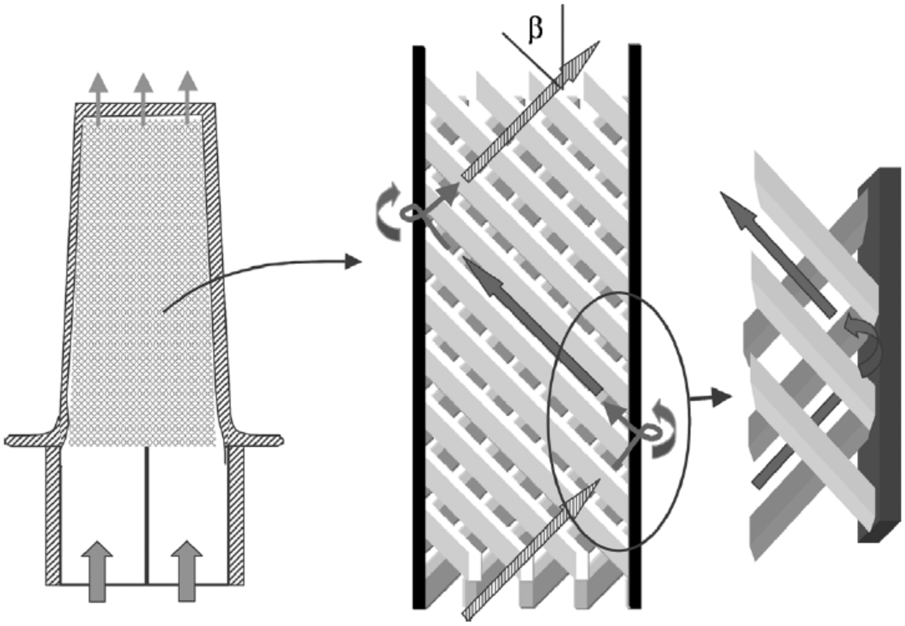

Fig. 1.3.2. Scheme of vortex cooling inside the turbine blade

1.3.3. Concavity surfaces cooling

Another class of surface improvement results from the penetration of elements into the cooling channel or the surface walls, forming cavities rather than projections. Generically, such characteristics are known as concavities (or dimples), and can be formed in an infinite variation of geometries with various resulting heat transfer and friction characteristics. Concavity surfaces are generally known for their drag reduction characteristics in external flows on bodies. The most famous example is golf balls, where they serve to delay the point of separation of the boundary layer, thereby reducing the overall drag of the sphere. In which defined networks of shallow concavities can cover the main hull or fuselage surfaces to prevent formation a thick boundary layer, thereby reducing drag.

A flow with boundary layer thickness less than the concavity surface diameter reacts with the cavity by flowing into the “bowl”, experiencing a separated region of some extent on the entry side as depicted in Fig. 1.3.3. The spherical shape, or one nearly approximating it, creates a pressure field within the bowl acting to collapse or concentrate the flow in the downstream portion of the recess, creating a vortex structure.

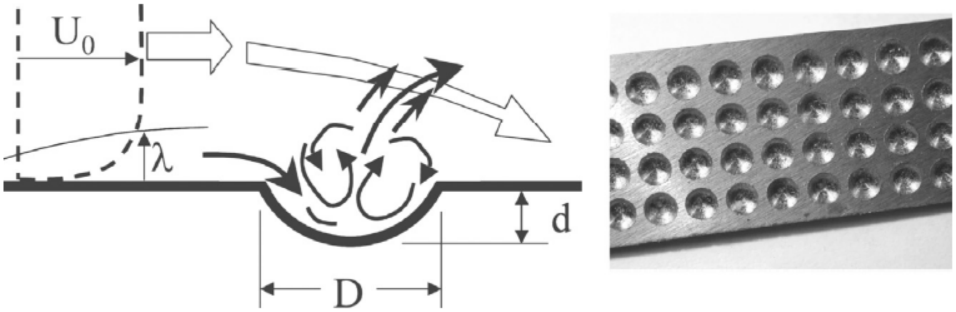

Fig. 1.3.3. The scheme of flow and blade surface used in concavity cooling

1.3.4. Swirl (cyclone) cooling

Another emerging vortex technology is the use of discrete wall jets injected into concave cooling passages, or along sections of concave internal walls, to induce massive vortex movement. This cooling technique is generally known as swirl cooling, as well as cyclone cooling from the original Russian studies. In the clearest sense, concavity surface flows are part of a broader category known as "vortex" technologies, which include various means of forming organized vertical or swirling structures flows into the turbines.

One of these vortices is the lattice cooling presented above. Technologies, using angular turn regions to generate a bulk vortex. Another emerging vortex technology is the use of discrete wall jets injected into cooling passages, or along sections of concave internal walls, to induce a massive vortex movement.

Fig. 1.3.4. illustrates two schemes of vortex cooling chambers implemented inside a blade leading edge, one without film extraction and the other with film extraction. Rather than using direct impact jets directed toward the top of the concave region, the track-shaped wall jets are injected tangentially to the surface at intervals along the height of the blade. The jets provide locally high heat transfer, but also serve to cool the local coolant closest to the surface at each new injection site.

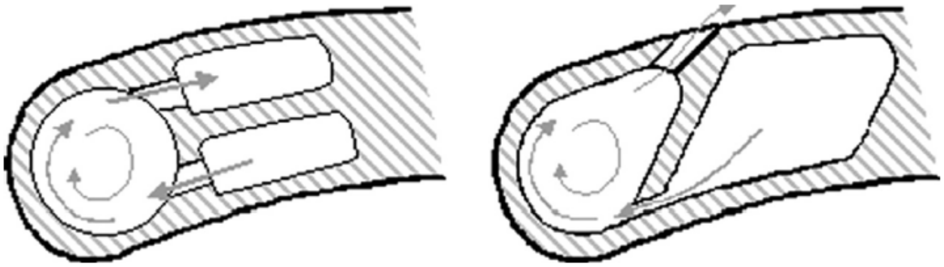

Fig. 1.3.4. Swirl (cyclone) cooling scheme

1.3.5. Film Cooling

Film cooling is one of the main technologies that allows modern gas turbines to achieve extremely high temperatures of radiator fans, high efficiency and longer service life. The art and science of film cooling is applied to the flow of cooling air through the inner part through the outer walls to form a protective layer of cooling between the hot gas and the outer surface. The use of effective film cooling methods provides the first and best line of protection on the surface of hot gas strong thermal attacks of fluxes, which directly reduce the risk of surface overheating [11].

Over the past 30+ years, investigations have been performed by a broad spectrum of researchers to understand the fundamental physics of film cooling, and to improve the state-of-the-art. The primary focus of most research has been on the use of discrete film holes, or rows of film holes, on the hot gas path surfaces of the turbine, since mechanical constraints dictate this format. Fig. 1.3.4.a. and 1.3.4.b. shows, for example, a guide for a normal high-pressure fan hole with several rows of cooling distance and orientation. One fundamental breakthrough in this technology has been made over the years. The only improvement was the change in the shape of the round holes for the film to the holes for the film. In addition,

The use of the word "shape", given the large number of geometries, is in fact again limited to one general geometric class.

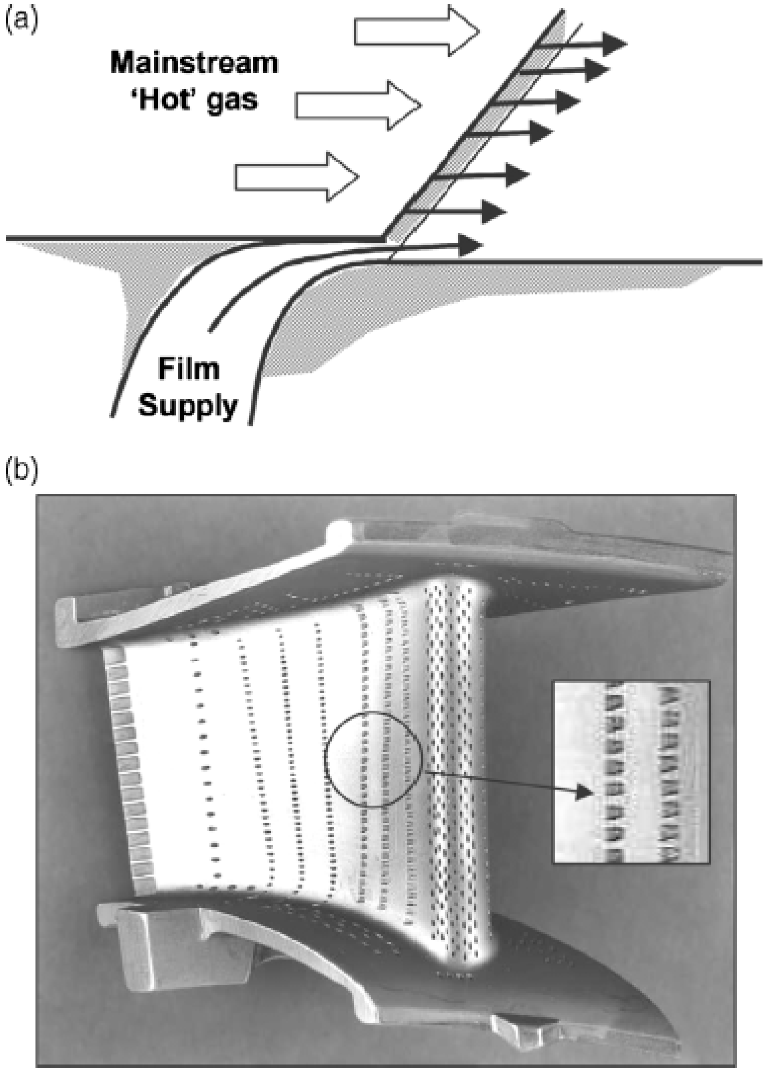

Fig. 1.3.5. (a) Scheme of film cooling, (b) HPT inlet guide vane with holes for film cooling

Conclusion: an analysis of turbine cooling the innovative cooling methods have been performed, application of which to decrease the bleed air volume and thus increase the thrust specific fuel consumption of the engine. Many other variations and combinations of these methods are expected when product development becomes a reality. Further improvements and new approaches may be possible to develop tools, system integrations and management tools.

The reduction of compressor bleed air G_{cool} will be taken as a base for the calculation of influence of the relative amount of intake air G_{cool} on specific fuel consumption of the engine SFC in the associated section of the qualification work.

1.4. Increasing of turbofan engine bypass ratio

1.4.1. Geared turbofan scheme

In a conventional turbofan engine, the shaft of the low pressure spool connects the fan, the low pressure compressor (LPC) and the low pressure turbine (LPT) while the second shaft connects the high pressure compressor (HPC) and high pressure turbine (HPT). For this layout, the maximum tip speed for the larger radius fan limits the rotational speed for the LP shaft and thus the LP compressor and turbine. At high bypass ratios the tip velocities of the LP turbine and LP compressor must be relatively low, which means extra compressor and turbine stages are required to keep the average stage loadings and, thus, overall component efficiencies to an acceptable level.

In a geared turbofan, a planetary reduction gearbox between the fan and the LP shaft permits the latter to run at a higher rotational speed thus enabling fewer stages to be used in both the LP turbine and the LP compressor, improving efficiency and reducing weight. However, some energy will be lost as heat in the gear mechanism and weight saved on turbine and compressor stages is partly offset by that of the gearbox. There are manufacturing cost and reliability complexions as well.

The lower fan speed allows higher bypass ratios, leading to reduced fuel consumption and much reduced noise. In conventional turbofans the fan tips exceed the speed of sound causing a characteristic drone, requiring sound deadening. Geared turbofans operate the fan at sufficiently low rotational speed to avoid supersonic tip speeds.

A typical scheme of the turbofan engine with the reduction gearbox is provided below on Fig. 1.4 1.

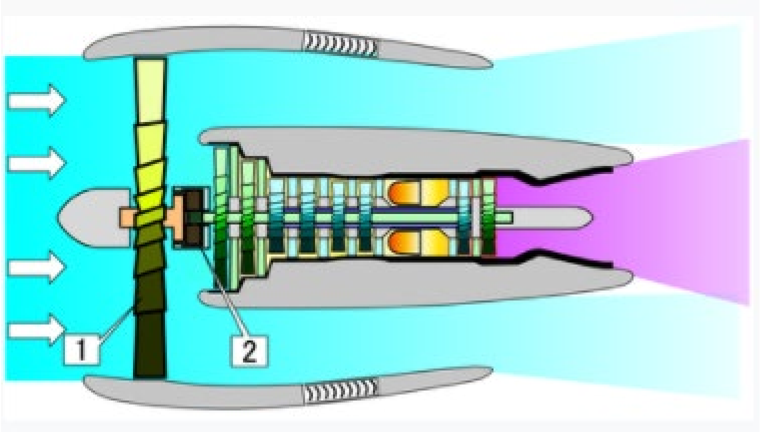

Fig. 1.4.1. Typical design of the geared turbofan (1-fan, 2-gearbox)

An application of reduction gearbox allows installation of modern fans made of composite material with improved characteristics, thus they are able to produce more thrust at less rotational speed that the engine used as object at this qualification work.

1.4.2. Improved design of the fan

The engine of a modern jet aircraft has a very high and very fast fan, the top of which is actually a hose, while the inside is a small compressor that puts pressure on the air entering the combustion chamber in the engine compartment. Most of the air entering the engine compartment will pass through the outside of the fan, completely beyond the core of the engine. This air will flow out of the engine compartment, along with the high-speed jet coming from the engine core. The overall effect is to create the overall flow required for medium velocity above a large area of intersections, not just high jet speeds. This improves the fuel efficiency of the normal speed of the aircraft and significantly reduces noise levels [13].

Turbofan machines of the current generation can have a median weight of up to 100 tons, which is equivalent to the weight of a diesel engine hanging from each blade. The GEnx fan will be larger, with a diameter of 111 inches, so you can achieve a higher throughput of 9.5: 1, which will increase the engine efficiency and reduce fuel combustion. During the trip, it will run at a speed of 2500 rpm. The centrifugal force increases with radius, velocity and density. Radius and speed are determined by considering air flow, but all designers can do to reduce the weight of the blade by reducing the load - so for some GE engines, the transition from the standard titanium blank to combination. According to Melvin Hurd, GEnx marketing manager, this will reduce the weight by 10-15%. On the Fig. 1.4.2. a GEnx series engine is presented as example of latest progress in fan design.

Fig. 1.4.2. GEnx generation engine

Expectations

GE expects to prove the original design of the GENx-1B64 engine B787 in late 2007, and is ready for service by mid-2008. GE's Mel Heard says the engine will be more efficient, burning 15.4%. fuel at lower flow speeds than the current generation CF6. The latest version of the new engine, GEnx-2B67, has been selected for the latest version of the Boeing 747 jumbo, the cargo ship B747-8, which will be operational within a year. Airbus can also use GEnx for its planned response of the 787, A350. The integrated equipment is the key to helping the engine achieve the goals set by the glider to reduce customer ownership costs by 20%, reduce fuel consumption and maintenance while increasing durability.

Conclusion: an engine redesign approach to achieve the highest bypass ratio is a crucial factor to reduce the thrust specific fuel consumption. However, for datum engine of the qualification work it is very complex to redesign the engine, and therefore cannot be used for the further thermodynamic and gas-dynamic calculations.

Conclusion to the Section 1

As provided above there are a lot of methods for the thrust specific fuel consumption reduction. Among discussed the main three methods are distinguished. They are active clearance control, bleed air system reduction, and increasing of the engine bypass ratio. All these methods significantly increase the overall engine performance. After reviewing and comparing all these methods the only active clearance control system improvement and bleed air system improvement can be carried out.

2. PATENT RESEARCH

The fuel consumption value is a one of crucial factor both for engine manufacturer and operator and it is known that this value should be the as less as possible. Every year a new researches and advanced technological technics are carried out and implementing in order to improve the fuel economy of engines.

A research of patents has been carried out devoted for improvement of thrust specific fuel efficiency. Some examples of the research that is included in the qualification work are provided below. The provided examples describe the latest developments of the last 10 years. The innovative methods provided in this patent research will be used in further calculations to show improvement in thrust specific fuel efficiency.

2.1. Active tip clearance control

Patent 1: Active clearance control for gas turbine engine

Patent number: US 2014661975161 P

Country: European Union

Application number: 151161187.8

Inventors: Gabriel Suciu, Jesse M. Chandler, Nathan Snape.

Date of publication: 07 October 2015

Assignee: United Technologies Corporation, Hartford, CT 06101 (US)

Abstract

The patent is related to the improving of turbine and compressor active clearance control for turbofan engines

Description of invention

The invention describes the improvement of active clearance control between blade tips and compressor or turbine casing. It is crucial to maintain as smaller gap between them as possible in order to provide maximum efficiency of airflow passing through the engine, minimize undesirable loss of air, and to maximize the engine fuel economy.

The distance between the compressor or the fan and the circuit around it are kept as low as possible to force as much air as possible into the gas channel through the coil to increase the efficiency of the engine. Tip clearance is most required in cruise conditions, but this can create “pinch” spots as the difference in heat expansion between the ducts and the surrounding canal causes the blades to stick to the duct walls.

Historically, the tip clearance has been calculated to avoid pinching points, but is not ideal for hot (normal) conditions of use. A well-known solution is the so-called "active clearance control", where cooling air is used to reduce the size of the air duct in hot conditions to reduce the independence of normal operating conditions.

Cooling air is turned off, for example at start-up and at other stages of flight, so that the airway size is sufficiently widened to prevent compression. Many modifications of active clearance control systems are known. Typically, fan support housing that supports the standing fan shield and/or the standing fan shield itself is cooled. One of the main problems with the active clearance operating system is how bleed the cooling air and how to supply the air to the compressor and turbine blades.

An active clearance control air cooling supply system is provided below as follows (Fig. 2.1.):

- a firewall (76);
- a fluid intake (70);
- an active clearance control manifold (62a, 62b);
- a conduit (74) configured to direct a fluid from
- the fluid intake (70) on a first axial side of the
- firewall through the firewall (76) to the active
- clearance control manifold (62a, 62b) on a second axial side of the firewall (76); and
- a valve (80) located on the first axial side of the
- firewall configured to regulate the flow of the fluid through the conduit (74)

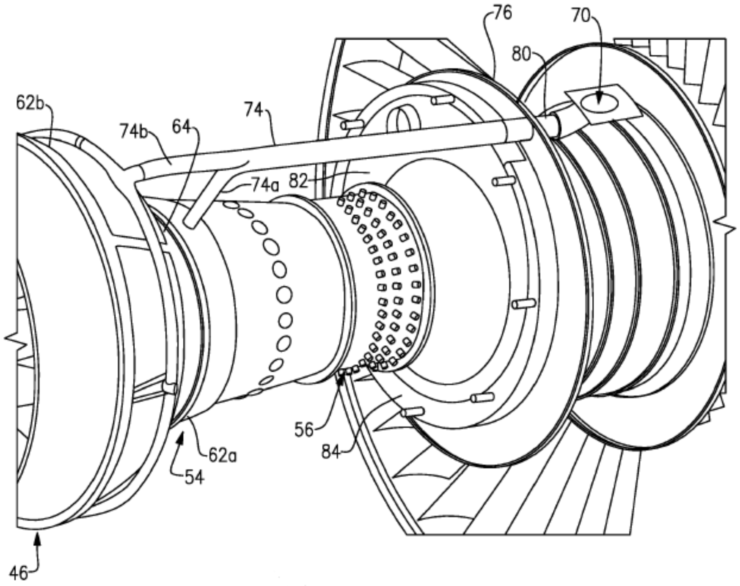

Fig 2.1. Active clearance control assembly

Conclusion of invention

An active clearance control system for maintaining the proper clearance between the blade tips and duct casing is one of the most influencing means to maximize the fuel economy of the turbofan and other types of jet engine. This approach is widely used on the newest models of turbofan engines, thus allowing to reach the most desirable thrust specific fuel consumption and satisfy the strict requirements of emissions.

2.2. Cooled cooling air system for a gas turbine engine

Patent 2: Cooled cooling air system for a gas turbine

Patent number: US 9,422,063

Country: United states

Inventor: Carlos Enrique Diaz.

Application number: 13/907,187

Publication of patent: 23 August 2016

Assignee: General Electric Company, Niskayuna, NY (US).

Abstract

In an aircraft including a gas turbine engine having a compressor including a compressor booster, a turbine, and a nacelle, a system for cooling compressor discharge air provided to the turbine to cool the turbine includes a heat exchanger provided in a nacelle compartment of the gas turbine engine configured to cool the compressor discharge air by exchanging heat from the compressor discharge air to a cooling fluid; and a cooling fluid circuit configured to circulate cooling fluid through the heat exchanger and a heat sink, wherein the heat sink is at least one of an inlet of the nacelle compartment, an inlet of the compressor booster, or outlet guide vanes of the gas turbine engine.

Description of patent

Referring to Fig. 2.3.1., a cooling system for a gas turbine engine assembly 10 according to one example of the present technology may include a heat exchanger, for example an evaporator, 2 configured to cool the compressor bleed air 12 with a cooling fluid 28. The cooling fluid 28 is put through a Rankine cycle during take-off and climb, and optionally during de-icing, and is routed through the gas turbine engine assembly 10 as shown schematically on the figure below.

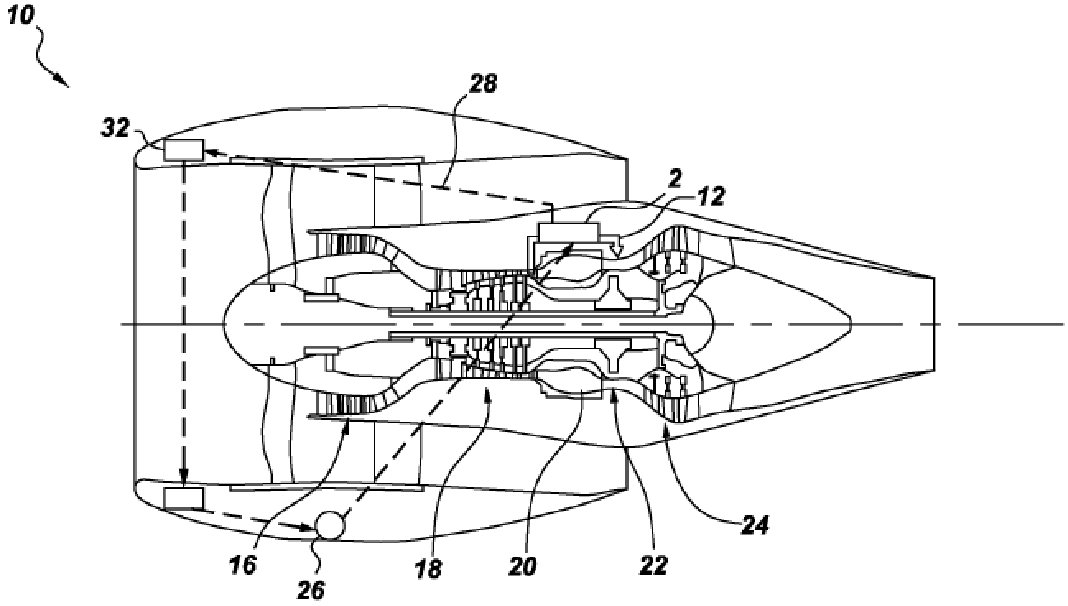

Fig. 2.2.1. Cross-sectional illustration of an of a cooling system example 1

The cooling fluid 28 is cooled at the nacelle air inlet 32, and is delivered back to the heat exchanger 2 by a pump 26 to cool the compressor bleed air 12.

The cooling fluid 28 may be a liquid that changes phases during the Rankine cycle. In that case, the nacelle air inlet 32 acts as a condenser, and the cooling fluid 28, in its gaseous phase prior to condensation, may be used as a de-icing system in the engine nacelle. Although the cooling fluid 28 may be a liquid that changes phases, it should also be appreciated that a cooling fluid that does not undergo a phase change may be used, for example water with glycol or ammonia. Furthermore, it should be appreciated that the cooling fluid 28 may be pumped through the heat exchanger 2 at a flow rate sufficient to prevent the cooling fluid 28 from changing phase as it is heated by the compressor bleed air 12.

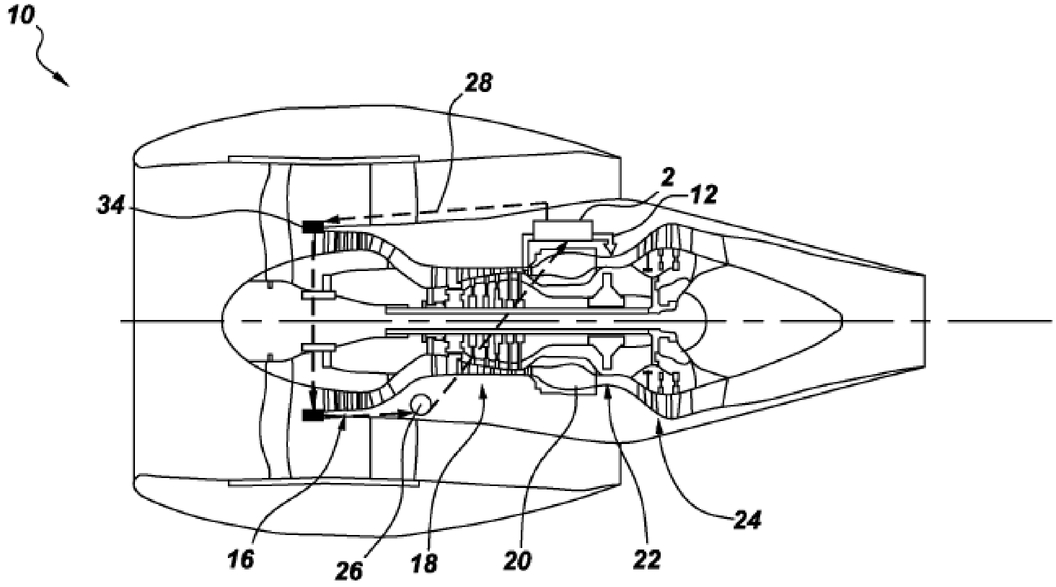

Fig 2.2.2. Cross-sectional illustration of an of a cooling system example 2

Referring to Fig. 2.2.2., a cooling system according to another example of the present technology utilizes the booster compressor air inlet 34 of the low pressure, or booster, compressor 16 as a condenser. The cooling fluid 28 is put through a Rankine cycle and is provided by a pump 26 to a heat exchanger, or evaporator, 2 that cools the compressor bleed air 12.

The cooled cooling air systems described herein may be used as, for example, nacelle and/or booster anti-icing system(s). This allows the aircraft to be operated without a traditional anti-icing system(s), while not adding any extra drag to the propulsion system, and providing weight savings.

As the heat is dumped to a cold sink with no additional heat exchanger, the fan air does not require any heat exchanger and there is no additional drag in the propulsion system.

Furthermore, as the cooled cooling air systems described herein use an intermediate fluid, rather than air, to transport heat from the compressor bleed pipes to the cold sink, the size of the heat exchanger may be reduced which permits the heat exchanger to be packaged in the nacelle core compartment. As fuel is not used as a heat sink, the fuel can still be used to cool oil in the FCOC and there is no need for a deoxygenator in the fuel system.

The use of the outlet guide vanes, the nacelle internal fixed structure (IFS), the nacelle aft core cowl (ACC), the thrust reverser outer fixed structure (OFS), the nacelle external cowl as a condenser provides heat to the fan duct air which provides extra thrust with no additional aerodynamic drag.

The secondary air system may also be designed for cruise conditions, i.e. it does not have to be overdesigned, and the cost and weight of the cooling pipes may be reduced. The air mass flow rate in the secondary air system used for turbine cooling may also be reduced, which improves the efficiency of the thermodynamic cycle and the propulsion efficiency.

Conclusion of invention

The cooled cooling air systems described herein reduce the amount of air flow used by bleed air system air system used for turbine cooling during cruise conditions and therefore provide a decrease in specific fuel consumption of the aircraft. This method is really interesting, however there are no any confirmation regarding the value of improved thrust specific fuel efficiency and therefore will not be used during engine designing in further calculations.

2.3. Environment Control System Improvement

Patent 3: Aircraft environmental control system that optimizes the proportion of the outside air from engines, APU’s, ground air sources and the recirculated cabin air to maintain occupant comfort and maximize fuel economy

Patent number: US 2016/0214723 A1

Country: United States

Inventors: Richard B. Fox, San Tan Valley, Bijan F. Hagh, Mike Koerner, Stephen Yates, Peter M. Michalakos, Russel W. Johnson.

Application number: 14/606,315

Publication of patent: 28 July 2016

Assignee: HONEYWELL INTERNATIONAL INC., Morristown, NJ (US).

Abstract: The environmental control system comprises sensors, an air purification subsystem and a controller that communicates these sensors and the air purification subsystem. Sensors detect contamination in the outside air supplied through the engine vents and APU or other air sources, including ground-based power supplies and electric compressors, ambient air pollutants, ambient air particles, ambient carbon dioxide, and ambient temperature in one neighborhood. These recorded parameters are compared with the threshold values. Changes in ambient air and/or recirculated air are made on the basis of comparisons.

Description of invention

A group if inventors suggested an approach to decrease the engine bleed air amount taken from the engine by means of determination of the air contamination status and more precisely regulate the amount of bleed air in order to maintain the acceptable proportion of clean air to be used in Environmental Control System.

A method of controlling the level of comfort of residents in the environment, including:

* Detection of outdoor air pollutants in ambient air entering the environment through engine vents or APUs or other air sources, including ground-based power sources and electric compressors;

* Comparison of detected outdoor air pollutants with the threshold of outdoor air pollution;

* Detection of pollutants in the circulating air entering the environment;

* Comparison of detected return air pollutants with the threshold of return air pollution;

* Detection of carbon dioxide in the ambient air leaving the environment,

* Compare the detected carbon dioxide with the threshold value of carbon dioxide;

* Detection of ambient mixed air temperature, mixed air, including outside air, and recirculated air supplied from the engine or APU, or from other air sources, including ground air and electric compressors;

* Compare the obtained temperature with the temperature threshold;

* Detection of mixed air pressure in the environment;

* Comparison of perceptible pressure with the pressure threshold;

* Change in the amount of outside air released into the environment through the vents of the engine or APU or other air sources, including ground air sources and electric compressors;

* Change in the amount of recirculated air entering the environment; and changing the temperature of the mixed air entering the environment.

Let's take a look to the Environmental Control System scheme provided below:

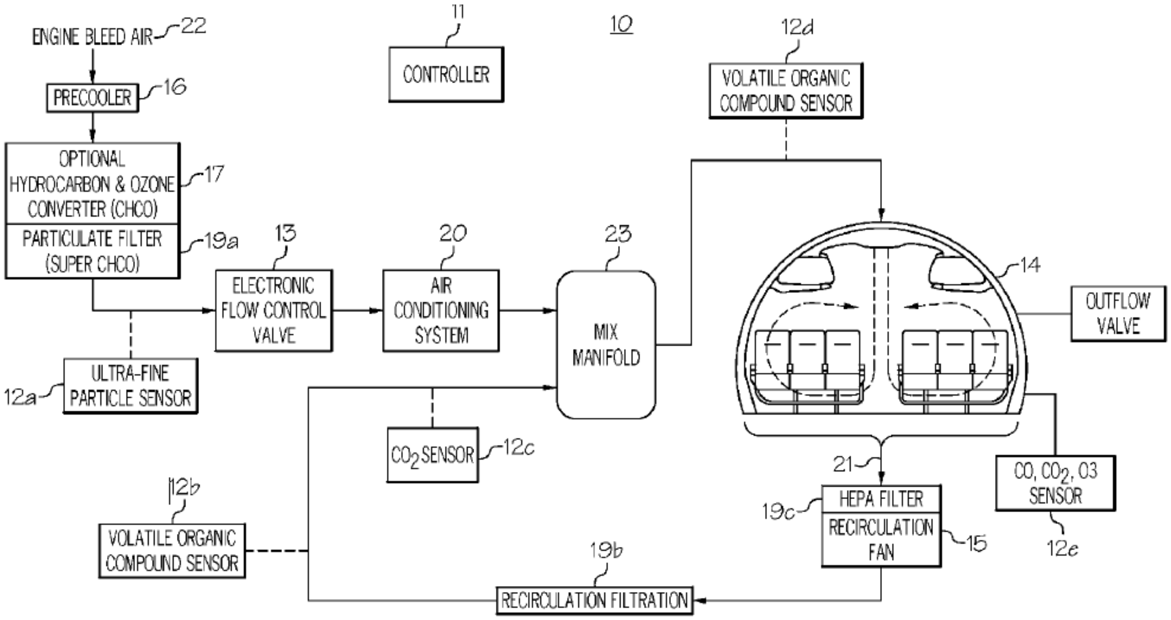

Fig. 2.3.1.a. Block diagram of an environmental control system according to an exemplary embodiment

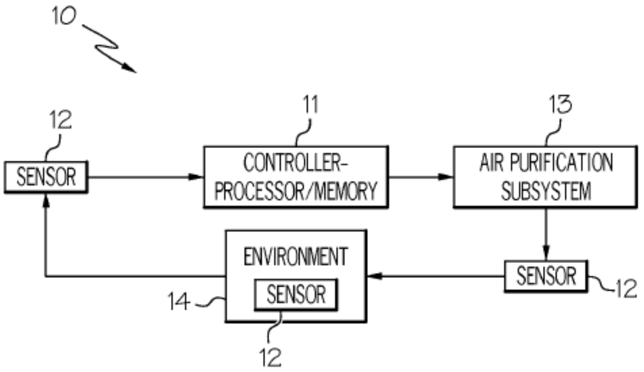

Fig. 2.3.1.b. Block diagram of an environmental control system according to an exemplary embodiment

Fig. 2.3.1. is a block diagram of an ECS 10 according to an exemplary embodiment of present invention. The ECS 10 may include a controller 11, such as a computer having a processor and a memory, in continuous or intermittent communication with an air purification Subsystem 13 and one or more sensors 12. The sensors 12 may be positioned in various points throughout the ECS to sense contaminants in, and/or air characteristics of the outside air Supplied through engine or APU bleeds or other air sources including ground Supplies and electric compressors, and/or recirculating air in the ECS and/or, in particular, an environment 14, Such an aircraft cabin. The contaminants in the ECS may include, for example, VOCs, SVOCs, ultrafine particles (UFPs), carbon monoxide, carbon dioxide, and ozone.

The controller 11 may include a processor and memory capable of storing instructions to be executed by the processor to implement a method of removing contaminants from and / or changing the properties of air in a space occupied by a person, such as an aircraft cabin according to the present invention. The controller 11 can receive contamination signals from the sensor(s) 12, which can detect contamination, for example, from the internal filter, the filter to the mixing manifold 23, the ECS unit to the mixing manifold 23 and the mixing manifold 23 to the mixing manifold 23. cabin. The controller 11 may also receive contamination signals from the sensor (s) 12, which may detect contamination in the exhaust air 22, for example, coming from one or more motors and/or APU. The controller 11 can also receive characteristic signals from the sensors 12, which can detect the properties of air, for example, from the cabin.

The controller 11 may control one or more components and / or subsystems of the ECS 10. The ECS 10 may include a pneumatic air precooler 17 that cools the outside or exhaust air 22 supplied from engine taps or APUs or other air sources, including ground power and electrical compressors entering the ECS 10. The outside air 22 supplied from the engine or APU, or from other air sources, including ground-based power sources and electric compressors, may contain contaminants that in certain concentrations may be undesirable for the occupants of the environment 14.

The hydrocarbon and ozone converter 18 can receive air from the pre-cooler 17 and convert hydrocarbons and ozone in the air into compounds which are considered to be harmless to humans.

An exemplary embodiment of the aircraft, Fig 2.3.2. is a block diagram of how a controller, such as controller 11, can monitor sensors and monitor the operational changes of ECS components such as pollution and / or particles and / or changes in air properties in the ECS. The in Fig. 2.3.2.a can be changed by changing / changing one or more of the performance / parameters of the ECS components described above (e.g. collector ratio, flow rate, ventilation rate, etc.). Accordingly, the combination of performance/parameters of ECS components is not an easy design decision.

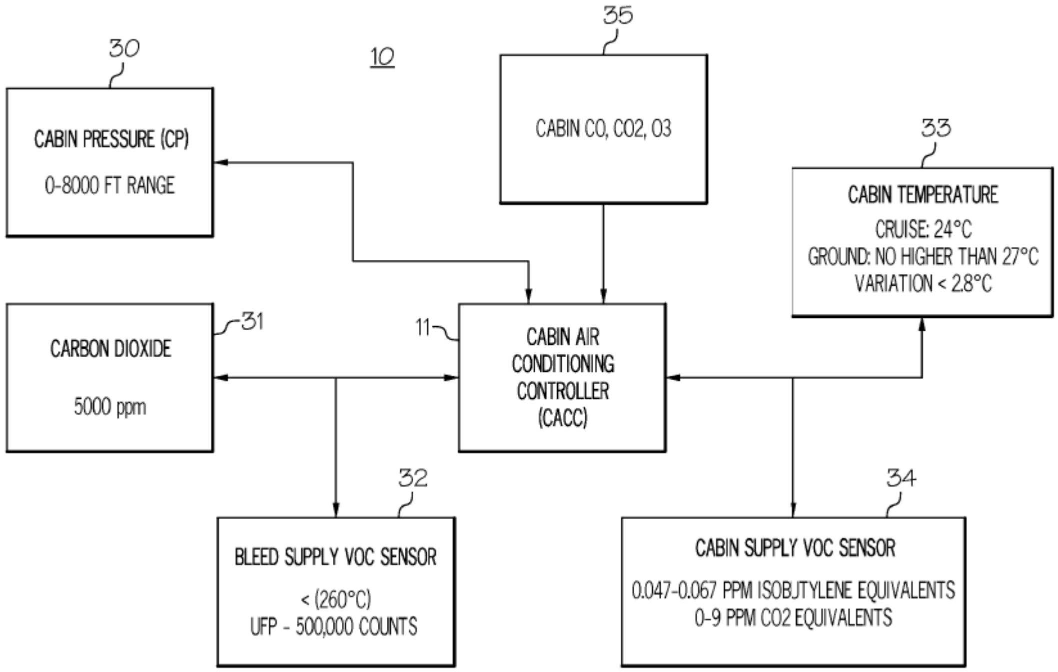

Fig. 2.3.2.a. Flow diagram of a method for controlling pollutants in an environmental control system

Conclusion of invention

The provided approach allows to control the bleed air feed into the environmental control system more precisely, reduces the amount of used air going into the atmosphere. According to the invention, the aircraft fuel consumption can be decreased up 1.5%.

Conclusion of the Section 2

Fuel economy is important for two obvious reasons. First, given the high price of oil, airlines can save significant amounts of money by using less fuel by improving fuel efficiency. Second, when the aircraft uses less fuel, it emits less CO2.

The trend towards fuel efficiency is an almost continuous and gradual improvement; modern aircraft use 70% less fuel at one point than early aircraft. About 40% of the improvements were due to improved engine efficiency. Historically, these improvements averaged 1-2% per year in new production aircraft.

The given patent research has shown the perspective approaches to that is implemented and be improved in the near future to increase the overall fuel economy in aviation.

As result the method of active clearance control will be used during the engine designing to show the improved thrust specific fuel efficiency.

3.1. Thermodynamic calculations of the engine

3.1.1. Initial data

Engine thrust $P := 137293.1$ (N)

Bypass ratio $m := 4.6$

Total pressure ratio $\pi^*_c := 29.5$

Fan pressure ratio $\pi^*_f := 1.61$

Turbine inlet temperature $T^*_{ti} := 1575$ (K)

Atmospheric constants and flight conditions

$H := 0$ $T_{am} := 288$ (K) $R := 287$ $k := 1.41$

$V := 0$ $P_{am} := 101300$ (Pa) $R_g := 288$ $k_g := 1.33$

3.1.2. Determination of air parameters in front of engine

Air temperature and pressure at *H=0*

$$T^*_{am} := T_{am} + \frac{k-1}{k} \cdot \frac{V^2}{2R} = 288 + \frac{1.41-1}{1.41} \cdot \frac{0^2}{2 \cdot 287} = 288.0 \text{ (K)}$$

$$P^*_{am} := P_{am} \cdot \left(\frac{T^*_{am}}{T_{am}}\right)^{\frac{k}{k-1}} = 101300 \cdot \left(\frac{288.0}{288}\right)^{\frac{1.41}{1.41-1}} = 101300.0 = 101300 \text{ (Pa)}$$

$$T^*_{fi} := T^*_{am} = 288 \text{ (K)}$$

Total pressure recovery coefficient $\sigma_i := 0.98$

$$P^*_{fi} := P^*_{am} \cdot \sigma_i = 101300 \cdot 0.98 = 99273.0 = 99273 \text{ (Pa)}$$

3.1.3. Determination of air parameters behind the fan in the secondary flow

Fan efficiency $\eta^*_{fanII} = 0.86$

The work of air compression

$$L_{fanII} := \frac{k}{k-1} \cdot R \cdot T^*_{fi} \cdot \left[\left(\pi^*_f\right)^{\frac{k-1}{k}} - 1\right] \cdot \frac{1}{\eta^*_{fanII}} = 49092.0 \text{ (J/kg)}$$

Temperature and pressure

$$T^*_{fdII} = T^*_{fi} + \frac{k-1}{k} \cdot \frac{L_{fanII}}{R} = 288 + \frac{1.41-1}{1.41} \cdot \frac{49092.0}{287} = 337.7 = 337.7 \text{ (K)}$$

$$P^*_{fdII} := P^*_{fi} \cdot \pi^*_{f} = 99273 \cdot 1.61 = 159829.0 = 159829 \text{ (Pa)}$$

3.1.4. Determination of air parameters at the exit from the secondary flow jet nozzle

Assume that $T^*_{jnII} = T^*_{fdII} = 337.7$ (K)

Total pressure recovery coefficient in the secondary flow $\sigma_{sf} = 0.995$

$$P^*_{jnII} := P^*_{fdII} \cdot \sigma_{sf} = 159829 \cdot 0.995 = 159029.0 = 159029 \text{ (Pa)}$$

Pressure ratio of secondary flow jet nozzle

$$\pi^*_{jnII} := \frac{P^*_{jnII}}{P_{am}} = 1.57$$

Critical jet nozzle pressure ratio

$$\pi_{cr} := \left(\frac{k+1}{2}\right)^{\frac{k}{k-1}} = 1.899$$

Velocity coefficient of the secondary flow jet nozzle $\varphi_{jnII} := 0.98$:

$$C_{jnII} := \varphi_{jnII} \cdot \sqrt{2 \cdot \frac{k}{k-1} \cdot R \cdot T^*_{jnII} \cdot \left[1 - \left(\frac{P_{am}}{P^*_{jnII}}\right)^{\frac{k-1}{k}}\right]} = 280.51296316639785853 \text{ (m/s)}$$

Temperature and pressure of secondary flow at the engine outlet

$$T_{jnII} := T^*_{jnII} - \frac{k-1}{k} \cdot \frac{C_{jnII}^{2}}{2 \cdot R} = 337.7 - \frac{1.41-1}{1.41} \cdot \frac{280.51296316639785853^{2}}{2 \cdot 287} = 297.8 = 297.8 \text{ (K)}$$

$$P_{jnII} := P_{am} = 101300 \text{ (Pa)}$$

3.1.5. Determination of air parameters behind the compressor

Compressor stage efficiency $\eta^*_{st} := 0.88$

Compressor efficiency

$$\eta^*_c := \frac{\pi^{*\,\frac{k-1}{k}}_c - 1}{\pi^{*\,\frac{k-1}{k\cdot\eta^*_{st}}}_c - 1} = \frac{29.5^{\frac{1.41-1}{1.41}} - 1}{29.5^{\frac{1.41-1}{1.41\cdot 0.88}} - 1} = 0.8134 = 0.813$$

The work of air compression in the compressor

$$L_c := \frac{k}{k-1} \cdot R \cdot T^*_{fi} \cdot \left(\pi^{*\,\frac{k-1}{k}}_c - 1\right) \cdot \frac{1}{\eta^*_c} = 585509.69971938647143 = 585509.0 = 585509 \text{ (J/kg)}$$

Temperature and pressure at the compressor outlet

$$T^*_{cd} := T^*_{fi} + \frac{k-1}{k} \cdot \frac{L_c}{R} = 288 + \frac{1.41-1}{1.41} \cdot \frac{585509}{287} = 881.2 = 881.2 \text{ (K)}$$

$$P^*_{cd} := P^*_{fi} \cdot \pi^*_c = 99273 \cdot 29.5 = 2.929e6 = 2929000 \text{ (Pa)}$$

3.1.6. Determination of parameters behind the combustion chamber

Total pressure recovery coefficient in the combustion chamber $\sigma_{cc} = 0.98$

Total air pressure before turbine

$$P^*_{ti} := P^*_{cd} \cdot \sigma_{cc} = 2929000 \cdot 0.98 = 2.87e6 = 2870000 \text{ (Pa)}$$

Average specific heat of gas in the combustion chamber

$$C_p = 848 + 0.208 \cdot (T^*_{ti} + 0.48 \cdot 0.208 \cdot T^*_{cd}) = 848 + 0.208 \cdot (1575 + 0.48 \cdot 0.208 \cdot 881.2) =$$

$$= 1194 \text{ (J/kg} \cdot \text{K}^{-2})$$

Combustion efficiency $\eta_{cc} =: 0.99$ and net calorific value of fuel $H_u := 43 \cdot 10^6$

$$g_f := \frac{C_p \cdot \left(T^*_{ti} - T^*_{cd}\right)}{\eta_{cc} \cdot H_u} = \frac{1194 \cdot (1575 - 881.2)}{0.99 \cdot 43 \cdot 10^6} = 0.01946 = 0.019$$

Average air-fuel ratio in the combustion chamber $l_0 = 14.85$

$$\alpha := \frac{1}{g_f \cdot l_0} = \frac{1}{0.01946 \cdot 14.85} = 3.46 = 3.46$$

3.1.7. Determination of gas parameters behind the turbine

Relative quantity of compressor-bleed air for the cooling turbine parts $g_{cool} =: 0.08$

Effective work of all stages of the turbine:

$$\eta_m := 0.99$$

$$L_t := \frac{m \cdot L_{fanII} + L_c}{\left(1 + g_f\right) \cdot \left(1 - g_{cool}\right) \cdot \eta_m} = \frac{4.6 \cdot 49092.0 + 585509}{(1 + 0.01946) \cdot (1 - 0.08) \cdot 0.99} = 873786.0 = 873786 \text{ (J/kg)}$$

Assume that turbine efficiency is $\eta^*_t =: 0.9$ and determine the tempreratura and pressure

$$T^*_{td} := T^*_{ti} - \frac{k_g - 1}{k_g} \cdot \frac{L_t}{R_g} = 1575 - \frac{1.33 - 1}{1.33} \cdot \frac{873786}{288} = 822.2 = 822.2 \text{ (K)}$$

$$P^*_{td} := P^*_{ti} \cdot \left(1 - \frac{T^*_{ti} - T^*_{td}}{T^*_{ti} \cdot \eta^*_t}\right)^{\frac{k_g}{k_g - 1}} = 2870000 \cdot \left(1 - \frac{1575 - 822.2}{1575 \cdot 0.9}\right)^{\frac{1.33}{1.33-1}} = 135620.0 = 135620 \text{ (Pa)}$$

Turbine pressure ratio

$$\pi_t := \left[\frac{1}{1 - \frac{1}{\eta^*_t}\left(1 - \frac{T^*_{td}}{T^*_{ti}}\right)}\right]^{\frac{k_g}{k_g - 1}} = 21.162$$

3.1.8. Determination of the gas parameters at the exit from the primary flow jet nozzle

Jet nozzle pressure ratio

$$\pi_{jnI} := \frac{P^*_{td}}{P_{am}} = \frac{135620}{101300} = 1.339 = 1.339$$

$$\pi_{jncr} := \left(\frac{k_g + 1}{2}\right)^{\frac{k_g}{k_g - 1}} = \left(\frac{1.33 + 1}{2}\right)^{\frac{1.33}{1.33-1}} = 1.851 = 1.851$$

Since $\pi_{jnI} < \pi_{jncr}$ then full expansion takes place in jet nozzle of the engine primary flow

$$\varphi_{jnI} := 0.985$$

$$C_{jnI} := \varphi_{jnI} \cdot \sqrt{2 \cdot \frac{k_g}{k_g - 1} \cdot R_g \cdot T^*_{td} \cdot \left[1 - \left(\frac{P_{am}}{P^*_{td}}\right)^{\frac{k_g-1}{k_g}}\right]} = 360\ \text{(m/s)}$$

Gas temperature at jet nozzle outlet

$$T_{jnI} := T^*_{td} - \frac{k_g - 1}{k_g} \cdot \frac{C_{jnI}^2}{2 \cdot R_g} = 822.2 - \frac{1.33 - 1}{1.33} \cdot \frac{359.6^2}{2 \cdot 288} = 766.5 = 766.5\ \text{(K)}$$

$$P_{jnI} = P_{am} = 101300\ \text{(Pa)}$$

3.1.9. Determination of the main specific parameters and mass air flow rate of TFE

Specific thrust

$$P_{spI} := C_{jnI} \cdot \left(1 + g_f\right) = 359.6 \cdot (1 + 0.01946) = 366.6 = 366.6\ \text{(N·s/kg)}$$

Specific thrust of the secondary flow

$$P_{spII} := C_{jnII} = 280.513\ \text{(N·s/kg)}$$

Total engine specific thrust

$$P_{sp} := \frac{P_{spI} + m \cdot P_{spII}}{1 + m} = \frac{366.6 + 4.6 \cdot 280.51296316639787}{1 + 4.6} = 295.9 = 295.9\ \text{(N·s/kg)}$$

Mass air flow rate

$$G_a := \frac{P}{P_{sp}} = \frac{137293.1}{295.9} = 464.0 = 464\ \text{(kg/s)}$$

Mass of core engine air passing through engine

$$G_{aI} := \frac{G_a}{1 + m} = 82.857142857142857143\ \mathit{float}\ ,4 = 82.86 = 82.86\ \text{(kg/s)}$$

Mass of fan air passing through engine

$$G_{aII} := \frac{m}{1+m} \cdot G_a \; explicit, ALL \;\; = \frac{4.6}{1+4.6} \cdot 464 \, float \; ,4 \;\; = 381.1 = 381.1 \text{ (kg/s)}$$

Internal engine efficiency

$$\eta_{in} := \frac{P_{spI}^{\;2} + m \cdot P_{spII}^{\;2}}{2 \cdot g_f \cdot H_u \cdot \left(1 - g_{cool}\right)} \; explicit, ALL \;\; = \frac{366.6^2 + 4.6 \cdot 280.51296316639787^2}{2 \cdot 0.01946 \cdot 43 \cdot 10^6 \cdot (1 - 0.08)} float \; ,4 \;\; = 0.3224$$

Thrust specific fuel consumption

$$C_{sp} := \frac{3600 \cdot g_f \cdot \left(1 - g_{cool}\right)}{P_{sp} \cdot (1+m)} = \frac{3600 \cdot 0.01946 \cdot (1 - 0.08)}{295.9 \cdot (1 + 4.6)} = 0.0389 = 0.039 \text{ (kg/N}\cdot\text{h}^{-1}\text{)}$$

Fuel consumtion per one hour

$$G_f := C_{sp} \cdot P = 5340.702 \text{ (kg/h)}$$

Total engine thust

$$P_{\Sigma} := G_a \cdot P_{sp} = 137297.6 \text{ (N)}$$

3.2. Gas-dynamic calculations of the engine

3.2.1. Determinaton of the cross section dimensions at the fan inlet

Assuming axial air speed at the fan inlet C1a and fan tip speed u1ft as follows:

$$C_{1a} := 220 \text{ (m/s)} \qquad u_{1ft} := 450 \text{ (m/s)}$$

Reduced velocity

$$\lambda_{1a} := \frac{C_{1a}}{\sqrt{2 \cdot \frac{k \cdot R \cdot T_{am}}{k+1}}} = 0.707$$

Relative density of flow

$$q_{.\lambda 1a} := \left(\frac{k+1}{2}\right)^{\frac{1}{k-1}} \cdot \lambda_{1a} \cdot \left(1 - \frac{k-1}{k+1} \cdot \lambda_{1a}{}^{2}\right)^{\frac{1}{k-1}} = 0.89732175887287487807 = 0.8973 = 0.897$$

Fan inlet area assuming tha $m_a := 0.0404$

$$F_{fi} := \frac{G_a \cdot \sqrt{T_{am}}}{m_a \cdot P_{am} \cdot q_{.\lambda 1a}} = \frac{464 \cdot \sqrt{288}}{0.0404 \cdot 101300 \cdot 0.8973} = 2.144 \text{ (m}^2\text{)}$$

Appriximate value of first-stage sleve relative diameter $d_1 := 0.35$ (m)

External diameter of the fan at the inlet in the first stage

$$D_{1ft} := \sqrt{\frac{4 \cdot F_{fi}}{\pi \cdot \left(1 - d_1{}^{2}\right)}} = \sqrt{\frac{4 \cdot 2.144}{\pi \cdot \left(1 - 0.35^{2}\right)}} = 1.764 = 1.764 \text{ (m)}$$

$$D_{1sl} := \sqrt{D_{1ft}{}^{2} - \frac{4 \cdot F_{fi}}{\pi}} = \sqrt{1.764^{2} - \frac{4 \cdot 2.144}{\pi}} = 0.618 = 0.618 \text{ (m)}$$

Mass of fan air passing through secondary flow jet nozzle

$$G_{aII} := G_a - \frac{G_a}{1+m} = 381.143 \text{ (kg/s)}$$

Imaginary cylinder dividing primary and secondary airflows

$$D_I := \sqrt{D_{1ft}{}^{2} - \frac{4}{\pi} \cdot \frac{G_{aII}}{G_a} \cdot F_{fi}} = \sqrt{1.764^{2} - \frac{4}{\pi} \cdot \frac{381.14285714285711}{464} \cdot 2.144} = 0.9324 = 0.932 \text{ (m)}$$

3.2.2. Determination of turbofan engines fan's stages number

Circumferntial velocity on diameter D1 and sleeve

$$u_1 := u_{1ft} \cdot \frac{D_I}{D_{1ft}} = 237.857 \text{ (m/s)}$$

$$u_{sl} := u_{1ft} \cdot \frac{D_{1sl}}{D_{1ft}} = 157.653 \text{ (m/s)}$$

Air twisting in rotor blades on D1 and near the sleeve:

Lattice density near the sleve $b_{sl} := 2.2$

$$b_{t1} := \frac{b_{sl} \cdot D_{1sl}}{D_I} = 1.458$$

$$\Delta W_{uI} := C_{1a} \cdot \frac{1.55}{1 + 1.55 \cdot \dfrac{1}{b_{t1}}} = 220 \cdot \frac{1.55}{1 + 1.55 \cdot \dfrac{1}{1.4581724581724582}} = 165.3 = 165.3 \text{ (m/s)}$$

$$\Delta W_{u.sl} := C_{1a} \cdot \frac{1.55}{1 + 1.55 \cdot \dfrac{1}{b_{sl}}} = 220 \cdot \frac{1.55}{1 + 1.55 \cdot \dfrac{1}{2.2}} = 200.1 = 200.1 \text{ (m/s)}$$

The work on diameter D1 and near the sleeve

$$L_1 := u_1 \cdot \Delta W_{uI} = 237.85714285714286 \cdot 165.3 = 39317.0 = 39317 \text{ (J/kg)}$$

$$L_{u.sl} := u_{sl} \cdot \Delta W_{u.sl} = 157.65306122448979 \cdot 200.1 = 31546.0 = 31546 \text{ (J/kg)}$$

$$D_{1sl} = 0.618 \text{ (m)} \qquad D_{1ft} = 1.764 \text{ (m)}$$

$$D_I = 0.932 \text{ (m)} \qquad u_{1ft} = 450 \text{ (m/s)}$$

Assuming single stage fan

$$L_{fanI} := \frac{1}{2}\left(L_1 + L_{u.sl}\right) = \frac{1}{2} \cdot (39317 + 31546) = 35431.0 = 35431 \text{ (J/kg)}$$

3.2.3. Distribution of work between compressor's spools and determination of the HPT stages

Distribution of compression work is made on condition of maximum loading of each stage

HPC compression work

$$L_{hpc} := L_c - L_{fanI} = 585509 - 35431 = 550078.0 = 550078 \text{ (J/kg)}$$

$$L_{hpt} := \frac{L_{hpc}}{\left(1 + g_f\right) \cdot \left(1 - g_{cool}\right) \cdot \eta_m} = \frac{550078}{(1 + 0.01946) \cdot (1 - 0.08) \cdot 0.99} = 592421.0 = 592421 \text{ (J/kg)}$$

Assuming that loading coefficient of HPT $Y^* =:0.55$, number of stages $z =:2, \eta^*_{hpt} =:0.89$)

$$u_{tmd} := Y^* \cdot \sqrt{\frac{2 \cdot L_{hpt}}{z \cdot \eta^*_{hpt}}} = 0.55 \cdot \sqrt{\frac{2 \cdot 592421}{2 \cdot 0.89}} = 448.7 = 448.7 \text{ (m/s)}$$

Accepting $z_{hpt} := 2$

Assumung engine with single stage fan and double-staged HPT

Work of HPT

$$L_{HPT} := L_{hpt} \qquad L_{HPT} = 592421 \text{ (J/kg)}$$

Determination of HPC work

$$L_{HPC} := 0.86 \cdot L_{HPT} \cdot \left(1 + g_f\right) \cdot \left(1 - g_{cool}\right) \cdot \eta_m = 473066.406 \text{ (J/kg)}$$

Work performed by fan additional stages (assuming 3 add stages)

$$L_{ad} := L_c - L_{fanI} - L_{HPC} = 77011.594 \text{ (J/kg)}$$

3.2.4. Determination of the air parameters and diametric dimensions at the fan exit

Assuming $\eta^*_{\text{lpc}} = \eta^*_{\text{fanII}} = 0.86$

$$\pi^*_{fanI} := \left(1 + \frac{L_{fanI} \cdot \eta^*_{lpc}}{\frac{k}{k-1} \cdot R \cdot T^*_{fi}}\right)^{\frac{k}{k-1}} = \left(1 + \frac{35431 \cdot 0.86}{\frac{1.41}{1.41 - 1} \cdot 287 \cdot 288}\right)^{\frac{1.41}{1.41-1}} = 1.419 = 1.419$$

Total air temperature

$$L_{LPC} := L_{fanI} = 35431 \text{ (J/kg)}$$

$$T^*_{lpcd} := T^*_{fi} + \frac{k-1}{k} \cdot \frac{L_{LPC}}{R} = 288 + \frac{1.41-1}{1.41} \cdot \frac{35431}{287} = 323.9 = 323.9 \text{ (K)}$$

Pressure ratio of air in low-pressure compressor (in a fan primary flow)

$$\pi^*_{lpc} := \left(1 + \frac{L_{LPC} \cdot \eta^*_{lpc}}{\frac{k}{k-1} \cdot R \cdot T^*_{fi}}\right)^{\frac{k}{k-1}} = 1.419$$

Total air pressure

$$P^*_{lpcd} := P^*_{fi} \cdot \pi^*_{lpc} = 99273 \cdot 1.4193419689698086 = 140902.0 = 140902 \text{ (Pa)}$$

The value of fan outlet axial air speed of primary and secondary flows

$$C_{fanI} := C_{1a} - 10 = 210 \text{ (m/s)}$$

$$C_{fanII} := C_{1a} - 10 = 210 \text{ (m/s)}$$

Reduced velocity of flows

$$\lambda_{afanI} := \frac{C_{fanI}}{18.3\sqrt{T^*_{lpcd}}} = \frac{210}{18.3 \cdot \sqrt{323.9}} = 0.6376 = 0.638$$

$$\lambda_{afanII} := \frac{C_{fanII}}{18.3\sqrt{T^*_{fdII}}} = \frac{210}{18.3 \cdot \sqrt{337.7}} = 0.6245 = 0.625$$

Relative densities of flows

$$q_{\lambda afanI} := \left(\frac{k+1}{2}\right)^{\frac{1}{k-1}} \cdot \lambda_{afanI} \cdot \left(1 - \frac{k-1}{k+1} \cdot \lambda_{afanI}^{\,2}\right)^{\frac{1}{k-1}} = 0.84364865364447035354 = 0.8436 = 0.844$$

$$q_{\lambda afanII} := \left(\frac{k+1}{2}\right)^{\frac{1}{k-1}} \cdot \lambda_{afanII} \cdot \left(1 - \frac{k-1}{k+1} \cdot \lambda_{afanII}^{\,2}\right)^{\frac{1}{k-1}} = 0.83241849558245781257 = 0.8324 = 0.832$$

Fan area at the fan exit

$$F_{fanI} := \frac{\left(G_a - G_{aII}\right) \cdot \sqrt{T^*_{lpcd}}}{m_a \cdot P^*_{lpcd} \cdot q_{\lambda afanI}} = \frac{(464 - 381.14285714285711) \cdot \sqrt{323.9}}{0.0404 \cdot 140902 \cdot 0.8436} = 0.3105 = 0.311\ (\mathrm{m}^2)$$

$$F_{fanII} := \frac{G_{aII} \cdot \sqrt{T^*_{fdII}}}{m_a \cdot P^*_{fdII} \cdot q_{\lambda afanII}} = \frac{381.14285714285711 \cdot \sqrt{337.7}}{0.0404 \cdot 159829 \cdot 0.8324} = 1.303 = 1.303\ (\mathrm{m}^2)$$

Accepting external diameter behind the fan being 8% less, than the fan inlet external diameter

$$D_{fanII} := (0.92) \cdot D_{1ft} = 0.92 \cdot 1.764 = 1.623 = 1.623\ (\mathrm{m})$$

Diameter of imaginary cylinder dividing primary and secondary airflows

$$D_{II} := \sqrt{D_{fanII}^2 - \frac{4}{\pi} \cdot F_{fanII}} = \sqrt{1.623^2 - \frac{4}{\pi} \cdot 1.303} = 0.9875 = 0.988\ (\mathrm{m})$$

Accepting the fan has add stages, therefore the width of a separating partition D_p is:

$$D_p := 0.01\ (\mathrm{m})$$

$$D_{fanI} := D_{II} - 4 \cdot D_p = 0.9875 - 4 \cdot 0.01 = 0.9475 = 0.947\ (\mathrm{m})$$

Fan sleve diameter

$$D_{sl.LPC} := \sqrt{D_{fanI}^2 - \frac{4}{\pi} \cdot F_{fanI}} = \sqrt{0.9475^2 - \frac{4}{\pi} \cdot 0.3105} = 0.7088 = 0.709\ (\mathrm{m})$$

3.2.5. Determination of diametric sizes at the entry to the HPC

σ_{icc} is total pressure recovery coefficient in the intermediate compressor casing

$$\sigma_{icc} := 0.995$$

$$T^*_{hpcd} := T^*_{lpcd} = 323.9\ (\mathrm{K})$$

$$P^*_{hpcd} = P^*_{lpcd} \cdot \sigma_{icc} = 140902 \cdot 0.995 = 140197.0\ (\mathrm{Pa})$$

Velocity of airflow at the HPC inlet

$$C_{a.HPC} := C_{fanI} + 5 = 215 \ \text{(m/s)}$$

Reduced velocity

$$\lambda_{a.HPC} := \frac{C_{a.HPC}}{18.3\sqrt{T^*_{hpcd}}} = \frac{215}{18.3 \cdot \sqrt{323.9}} = 0.6528 = 0.653$$

Relative density of flow

$$q_{\lambda.a.HPC} := \left(\frac{k+1}{2}\right)^{\frac{1}{k-1}} \cdot \lambda_{a.HPC} \cdot \left(1 - \frac{k-1}{k+1} \cdot \lambda_{a.HPC}{}^{2}\right)^{\frac{1}{k-1}} = 0.856$$

HPC inlet area

$$F_{a.HPC} := \frac{\left(G_a - G_{aII}\right) \cdot \sqrt{T^*_{lpcd}}}{m_a \cdot P^*_{hpcd} \cdot q_{\lambda.a.HPC}} = \frac{(464 - 381.14285714285711) \cdot \sqrt{323.9}}{0.0404 \cdot 140197.0 \cdot 0.8562} = 0.3075 = 0.308 \ \left(\text{m}^2\right)$$

Relative diameter of the first stage HPC sleeve

$$d_{sl} := 0.5$$

Circumferential diameter of the first axial compressor stage rotor

$$D_{1.HPC} := \sqrt{\frac{4 \cdot F_{a.HPC}}{\pi\left(1 - d_{sl}{}^{2}\right)}} = \sqrt{\frac{4 \cdot 0.3075}{\pi \cdot \left(1 - 0.5^{2}\right)}} = 0.7225 = 0.723 \ \text{(m)}$$

Diameter near the sleeve

$$D_{1.HPC.sl} := \sqrt{D_{1.HPC}{}^{2} - \frac{4}{\pi} \cdot F_{a.HPC}} = \sqrt{0.7225^{2} - \frac{4}{\pi} \cdot 0.3075} = 0.3612 = 0.361 \ \text{(m)}$$

Height of blades at the HPC inlet

$$h_{hpc.bl.st.1} := \frac{D_{1.HPC} - D_{1.HPC.sl}}{2} = \frac{0.7225 - 0.3612}{2} = 0.1806 = 0.181 \ \text{(m)}$$

3.2.6. Determination of air parameters and diametric sizes at the HPC exit

Air temperature at the HPC exit

$$T^*_{cd} := T^*_{hpcd} + \frac{k-1}{k} \cdot \frac{L_{HPC}}{R} = 323.9 + \frac{1.41-1}{1.41} \cdot \frac{473066.40587242611}{287} = 803.2 = 803.2 \text{ (K)}$$

HPC pressure ratio

$$\pi^*_{hpc} := \frac{P^*_{cd}}{P^*_{hpcd}} = \frac{2929000}{140197.0} = 20.89 = 20.89$$

Velocity of airflow at the HPC exit

$$C_{a.cd} := 120 \text{ (m/s)}$$

Reduced velocity and relative density of airflow

$$\lambda_{a.cd} := \frac{C_{a.cd}}{18.3\sqrt{T^*_{cd}}} = \frac{120}{18.3 \cdot \sqrt{803.2}} = 0.2314 = 0.231$$

$$q_{\lambda.cd} := \left(\frac{k+1}{2}\right)^{\frac{1}{k-1}} \cdot \lambda_{a.cd} \cdot \left(1 - \frac{k-1}{k+1} \cdot \lambda_{a.cd}^{\,2}\right)^{\frac{1}{k-1}} = 0.357$$

Area on the HPC exit

$$F_{cd} := \frac{\left(G_a - G_{aII}\right) \cdot \sqrt{T^*_{cd}}}{m_a \cdot P^*_{cd} \cdot q_{\lambda.cd}} = \frac{(464 - 381.14285714285711) \cdot \sqrt{803.2}}{0.0404 \cdot 2929000 \cdot 0.3566} = 0.05565 = 0.056 \text{ (m}^2\text{)}$$

Sleeve diameter of the HPC last stage

$$D_c := 0.95 \cdot D_{1.HPC} = 0.686 \text{ (m)}$$

$$D_{c.sl} := \sqrt{D_c^{\,2} - \frac{4}{\pi} \cdot F_{cd}} = \sqrt{0.686375^2 - \frac{4}{\pi} \cdot 0.05565} = 0.6327 = 0.633 \text{ (m)}$$

Height of blades at the HPC exit

$$h_{hpc.bl.st.2} := \frac{D_c - D_{c.sl}}{2} = \frac{0.686375 - 0.6327}{2} = 0.02684 = 0.027 \text{ (m)}$$

Relative sleeve diameter

$$d_{hpc.sl} := \frac{D_{c.sl}}{D_c} = 0.922$$

3.2.7. Determination of diametrical sizes at the HPT inlet

$\alpha_1 = 18$ is the angle of a stream output from ND

$$L_{st1} = L_{HPT} \cdot 0.53 = 313983.13 \text{ (J/kg)}$$

$$C_1 := \frac{L_{st1}}{u_{tmd} \cdot 0.951} = \frac{313983.13}{448.7 \cdot 0.951} = 735.8 = 735.8 \text{ (m/s)}$$

$$\lambda_1 := \frac{C_1}{18.3\sqrt{T^*_{ti}}} = \frac{735.8}{18.3 \cdot \sqrt{1575}} = 1.013 = 1.013$$

$$q_{\lambda 1.nd} := \left(\frac{k_g + 1}{2}\right)^{\frac{1}{k_g - 1}} \cdot \lambda_1 \cdot \left(1 - \frac{k_g - 1}{k_g + 1} \cdot \lambda_1^2\right)^{\frac{1}{k_g - 1}} = 0.99980341432827522192 = 0.9998$$

Mass flow rate through the first stages ND

$\sigma_{nd} = 0.98$ is total pressure recovery coefficient in the ND

$$m_g = 0.0396 \text{ (kg·K/J)}$$

$$G_g = (G_a - G_{all}) \cdot (1 + g_f) \cdot (1 - g_{cool}) = (464 - 381.14) \cdot (1 + 0.01946) \cdot (1 - 0.08) = 77.71 \text{ (kg/s)}$$

$$P^*_{hpt.inl} := P^*_{cd} \cdot \sigma_{cc} \cdot \sigma_{nd} = 2929000 \cdot 0.98 \cdot 0.98 = 2.813e6 = 2813000 \text{ (Pa)}$$

Area of the turbine air-gas channel at the exit from ND

$$F_{1nd} := \frac{G_g \cdot \sqrt{T^*_{ti}}}{m_g \cdot P^*_{hpt.inl} \cdot q_{\lambda 1.nd} \cdot 0.309} = \frac{77.71 \cdot \sqrt{1575}}{0.0396 \cdot 2813000 \cdot 0.9998 \cdot 0.309} = 0.08961 = 0.09 \text{ (m}^2\text{)}$$

Middle turbine diameter at the ND exit

$$D_{t.md} := 1.1 \cdot D_c = 1.1 \cdot 0.686375 = 0.755 = 0.755 \text{ (m)}$$

Height of ND blade (on target edge)

$$h_1 := \frac{F_{1nd}}{\pi \cdot D_{t.md}} = \frac{0.08961}{\pi \cdot 0.755} = 0.03778 = 0.038\,(\mathrm{m})$$

Height of turbine wheel blade

$$D_t := D_{t.md} + h_1 = 0.755 + 0.03778 = 0.7928 = 0.793\,(\mathrm{m})$$

Sleeve diameter

$$D_{sl} := \sqrt{D_t^2 - \frac{4}{\pi} \cdot F_{1nd}} = \sqrt{0.7928^2 - \frac{4}{\pi} \cdot 0.08961} = 0.7172 = 0.717\,(\mathrm{m})$$

Axial velocity of the gas at the working wheel inlet

$$C_{1a} := C_1 \cdot 0.309 = 735.8 \cdot 0.309 = 227.4 = 227.4\,(\mathrm{m/s})$$

Verification of strengh conditions under the action of centrifugal forces

$\rho := 8 \cdot 10^3$ is density of blades material

$K_f := 0.5$ is coefficient of blades form

$$D_{t.md} := \frac{D_{sl} + D_t}{2} = 0.755\,(\mathrm{m})$$

$$\sigma_{ten} := 2 \cdot K_f \cdot \rho \cdot u_{tmd}^2 \cdot \frac{h_1}{D_{t.md}} = 2 \cdot 0.5 \cdot 8 \cdot 10^3 \cdot 448.7^2 \cdot \frac{0.03778}{0.75499999999999989} = 80.6 \cdot 10^6\,(\mathrm{Pa})$$

Accepting alloy ЖС6К for turbine blades. Cooling to T = 1150K:

Safety factor at $\sigma_{t.200.1150} := 350 \cdot 10^6$ (Pa)

$$n := \frac{\sigma_{t.200.1150}}{\sigma_{ten}} = \frac{350 \cdot 10^6}{80600000} = 4.342 = 4.342$$

Selected material satisfies the requirement of safety factor

3.2.8. Determination of diametric sizes at the HPT exit

Temperature and pressure of gas at $\eta_{hpt.exit} := 0.89$

$$T^*_{hptd} := T^*_{ti} - \frac{L_{HPT}}{\dfrac{k_g}{k_g - 1} \cdot R_g} = 1575 - \frac{592421}{\dfrac{1.33}{1.33 - 1} \cdot 288} = 1065.0 = 1065 \text{ (K)}$$

$$P^*_{hptd} := P^*_{ti} \cdot \left(1 - \frac{T^*_{ti} - T^*_{hptd}}{T^*_{ti} \cdot \eta_{hpt.exit}}\right)^{\frac{k_g}{k_g - 1}} = 2870000 \cdot \left(1 - \frac{1575 - 1065}{1575 \cdot 0.89}\right)^{\frac{1.33}{1.33 - 1}} = 463681 \text{ (Pa)}$$

Reduced velocity and relative density of gas flow

$$C_{hpt.exit} := 320 \text{ (m/s)}$$

$$\lambda_{2a} := \frac{C_{hpt.exit}}{\sqrt{2 \cdot R_g \cdot T^*_{hptd} \cdot \dfrac{k_g}{k_g + 1}}} = 0.541$$

$$q_{\lambda 2} := \left(\frac{k_g + 1}{2}\right)^{\frac{1}{k_g - 1}} \cdot \lambda_{2a} \cdot \left(1 - \frac{k_g - 1}{k_g + 1} \cdot \lambda_{2a}^{\;2}\right)^{\frac{1}{k_g - 1}} = 0.75567439904659186056 = 0.7557 = 0.756$$

Gas consumption at the exit of the HPT

$$g_{cool2} := 0.04$$

$$G_g = (G_a - G_{aII}) \cdot (1 + g_f) \cdot (1 - g_{cool2}) = (464 - 381.14) \cdot (1 + 0.01946) \cdot (1 - 0.04) = 81.1 \text{ (kg/s)}$$

Area at the exit of the HPT

$$F_{hpt} := \frac{G_g \cdot \sqrt{T^*_{hptd}}}{m_g \cdot P^*_{hptd} \cdot q_{\lambda 2}} = \frac{81.09 \cdot \sqrt{1065}}{0.0396 \cdot 463681 \cdot 0.7557} = 0.1907 = 0.191 \text{ (m}^2\text{)}$$

HPT exit diameter

$$D_{hpt.exit} := \sqrt{D_{sl}^{\;2} + \frac{4}{\pi} \cdot F_{hpt}} = \sqrt{0.7172^2 + \frac{4}{\pi} \cdot 0.1907} = 0.8702 = 0.87 \text{ (m)}$$

Height of blades at the HPT exit

$$h_2 := \frac{D_{hpt.exit} - D_{sl}}{2} = 0.077 \text{ (m)}$$

3.2.9. Determination of the HPC number of stages

Circumferential velocities on the periphery u1c, near the sleve of the first stage and last stage

$$u_{1c} := u_{tmd} \cdot \frac{D_{1.HPC}}{D_{t.md}} = 448.7 \cdot \frac{0.7225}{0.75499999999999989} = 429.4 = 429.4 \text{ (m/s)}$$

$$u_{1sl} := u_{tmd} \cdot \frac{D_{1.HPC.sl}}{D_{t.md}} = 448.7 \cdot \frac{0.3612}{0.75499999999999989} = 214.7 = 214.7 \text{ (m/s)}$$

$$u_{z.sl} := u_{tmd} \cdot \frac{D_{c.sl}}{D_{t.md}} = 448.7 \cdot \frac{0.6327}{0.75499999999999989} = 376.0 = 376 \text{ (m/s)}$$

Lattice density coefficients for the 1st and last stages of the HPC

$$b_{st1} := 1.6 \qquad b_{stz} := 1.8$$

Twisting of air in the first and last stage rotors

$$\Delta W_{u1.sl} := C_{a.HPC} \cdot \frac{1.55}{1 + \frac{1.5}{b_{st1}}} = 215 \cdot \frac{1.55}{1 + \frac{1.5}{1.6}} = 172.0 = 172 \text{ (m/s)}$$

$$\Delta W_{uz.sl} := C_{a.cd} \cdot \frac{1.55}{1 + \frac{1.5}{b_{stz}}} = 120 \cdot \frac{1.55}{1 + \frac{1.5}{1.8}} = 101.5 = 101.5 \text{ (m/s)}$$

Compression work of blades of the 1st and last compressor stages

$$L_{st.1} := u_{1sl} \cdot \Delta W_{u1.sl} = 214.7 \cdot 172 = 36928.0 = 36928 \text{ (J/kg)}$$

$$L_{st.z} := u_{z.sl} \cdot \Delta W_{uz.sl} = 376 \cdot 101.5 = 38164.0 = 38164 \text{ (J/kg)}$$

Average work of HPC stages

$$L_{av} := \frac{L_{st.1} + L_{st.z}}{2} = \frac{36928 + 38164}{2} = 37546.0 = 37546 \text{ (J/kg)}$$

$$z_{hpc} := \frac{L_{HPC}}{L_{av}} = \frac{473066.40587242611}{37546} = 12.6 = 12.6$$

Accepting the number of HPC stages $z_{hpc} := 13$

Verification the condition of power balance

$$N_{hpc} = (G_a - G_{aII}) \cdot L_{HPC} = (464 - 381.14) \cdot 473066 = 39200000 \text{ (W)}$$

$$N_{hpt} := G_g \cdot L_{HPT} = 81.09 \cdot 592421 = 4.804e7 = 48040000 \text{ (W)}$$

Verification of the rotational speed

$$n_{hpc} := \frac{60 \cdot u_{1c}}{\pi \cdot D_{1.HPC}} = \frac{60 \cdot 429.4}{\pi \cdot 0.7225} = 11350.0 \text{ (rev/min)}$$

$$n_{hpt} := \frac{60 \cdot u_{tmd}}{\pi \cdot D_{t.md}} = \frac{60 \cdot 448.7}{\pi \cdot 0.75499999999999989} = 11350.0 \text{ (rev/min)}$$

3.2.10. Determination of the LPT number of stages and distribution of work between them

$T^*_{hptd} = 1065$ (K) Cooling is not required (<1200K)

$$G_{aI} := G_a - G_{aII} = 82.857 \text{ (kg/s)}$$

$$G_{g.lpt} := G_{aI} \cdot \left(1 + g_f\right) = 82.85714285714289 \cdot (1 + 0.01946) = 84.47 = 84.47 \text{ (kg/s)}$$

From the power balance condition

$$L_{LPT} := \frac{m \cdot L_{fanII} + L_{LPC}}{\left(1 + g_f\right) \cdot \eta_m} = \frac{4.6 \cdot 49092.0 + 35431}{(1 + 0.01946) \cdot 0.99} = 258855.0 = 258855 \text{ (J/kg)}$$

Average diameter at the LPT inlet

$$D_{lpt.av} := 0.87 \text{ (m)}$$

$$u_{lpt.av} := u_{1ft} \cdot \frac{D_{lpt.av}}{D_{1ft}} = 450 \cdot \frac{0.87}{1.764} = 221.9 = 221.9 \text{ (m/s)}$$

Number of LPT stages

$$z_{lpt} := 3$$

Loading coefficient

$$\eta_{lpt} := 0.89$$

$$Y_t := u_{lpt.av} \cdot \sqrt{\frac{z_{lpt} \cdot \eta_{lpt}}{2 \cdot L_{LPT}}} = 221.9 \cdot \sqrt{\frac{3 \cdot 0.89}{2 \cdot 258855}} = 0.5039 = 0.504$$

$$L_{lpt.1} := 0.45 \cdot L_{LPT} = 116484.75 \text{ (J/kg)}$$

$$L_{lpt.2} := 0.3333 \cdot L_{LPT} = 86276.371 \text{ (J/kg)}$$

$$L_{lpt.3} := 0.2167 \cdot L_{LPT} = 56093.878 \text{ (J/kg)}$$

$$L_{lpt.1} + L_{lpt.2} + L_{lpt.3} = 258855 \text{ (J/kg)}$$

$$L_{LPT} = 258855 \text{ (J/kg)}$$

3.2.11. Determination of diametrical sizes at the LPT inlet

Velocity of gas passing though the first ND

$$C_{lpt.in} := \frac{L_{lpt.1}}{u_{lpt.av} \cdot 0.9063} = \frac{116484.75}{221.9 \cdot 0.9063} = 579.2 = 579.2 \text{ (m/s)}$$

Reduced velocity

$$\lambda_{lpt.in} := \frac{C_{lpt.in}}{\sqrt{2 \cdot R_g \cdot T^*_{hptd} \cdot \frac{k_g}{k_g + 1}}} = \frac{579.2}{\sqrt{2 \cdot 288 \cdot 1065 \cdot \frac{1.33}{1.33 + 1}}} = 0.9788 = 0.979$$

Relative density

$$q_{\lambda lpt} := \left(\frac{k_g+1}{2}\right)^{\frac{1}{k_g-1}} \cdot \lambda_{lpt.in} \cdot \left(1 - \frac{k_g-1}{k_g+1} \cdot \lambda_{lpt.in}{}^2\right)^{\frac{1}{k_g-1}} = 0.99947520980476448558 = 0.9995 = 1$$

Total pressure recovery coefficient in the transition casing of HPT and LPT

$$\sigma_{int} := 0.98$$

Area of the LPT ND exit

$$F_{1.nd.lpt} := \frac{G_{g.lpt} \cdot \sqrt{T^*_{hptd}}}{m_g \cdot P^*_{hptd} \cdot \sigma_{int} \cdot q_{\lambda lpt} \cdot 0.309} = \frac{84.47 \cdot \sqrt{1065}}{0.0396 \cdot 463681 \cdot 0.98 \cdot 0.9995 \cdot 0.309} = 0.496 = 0.496\ (\mathrm{m}^2)$$

Height of LPT blades

$$h_{bl} := \frac{F_{1.nd.lpt}}{\pi \cdot D_{lpt.av}} = \frac{0.496}{\pi \cdot 0.87} = 0.1815 = 0.181\ (\mathrm{m})$$

Height of one blade is 0.181/2 = 0.091 (mm)

$$D_{sl.lpt} := D_{sl} = 0.717\ (\mathrm{m})$$

Outer diameter at the LPT inlet

$$D_{lpt} := D_{sl.lpt} + h_{bl} = 0.7172 + 0.1815 = 0.8987 = 0.899\ (\mathrm{m})$$

3.2.12. Determination of diametric sizes at the exit of the low-pressure turbine

Parameters of gas at the LPT exit

$$\sigma_{lpt} := 0.975$$

$$T^*_{td} := T^*_{hptd} - \frac{L_{LPT}}{\frac{k_g}{k_g-1} \cdot R_g} = 1065 - \frac{258855}{\frac{1.33}{1.33-1} \cdot 288} = 842.0 = 842\ (\mathrm{K})$$

$$P^*_{td} := P^*_{hptd} \cdot \sigma_{lpt} \cdot \left(1 - \frac{T^*_{hptd} - T^*_{td}}{T^*_{hptd} \cdot \eta_{lpt}}\right)^{\frac{k_g}{k_g-1}} = 153365.61017633405438 = 153365.0 = 153365\ (\mathrm{Pa})$$

Assume the speed axial component of the gas at the LPT exit

$$C_{1a.lpt} := 358 \text{ (m/s)}$$

Reduced velocity

$$\lambda_{lpt.exit} := \frac{C_{1a.lpt}}{\sqrt{2 \cdot R_g \cdot T^*_{td} \cdot \frac{k_g}{k_g + 1}}} = 0.68$$

Relative density of flow

$$q_{\lambda lpt.exit} := \left(\frac{k_g + 1}{2}\right)^{\frac{1}{k_g - 1}} \cdot \lambda_{lpt.exit} \cdot \left[1 - \frac{k_g - 1}{k_g + 1} \cdot \left(\lambda_{lpt.exit}\right)^2\right]^{\frac{1}{k_g - 1}} = 0.88$$

Area at the LPT exit

$$F_{lpt.exit} := \frac{G_{g.lpt} \cdot \sqrt{T^*_{td}}}{m_g \cdot P^*_{td} \cdot q_{\lambda lpt.exit}} = \frac{84.47 \cdot \sqrt{842}}{0.0396 \cdot 153365 \cdot 0.88} = 0.4586 = 0.459 \text{ (m}^2\text{)}$$

Diameter at the LPT exit

$$D_{lpt.exit} := \sqrt{D_{sl.lpt}^{\;2} + \frac{4}{\pi} \cdot F_{lpt.exit}} = \sqrt{0.7172^2 + \frac{4}{\pi} \cdot 0.4586} = 1.048 = 1.048 \text{ (m)}$$

Height of blade at the LPT exit

$$h_{bl.lpt.exit} := \frac{D_{lpt.exit} - D_{sl.lpt}}{2} = \frac{1.048 - 0.7172}{2} = 0.1654 = 0.165 \text{ (m)}$$

$$D_{lpt.av.exit} := \frac{D_{lpt.exit} + D_{sl.lpt}}{2} = 0.883 \text{ (m)}$$

LPT sleeve diameter

$$D_{sl.lpt.exit} := D_{sl.lpt} = 0.717 \text{ (m)}$$

Verification of safety factor of centrifugal forces action

$$\rho 1 := 8.1 \cdot 10^{3}$$

$$\sigma_p := 2 \cdot K_f \cdot \rho \cdot u_{lpt.av}^{2} \cdot \frac{h_{bl.lpt.exit}}{D_{lpt.av.exit}} = 2 \cdot 0.5 \cdot 8 \cdot 10^{3} \cdot 221.9^{2} \cdot \frac{0.1654}{0.8826} = 7.382e7 = 73820000 \text{ (Pa)}$$

Accepting alloy ЭИ-437Б with ultimate strength $\sigma_t := 260 \cdot 10^{6}$ (Pa)

$$n_{str} := \frac{\sigma_t}{\sigma_p} = \frac{260 \cdot 10^{6}}{73820000} = 3.522 = 3.522$$

Verification of LPT and LPC power balance

$$N_{lpt} := G_{g.lpt} \cdot L_{LPT} = 21865481.85 \text{ (W)}$$

$$N_{lpc} := G_{aII} \cdot L_{fanII} + G_{aI} \cdot L_{LPC} = 21646776.571 \text{ (W)}$$

Rotational frequencies of the LPT

$$\frac{60 \cdot u_{lpt.av}}{\pi \cdot D_{lpt.av.exit}} = \frac{60 \cdot 221.9}{\pi \cdot 0.8826} = 4802.0 \text{ (min}^{-1}\text{)}$$

$$n_{lpt} := 5720 \text{ (rev/min)}$$

$$\frac{60 \cdot u_{1ft}}{\pi \cdot D_{1ft}} = \frac{60 \cdot 450}{\pi \cdot 1.764} = 4872.0 \text{ (min}^{-1}\text{)}$$

$$n_{sl} := 5722 \text{ (rev/min)}$$

$$\frac{n_{lpt}}{n_{sl}} = 1$$

3.2.13. Determination of diametrical sizes of sections at the exit from jet nozzles

Reduced velocity of gas flow at the primary flow jet nozzle exit

$$\lambda_c := \frac{C_{jnI}}{18.15 \cdot \sqrt{T^*_{td}}} = \frac{359.6}{18.15 \cdot \sqrt{842}} = 0.6828 = 0.683$$

Relative density of flow

$$q_{\lambda c} := \left(\frac{k_g+1}{2}\right)^{\frac{1}{k_g-1}} \cdot \lambda_c \cdot \left(1 - \frac{k_g-1}{k_g+1} \cdot \lambda_c^{\,2}\right)^{\frac{1}{k_g-1}} = 0.88182039623890634661 = 0.8818 = 0.882$$

Nozlle area

$$F_{jnI} := \frac{G_g \cdot \sqrt{T*_{td}}}{m_g \cdot P*_{td} \cdot q_{\lambda c}} = \frac{81.09 \cdot \sqrt{842}}{0.0396 \cdot 153365 \cdot 0.8818} = 0.4394 = 0.439\ (\mathrm{m}^2)$$

Nozzle diameter

$$D_{jnI} := \sqrt{\frac{4 \cdot F_{jnI}}{\pi}} = \sqrt{\frac{4 \cdot 0.4394}{\pi}} = 0.748 = 0.748\ (\mathrm{m})$$

Velocity of gas at the exit of the secondary flow jet nozzle

$$C_{jnII} = 280.513\ (\mathrm{m/s})$$

Reduced velocity of gas at the exit of the secondary flow jet nozzle

$$\lambda_{c2} := \frac{C_{jnII}}{18.15 \cdot \sqrt{T*_{fdII}}} = \frac{280.51296316639785853}{18.15 \cdot \sqrt{337.7}} = 0.841 = 0.841$$

Relative density of flow

$$q_{\lambda c2} := \left(\frac{k_g+1}{2}\right)^{\frac{1}{k_g-1}} \cdot \lambda_{c2} \cdot \left(1 - \frac{k_g-1}{k_g+1} \cdot \lambda_{c2}^{\,2}\right)^{\frac{1}{k_g-1}} = 0.97$$

Nozzle area

$$F_{c2} := \frac{G_{aII} \cdot \sqrt{T*_{fdII}}}{m_a \cdot P*_{jnII} \cdot q_{\lambda c2}} = \frac{381.14285714285711 \cdot \sqrt{337.7}}{0.0404 \cdot 159029 \cdot 0.9702} = 1.124 = 1.124\ (\mathrm{m}^2)$$

Inner diameter of the secondary flow jet nozzle

$$D_{cII} := D_I = 0.932 \text{ (m)}$$

$$D_{jnII} := \sqrt{D_{cII}^2 \cdot \frac{4 \cdot F_{c2}}{\pi}} = \sqrt{0.9324^2 \cdot \frac{4 \cdot 1.124}{\pi}} = 1.115 = 1.115 \text{ (m)}$$

3.2.14. Refinement of the engine parameters

$$P_{sp1} := C_{jnI} \cdot \left(1 + g_f\right) = 359.6 \cdot (1 + 0.01946) = 366.6 = 366.6 \text{ (N·s/kg)}$$

$$P_{sp2} := C_{jnII} = 280.51296316639785853 = 280.5 = 280.5 \text{ (N·s/kg)}$$

$$P_{sp\Sigma} := \frac{P_{sp1} + m \cdot P_{sp2}}{1 + m} = \frac{366.6 + 4.6 \cdot 280.5}{1 + 4.6} = 295.9 = 295.9 \text{ (N·s/kg)}$$

Engine thrust is determined by the equation

$$P_{eng} := P_{sp\Sigma} \cdot G_a = 295.9 \cdot 464 = 137297.0 = 137297 \text{ (N)}$$

Thrust specific fuel consumption

$$C_{sp} := \frac{3600 g_f \cdot \left(1 - g_{cool}\right)}{P_{sp\Sigma} \cdot (1 + m)} = \frac{3600 \cdot 0.01946 \cdot (1 - 0.08)}{295.9 \cdot (1 + 4.6)} = 0.0389 = 0.039 \text{ (kg/N·h}^{-1}\text{)}$$

Table 1

Results of Turbfan Engine Thermo– and Gas–Dynamic Calculations

TPE elements (units)	Element (unit) parameters				Cross-sections	Working body parameters			Cross-sections dimensions		
	Air/Gas flow rate	Rotational speed	Work	Number of stages		Total pressure	Total temperature	Axial velocity	External diameter	Sleeve diameter	Length (height) of blade
	G, kg/sec	n, rpm	L, kJ/kg			P^*, Pa	T^*, K	ca, m/sec	Dy, mm	dsl, mm	h , mm
Low pressure compressor	82.86 (primary flow) + 381.14 (fan)	5721	35.4 (fan) + 77 (add stages)	1 main (fan) , 3 add	Inlet	101325	288	220	1764	618	573
					Exit (fan)	140197	323.9	210	1623	709	457
					Exit (add stages)	140197	323.9	210	947	709	119
High pressure compressor	82.26	11350	550.1	13	Inlet	140197	323.9	215	723	361	181
					Exit	2929000	803.2	120	686	633	27
High pressure turbine	77.71	11350	592.4	2	Inlet	2813000	1575	753.8	793	717	38
					Exit	463681	1065	320	870	717	77
Low pressure turbine	84.47	5721	258.9	3	Inlet	463681	1065	579.2	899	717	91
					Exit	153365	842	358	1048	717	165

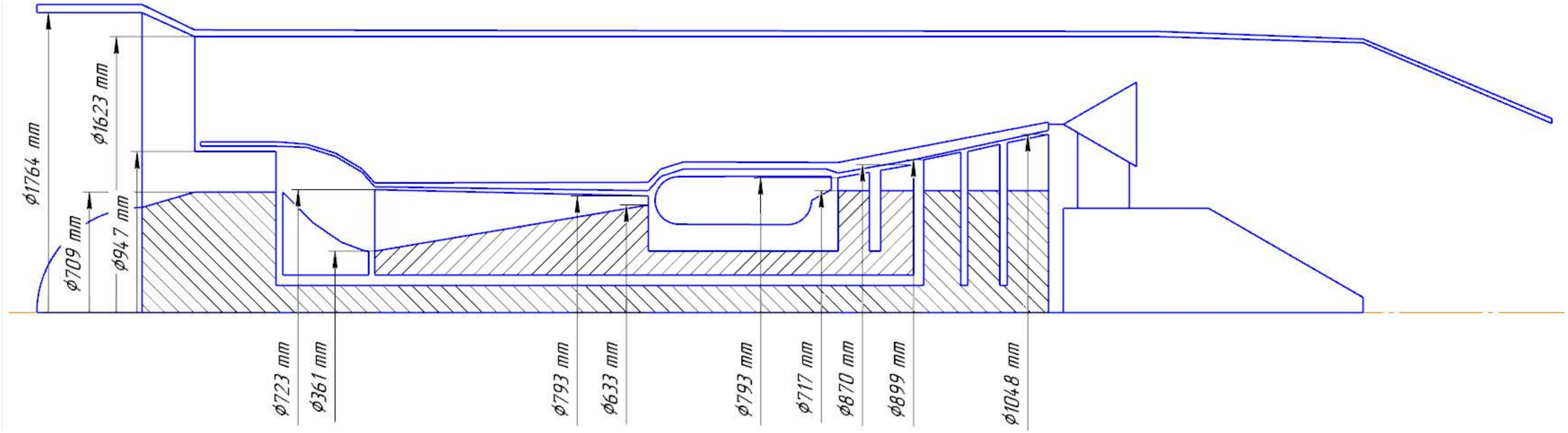

Fig. 3.1. Structural scheme of designed engine

Conclusion to Section 3

The main thermodynamic and gas-dynamic parameters were calculated. The diameters on each cross section are provided and they are sufficient to construct engine scheme and develop entire drawing.

According to the thermodynamic and gas dynamic calculations we accept the engine design with single stage compressor with 3 add stages, triple staged LPC. HPC has 13 stages and the HPT consists of 2 stages. The engine has mixing of flows layout.

The value of the thrust specific fuel consumption $C_{sp} = 0.039$ (kg/N·h^{-1}). This value will be considered as initial during further calculation of thrust specific fuel consumption after implementation of improving methods.

5. Labor protection

This type of aircraft is used to transport passengers and cargo in commercial air transport or even in the field of air freight. The production and maintenance process includes operations to remove, manufacture, replace and / or install aircraft parts. These aircraft vary in size, but some (such as the Boeing 747, Airbus A340) are some of the largest aircraft in the world. Due to the size of the aircraft, some operations require personnel to work above or below ground.

There are many situations in which there is a decline in aircraft production and maintenance in the aviation industry. Although each situation is unique and may require a different protection solution, the best way to prevent failure is to prevent risk identification and control planning. Effective fall protection requires an institutional commitment that covers all aspects of risk identification and control. Each operator must regularly evaluate their own autumn exposure operation and develop an adequate and comprehensive protection plan to combat any exposure during operation.

5.1. Analysis of the conditions in the manufacturing workplace

The process of production of aircraft, piston or jet engines involves the replacement of raw materials with the most reliable equipment. Difficult working conditions associated with air transport require the use of a variety of powerful materials. Standard and non-standard production methods are used (ДСТУ Б В.1.1-36:2016., ДБН В.2.2-28:2010.).

5.1.1. Construction materials

Aircraft engines are mostly made of metal parts, although in recent years a number of plastic composites made of special parts have appeared. Different types of aluminum and titanium are used when strength and light are of paramount importance (structural components, composite components, mechanical components). Alloys of chromium, nickel and cobalt are used in areas where high heat resistance and corrosion resistance are required (combustion chamber and fan components). Many metal products are used in the central areas. As aircraft weight reduction is an important factor in shortening the life cycle (weight gain, fuel consumption reduction), more advanced composite materials have recently been introduced to replace lightweight aluminum, titanium and some metal parts. The structure and high-temperature channels are unknown. This composite is usually made of polyimide, epoxy and other adhesive methods reinforced with fiberglass or graphite fibers (URL: http://zakon.rada.gov.ua/laws/show/11-2014-п.).

5.1.2. Manufacturing operations

Almost all conventional metallurgical industries and mechanical engineering are used to make aircraft engines. These include hot forging (blade, plates, rotors, cans), casting (structural parts, machine), grinding, drawing, turning, digging, grinding, cutting, sawing, threading, welding, welding, etc. Related systems include metal processing (anodizing, chromatin, etc.), electroplating, heat treatment and heat transfer (plasma, flame).

High stability and durability of the used breeds of wood together with their rigid form and accuracy of tolerance; they require more complex and complex technical needs than other industries. Some of the most unique metalworking methods include chemistry and chemical engineering, electrical engineering, laser drilling and electronic welding. Metabolism and chemical reactions involve the removal of iron from large areas to maintain or create an overview. Parts, according to special treatment, are placed in concentrated acid, bath or electrolytic. Iron is destroyed by chemical action or chemical reaction. Chemicals are often used after the manufacture of air markers to ensure a wall thickness that meets the requirements while preserving the texture (ДБН В.2.5-56:2014.).

Electric and laser drilling machines are commonly used to make small diameter holes and rigid steel structures. Many of these openings are required for combustion chambers and cooling fans. Decomposition of metal is carried out by high-temperature mechanical reaction of electrically conductive fluid. The procedure is performed using a dielectric bath with mineral oil. The electrode is an inverted image of the desired section. Electronic welding is used to fasten parts, while deep welding is required for hard-to-reach geometries. Welding is generated by focused and accelerated electronic light in an empty room. The kinetic energy of the electrons hitting the particle is converted into heat by welding the components (ДБН В.2.5-56:2014.).

5.1.3. Development of safety measures

The health risks associated with the design of aircraft engines are often related to the toxicity of the materials used and their potential exposure. Aluminum, titanium and iron are not considered highly toxic, while chromium, nickel and cobalt are less toxic. Certain compounds and valence conditions in the latter three metals have shown cancer characteristics in humans and animals. Their metallic forms are generally not considered as toxic as their ionic forms, which are generally found in metal finishes and paints.

In conventional machines, most operations are performed by cooling or cutting the liquid which reduces the generation of dust and fumes. Aside from dry grinding, metals generally do not pose a risk of inhalation, although breathing in frostbite is a concern. A good amount of grinding is done, especially on parts of jet engines, to combine the parameters and bring the air into the final volume. Portable microwave ovens are generally used. When such grinding is carried out on chromium, nickel or cobalt-based alloys, local ventilation is required. This includes down tables and air vents with direct ventilation. Skin rashes and rashes are additional health hazards associated with conventional machines. The staff will have different levels of skin contact in the refrigerators and liquid cutters when assembling, inspecting and removing components. Frequent contact with the skin can manifest itself in different types of dermatitis in some workers. Overall, protective gloves, protective creams and proper hygiene will reduce these cases. High noise levels are often present when manufacturing a thin wall, high-strength materials due to vibration of equipment and parts. This can be controlled to some extent by the use of solid equipment, pillows, changing the size of the machine and the protection of sharp tools. Otherwise, PPE (for example, earbuds, keys) is required. Safety hazards associated with conventional machine operations often involve the possibility of physical injuries due to workplace, repair and power transmission movements. Control is completed by means of fixed guards, integrated entry doors, light curtains, pressure mats and training and awareness of staff. Eye protection should always be used in the vicinity of machine operations to protect against flying debris, particles and frosts in refrigerators and liquid cleaners.

Metal finishing operations, chemical grinding, grinding of electric and welded chemicals involve the introduction of surface acid reservoirs, bases and electrolytes. Most toilets contain large amounts of molten metal. Depending on the operating operating conditions and composition (observation, temperature, tension, size), most will require some type of local ventilation to control air levels of gases, vapors and fog. In a variety of ways, space-type cover designs are commonly used for control. Ventilation designs and operation guides for various types of baths are available from technical institutions such as the American Conference on Industrial Hygiene (ACGIH) and the American National Standards Institute (ANSI). The corrosive nature of these baths indicates the use of eye and skin protection (eyeglasses, face shields, gloves, goggles etc.) when working around these tanks. Emergency eyeglasses and showers should also be prepared for immediate use (https://zakon.rada.gov.ua/laws/show/2694-12).

The health hazards associated with testing operations often involve radiation (x or gamma rays) from radiation testing and noise from final product tests. Radiation operations should include a comprehensive, comprehensive radiation safety program with training, signal monitoring and periodic surveys. Radiation testing rooms should be designed with interlocking doors, working lights, quick connection and proper protection. The test sites or test units for composite products should be treated with noise, especially jet engines (ДГН 6.6.1.- 6.5.061-2000 (НРБУ-97/Д-2000).

Noise levels on control consoles should be controlled below 85 dBA. This should also be done to prevent any buildup of fumes, fumes or liquids in the test (ДСН 3.3.6.037-99.).

The mixing and mixing of chemicals may also be complex and very different. Delay work performed on a regular basis may result in the use of hazardous materials without proper engineering controls or adequate personal protective measures.

Differences in work behavior between individuals and different airflow patterns and designs may have a significant impact on exposure. The difference in fluid exposure for individuals performing wing cleaning has exceeded two major orders, due to the effect of body size on the flow of air in solvent in very limited areas.

Potential hazards must be identified and refined, and the necessary controls implemented, before materials or procedures enter the workplace. Safe use standards must also be developed, established and documented compulsory compliance before work can begin. Where information is incomplete, it is important to take the highest possible risk and expect appropriate protection measures. Industrial hygiene surveys should be conducted on a regular basis to ensure that the controls are adequate and operational.

The problem with identifying the airborne workplace requires close collaboration between hygienists, physicians, toxicologists and infectious diseases (see Table 5.1.). The presence of knowledgeable staff and management cadres is also essential. Reporting on staff signs should be encouraged, and supervisors should be trained to be wary of signs and exposure. Biological exposure monitoring may serve as an important supplement for air monitoring while exposure may be very different or skin exposure may be important. Biological monitoring can also be used to determine whether controls are effective in reducing employee exposure to pollution. Analysis of health data in the form of signs, symptoms and complaints should be done regularly (URL: http://zakon2.rada.gov.ua/laws/show/z0472-14).

Table 5.1. - Technological development requirements for health, safety and environmental control for new processes and materials.

Parameter	**Technological requirement**
Airborne levels of contaminants	Analytical methods for chemical quantification Air monitoring techniques
Potential health impact	Acute and chronic toxicology studies
Environmental fate	Bioaccumulation and biodegradation studies
Waste characterization	Chemical compatibility test Bioassays

Paint paints, air fuses and fuel tanks may serve as high volume smoke systems during paint, operation and emergency cleaning operations. Residual exposure and the inability of these systems to control air flow away from workers often requires additional use of breathing.

Local smoke is required for minor painting, metal treatment and liquid cleaning operations, chemical laboratory work and some plastics work. Ventilation is usually sufficient only in areas with minimal chemical consumption or supplemented by exhaust fumes. Critical air exchange during the winter can lead to excessive indoor dry air. Poorly designed smoke systems that regulate excessive cold air flow in the hands or backs of workers in small areas of the joints can exacerbate problems with the arm, arm and neck. In large, complex production areas, care must be taken to accurately locate exhaust fumes and vents to avoid re-entry pollution.

Proper production of airborne products requires a clear, organized and well-managed working environment. Tanks, barrels and containers containing chemicals should be labeled with hazardous materials. First aid information should be available. Immediate response and leak control information should also be obtained from MSDS or similar data sheet. Hazardous workplaces must be installed, controlled and verified (ДБН В.2.5-67:2013.).

5.2 Fire safety

5.2.1 Engine fire detection

Detection is completed by direct pneumatic detection methods, commonly known as fire extinguishers, which are pipes filled with gas passing through abnormal heat sources. If the temperature around the sensor increases, the electrical resistance of the primary element decreases and an alarm may be issued. It is copied to allow regular detection if one cycle of the system crashes. The open circuit due to a short defect will be detected during the daily pre-flight tests or a service error is announced. Physical damage to the loop as a "pinch" may result in a false fire alarm but it will also issue a false independent notice. The same principles apply to the protection of APUs (ДСТУ ISO 6309:2007).

5.2.2 Engine fire extinguishing

In present day passenger airplanes, the engine compartments are usually divided into two zones "1" and "2" for fire protection. Two electric fire engines are available for each engine, including the Halon 1301 or the new HFC (Hydrofluorocompounds).

Sometimes they are equipped with a nose cover for each nacelle, but they are also located inside the fuselage and "joint" engines with two aircraft or in the dry shoulder area, which is "shared" by the engines in these multi-engine wings. After activation, the contents of the shutter bottle will be released into zone 1 of the engine, the engine fan unit. The fire in zone 2, in the center of the engine, is extinguished when the engine is switched off. Fire drills for an aircraft engine include the shutdown of fuel and hydraulic fluid in the engine and fuel supply, as well as the ability to separate flammable, fast-moving material from any engine. APU Activation of the engine wipers is also usually recommended as a precaution when the engine is stopped due to severe damage. APU fire extinguishers are activated by the flight crew in the same way as engine extinguishers, by manual selection when receiving a fire warning, when they are in the air, but automatically, and with the automatic APU shutdown that the companion, in the case of fire detection during ground operation.

If there are signs that the fire in the engine or APU has been successfully eliminated, the fact of the fire does not affect the decision of emergency flight attendants to land the aircraft. However, in a twin aircraft, stopping the engine often causes it to land as quickly as possible.

Experience has shown that in some cases they can be permanent signs of engine fire after stopping the engine and that the discharge from both bottles caused a complete ceasefire. If this happens, the crew may not be sure that their actions have completely extinguished the fire, and should decide to "settle down as soon as possible" НАПБ А.01.001-14.

5.3 Typical calculation or safety issue detail

Aircraft maintenance work includes inspection and maintenance of structures, pavements, hangars and airports. Good training and work ethic ensure the safety of the aircraft and crew.

Large physical flights make it difficult to see people on the ground when they are busy in a hangar or repair area. Watch and contact the flight attendant to avoid accidents (accidents or falls on the wing or tail). Never enter the aisle without the permission of the airport manager.

Work at a constant speed. Accelerating work increases the number of plane crashes and accidents. To avoid accidents, think about ground cables in the plane. Workplaces with good lighting are safer. View sharp edges such as wingtips and sharp antennas, sensors, and the Remove Before Flight check box on the aircraft. Compact, sharp or protruding surfaces cause bumps, bruises and cuts.

Stay inside dangerous paint lines and avoid "spicy" planes. Contact with the machine, rotor or breakage can cause serious injuries. Tie your hair back and avoid loose clothing and jewelry to prevent getting stuck in moving parts. Do not bend or raise your arms or legs too close to the engine compartment. Remove the appliance and remove the debris near the engine. If the engine starts, you can get serious injuries or small objects can turn into shells.

Large areas of the body require stairs, mattresses and stairs to get to work. Follow the safety instructions on the stairs. Use a fall protection belt where necessary. You may need to work in tight spaces while repairing your aircraft. Evaluate airline entries and restricted flights and follow space procedures if required.

Aircraft chemicals include oils, lubricants, coatings, paints and liquids. They can be collected and may contain hazardous substances; use the Product Safety Data Sheet (MSDS). The MSDS explains how to handle chemicals, properly store and dispose of them, and the necessary personal protective equipment (PPE) for safe operation. Do not smoke near aircraft maintenance areas where chemicals and fuels may burn.
Mechanical work and maintenance require tools such as flashlights, lanterns, rivets or grinders. Properly protect your equipment and follow safety rules. When moving large, large parts and aircraft equipment, use ancillary devices or seek assistance to make the elevator safer. Use good ergonomic behavior, such as a 30-second repetition with minimal rest and work cycle, to prevent fatigue and injury.

PPE depends on the task. Sweaty hats will protect you from a collision in the cabin. Helmets will protect you from falling objects. Goggles, shields and goggles protect your face and eyes depending on the task and equipment. Plastic caps, gloves and shoes protect your hands and feet from chemicals. Durable work gloves protect your hands from scratches and scuffs, and shoes with a steel toe and non-slip sole protect your toes and reduce the likelihood of falling. Wear suitable hearing aids (earplugs, clutches, etc.) to protect yourself from aircraft noise. Breathing equipment may be required to control dust from grinding and daily activities (НПАОП 0.00-4.12-05).

Conclusion to Section 5

Maintenance hangars perform very specific, important tasks, so fire detection and extinguishing technology should meet the needs of ongoing maintenance. This includes improving heat and smoke detection systems, using a three-dimensional map and analysis to verify the location and placement of eye flame detection, and the use of modern commissioning equipment such as jet fuel simulator check detectors. production. Providing fire protection at MRO facilities is certainly a task for industry experts, but knowing what is available for fire protection on airplanes is an important part of every MRO facility manager's job. Higher ratings and / or recommendations are for guidance only and should not be relied upon to comply with the law. They are based solely on the information provided to us and apply only to the terms specifically addressed. We do not guarantee, certify or imply, that your workplace is safe or healthy or that it complies with all laws, regulations or standards.

6. Environmental protection

6.1 Aviation industry pollution

Among the human activities likely to alter the environment, aviation deserves special attention. On the one hand, it has a high growth rate compared to other anthropogenic sources (increase in passenger traffic by almost 9% per year between 1960 and 1990, stabilized since at around 2% per year).

The global aviation industry produces around 2% of all human-induced carbon dioxide (CO2) emissions. Aviation is responsible for 12% of CO2 emissions from all transports sources, compared to 74% from road transport. With the rapid development of modern aviation it is very important to minimize the emissions as much as possible.

Measuring atmospheric pollution and analyzing its nature and source is difficult because pollution moves and changes chemically. In fact, primary pollutants such as oxides of carbon, sulfur and nitrogen, emitted directly into the air, are transported by the movements of air masses at variable distances. Secondary pollutants, such as ozone, are formed by chemical transformation of certain primary pollutants, during their transport, notably under the action of solar radiation.

The main harmful substances contained in flue gases thermal power plants include sulfur dioxide SO2, carbon monoxide CO, nitrogen oxides NOx, solid carbon particles (soot). One of the most important conditions for minimal emissions of harmful substances from engines is the choice of fuel combustion mode, which achieves its complete combustion. If necessary, when the air removed from the workplace contains harmful substances in large quantities, before being released into the atmosphere, it is cleaned in dust collection and gas treatment plants.

Vapors of oil products, solvents, air in the production facilities of the airport or aircraft factory enter paints and varnishes, alkalis, acids, aerosols of aqueous solutions of caustic, carbonate and phosphate sodium, sulfur dioxide, oxides of nitrogen, carbon monoxide, dust.

The amount of harmful substances entering the air from the production facilities of the airport or aircraft factory through ventilation systems may exceed the maximum permissible values, which cause exceeding the maximum permissible concentrations (MPC) of these harmful substances. This can be especially in the case with group arrangement of ventilation shafts, when there is an effect of summation of harmful emissions and even the formation of new harmful substances of greater toxicity.

6.2. Water pollution

Airports can generate significant water pollution due to their extensive use and handling of jet fuel, lubricants and other chemicals. Airports install spill control structures and related equipment (e.g., vacuum trucks, portable berms, absorbents) to prevent chemical spills, and mitigate the impacts of spills that do occur Air pollution is both global and local. Overall, aircraft emissions contribute to the increase in the greenhouse effect and therefore to global warming. Locally, the rotation of airplanes at airports, the heating of engines at the end of the runway, takeoffs, landings and overflight of more or less inhabited areas cause noise pollution and contribute to air pollution. The flights of military aircraft at low altitudes are also a source of noise and pollution. The combustion of kerosene in reactors leads to the release of pollutants, mainly nitrogen oxides (NOx), sulfur dioxide (SO2) and particles. Secondary pollutants can then be generated under the effect of solar radiation, mainly ozone (O3).

Additionally, it is very important not to allow fuel entering to the water sources, such as lakes, rivers, etc. in the areas where airports are located near them. All fuels have a negative impact on the processes of natural self-cleaning of water bodies and soils, causing an increase in biochemical oxygen consumption and inhibition of processes nitrification.

Threshold concentration in water on the organoleptic index, for example, for T-1 - 0.03 mg / l, the concentration of T-1 to 25 mg / l does not slow down the process of biochemical oxygen consumption.

Fuels are chemically stable in water. Fuel in solution with the original concentration of 1-10 mg / l in cold water is stable for month. In summer, with an increase in surface water temperature for three days there is a decrease in fuel concentration by 60-90%. At low concentrations (up to 20 mg/l) biodegradation is observed (especially after the adaptation period). As the concentration of fuels in the reservoir increases, the stability increases, and the stability depends on the alkaline-acid and redox parameters of the waters in which it is destroyed. For example, in lake or low-flowing waters with low dissolved oxygen content and low pH, the stability of GDP is reduced.

6.3. Noise pollution

During the engine design planning and incorporation of new developments, it is extremely important to take care about noise problem. It is very crucial factor when creating a large turbofan engine for the newest airplanes.

Air transport occupies a significant place in the noise regime of many cities. Sources of noise on the territory of airlines and adjacent areas are aviation power plants (AU) with gas turbine and reciprocating engines; auxiliary power plants (ACS) of aircraft and. Curves of the same noise of units of start; special aerodrome maintenance vehicles for various purposes, including heat and wind machines, created on the basis of aircraft engines that have exhausted the flight resource; machine and technological equipment of production processes.

The acoustic situation in the area of the airport is determined by the mode of operation of the airline; types of aircraft operated at the airport; current routes of arrival and departure of aircraft; the location of residential buildings relative to the runway, as well as measures taken by the airport to reduce the adverse effects of aviation noise on the environment.

Noise pollution, air pollution and climatic disturbances can affect humans, animal and plant health. Significant increase in air traffic and under the pressure of the aeronautical industry is trying to develop less noisy and more fuel-efficient engines, but these advances are partially or totally canceled out by the strong increase in traffic, the increase in size and power of aircraft. In some places, authorities are studying, developing and applying “continuous descent” approach techniques rather than stepping, altitude interceptions of aircraft by automatic landing systems, and optimizing the departure and arrival paths. Local regulative authorities manage the use of airspace in order to protect the economic interests of the regions concerned, employment and the interests of people living near airports.

Currently, approximately 1 aircraft flight per second worldwide is occurring and this value is constantly increasing. Continuous work is being conducted by ICAO to ensure the currency of the technical basis underpinning the ICAO Standards, guidance and policies associated with reducing aircraft noise. This work includes, among several topics, investigations into emerging noise reduction technologies, noise impacts from new aircraft concepts (e.g. Unmanned Air Vehicles), and the development of SARPs for future supersonic aeroplanes.

6.4. Emission of aircraft engines

In modern internal combustion engines, two primary systems are responsible for the formation and reduction of pollutants:

- the combustion system
- the emission aftertreatment system.

The combustion cycle comprises the combustion chamber, its structure and characteristics, and fuel distribution. Contaminants such as NOx and CO are forming in burning process along with incomplete fuel burning. The main goal of these above-mentioned methods is to influence how the combustion process proceeds.

Exist several approaches to limit the formation of contaminants as a result of the combustion process. After the exhaust gas leaves the combustion system, it basically consists of ice until it reaches the release treatment system (ATS, also abbreviated EAT or EATS), where pollution can be further reduced, as well as where there may be. high emissions such as N2O, NO2 and NH3.

The post-treatment method consists of catalytic reactors which try to further reduce the amount of pollution. In some cases, such as stoichiometric spark ignition (SI) engines, a single triangular capacitor (TWC) is sufficient to achieve a significant reduction in pollution.

Controlling the smoke composition using special means installed in the exhaust pipe or supplying additional reagents that are not normally found in the exhaust gas or, heat control to make sure that the operation of the ignition inside the required temperature window, systems to inspect for for contamination and pollution may be collected (filtration recovery, sulfur control, urea storage) and systems to decrease the formation of additional contaminants such as ammonia stimulants (ASC).

The above described approaches, can be used on new internal combustion engines. Some of these technologies can also be used to reduce emissions and/or improved the existing engines. There is also a technology group specifically designed for applications that are not normally used in new engines.

The composition of the CO and CXHY in the exhaust gases of the engines is due to the incomplete burning of the fuel in the engine, depending on the characteristics of the combustion chamber in its combustion chamber (combustion value ξ) and engine mode. The best mode is cruising mode, mostly a complete burning is monitored. In this way, modern engines have $\xi = 0.97...0.99$. For all types of flights the cost is low, for example the rate of fuel burn completeness is less than 0.75. . .0.85, incomplete combustion products (CO and CXHY and others) are released into the atmosphere, and air pollution is happening.

The amount of NOx in the engine exhaust depends on the combustion chamber temperature (high NOx is formed), and maximum (up to 2500 - 3000 K) when taken, and the conversion time of the combustion chamber mixture (usually NOx made), occurs at their lower velocities. That is, most NOx production takes place in and out of the machine, during flight and altitude. It is obvious that the area of the airport engine emissions depends on the way it operates and the duration of operation of this system. Airport area refers to a limited space of 1000 m height and airport size.

$$R^* = R/R0,$$

where R is the thrust of the engine at a given mode; Ro - engine thrust on takeoff mode. The longest and most harmful mode is the low gas mode (idle). The amount of thrust in this mode for newest engines is 3 ... 9% from its maximum value R0. The mode is used for taxiing before take-off and right after arrival, and during engine warm-up. The duration of taxiing depends from the size of the airport, time of departure and arrival, intensity flights and meteorological conditions.

The ICAO Aircraft Engine Emissions Databank comprises all data regarding emissions and pollutants of aircraft engines, calculated in accordance with the procedures in ICAO Annex 16, Volume II, and additionally certified by the engine States of Design and agreed with national regulations. Databank update rate depends on the availability of new data and refreshes at least once a year.

6.5. ICAO CO2 certification requirement

In February 2013, the committee of environment at ICAO issued the final CO2 certification requirement to be referred as the basis for a global CO2 (efficiency) standard for new airplanes. Under the datum requirement, CO2 emissions of new aircraft will be evaluated at three main cruise test points, with aircraft required to satisfy efficiency targets set as a function of their maximum take-off mass (MTOM) after correcting airplane floor area. This way is expected to categorize the CO2 emission condition of new commercial aircraft in proportion to emissions per seat kilometer flown, and in further can be used to set a standard via a single continuous line, and should be inexpensive for manufacturers to certify as it is patterned on existing data gathering practices. Disadvantages of the procedure include its failure to measure non-cruise fuel burn, the use of flight conditions unrepresentative of day-to-day operations, providing no direct crediting for lightweight materials, and uncertainty about whether some future technologies to reduce fuel burn will be accurately characterized under the procedure.

After the three years of work, the International Civil Aviation Organization's (ICAO) Committee for Environmental Protection (CAEP) issued the final version of a carbon dioxide (CO2) certification requirement, including statistics, fuel efficiency tests, and enhanced certification procedures, that will be added as a new revision of the Annex 16 of ICAO's Convention on International Civil Aviation. The certification task describes the steps for manufacturers on how to measure and report the CO2 emissions of new aircraft to certificating authorities, and will serve as the basis for a global CO2 (efficiency) standard for new airplanes.

Key point of the system are:

1. A metric of 1/[SAR], divided by a proxy of aircraft floor area raised to an exponent of 0.24, by which CO2 emissions intensity will be reported.

2. A multiplication factor of maximum take-off mass (MTOM) to meet the regulatory requirement for individual aircraft types.

3. Three equally weighted steady-state test aspects, including high, medium, and low gross weights for which of them the efficiency of each aircraft type is evaluated. ICAO's CO2 certification requirement contains statistical data. As noted above, the metric system is able to differentiate various aircraft technology levels, and thetrefore allows to rank the efficiency of commercial fleet of airplanes, which are responsible for the vast majority of civil aviation fuel use and CO2 emissions.

This is crucial since the latter value is not certifiable because of the number of seats on a given aircraft is selected by an operator, not the manufacturers. The metric system can be used to set a CO2 standard via a single continuous line, reducing the opportunity for gaming through means such as corner effects or reclassifying a given aircraft as a different type in order to gain access to a weaker standard.

The metric system illustrates the following milestones:

1. Failure to measure non-cruise fuel burn: since SAR does not directly measure fuel consumed in non-cruise flight segments – landing and take-off, taxiing, climb and descent – technology such as auxiliary power units improvement that reduce fuel burn on the flight segments is not accespted by the standard.

2. Unrepresentative of day-to-day operations: Airplanes are mostly operated at out of optimal flight conditions, meaning that the fuel efficiency test points does not correspond to the typical operations, generally for practical ceiling altitude limited aircraft such as turboprops and some regional jets. This inconsistency of test conditions from real ones means that improvements measured on the metric may not be referred to the real emission improvements in-service.

3. No direct crediting of lightweight materials: because of the empty weight of the aircraft it is not defined in the requirement for certification and thus ICAO's CO2 standard will provide only limited, impure incentives for technologies to reduce aircraft weight, by means of composites application.

4. Concerns about "futureproofing"*:* The RGF factor, which helps to equilize the efficiency scores all along different aircraft types, was developed from empirical comparisons between nowadays business jets, turboprops, and turbofan aircraft, not an assessment of future approaches. It not known whether this metric system will be convenient for future aircraft with radically different engine type or airframe layout, including open rotor engines and, more speculatively, blended wing body configurations.

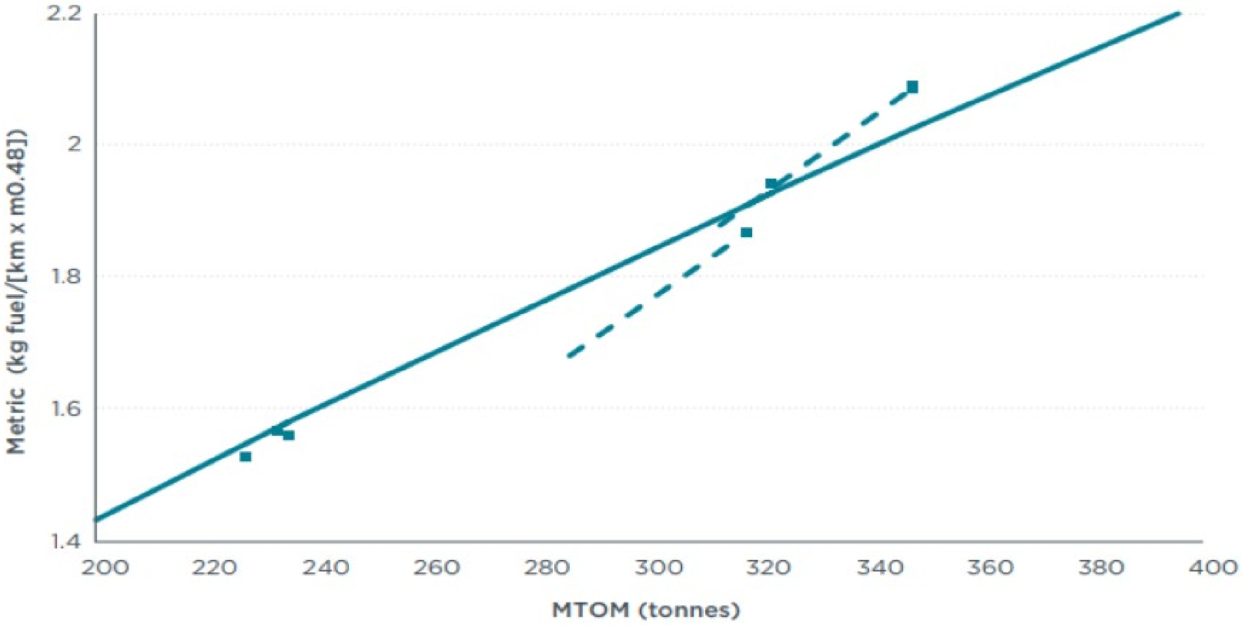

Fig. 6.1. Figure 5.1 - MTOM “paper” changes under a CO2 standard

For this reason, manufacturers will be able to make aircraft with the CO2 standard without gradual improvement in fuel efficiency technology by lowering the range of MTOMs at which they are marketed. These lower paper MTOM positions, while nominally met with the standard, will have the same emissions to higher, non-compliant MTOM variants when used in service. As a rule of thumb, a 5% paper MTOM reduction, which would have significant impacts on revenue and aircraft values, should provide an additional 1.5% margin to a standard.

6.6. Emissions trading system

Effectively addressing the impact of aviation on climate change may prove a major challenge for policymakers. The European Union Emissions Trading Scheme (EU ETS) is one of the main instruments used to reach the statutory reduction of greenhouse gas emissions. This paper defines policy problems regarding the incorporating of the EU ETS in aviation. A two-round Delphi study was undertaken based on a sample of 31 experts from Airlines and the International Air Transport Association; Air Navigation Service Providers; Civil Aviation Authorities;

Government Institutions; consultants and academics. The different allocation approaches of allowances; the linking of EU ETS to similar schemes in other counties/continents; and the interconnection of the scheme with related environmental policies in Europe are found to have a positive effect on the efficiency of the EU ETS.

Aviation was brought into the EU's emission trading system (ETS) in 2012, influencing all flights to and from EU airports. Experiencing the significant international and industry pressure, the scope was decreased to cover intra-EU flights only (known as "stop the clock"). This was assertedly to give time for the UN agency which regulates aviation, ICAO, to satisfy a global measure. A second stop-the-clock regulation to extend the decreased scope was founded in 2014 to grant ICAO more time. At its 2016 triennial assembly, ICAO accepted the outline of a global offsetting scheme known as Corsia.

However, the environmental integrity of that scheme remains unclear, and T&E is among those who have severe doubts as to its potential effectiveness. As a result, the flights to and from Europe was postponed only until 2024, by which time regulators in Europe will have a better understanding of how Corsia is working. Each year, polluters have to experience a number of permits equal to the value of CO2 they procure in the preceding year. Polluters gain permission through an annual allocation system and some are issued by member states for free. If polluters don't have enough permission to justify their previous year's emissions, they can order additional permission at auction or from other air companies having a redundancy. The EU puts a maximum cap on the CO2 emissions that can be emitted by restricting the number of permits available on the market. As issued permits become scarcer due to progressive reductions in the cap, the permit price goes up, providing emitters with an incentive to reduce their emissions where that is cheaper than buying permits.

Conclusion to the Section 6

The following conclusions are provided below based on the research of the aviation engine design development and its influence on the environment:

– regulatory documents have been reviewed related for the environmental protection during aircraft operation;

– analysis of harmful factors during operation and maintenance of the aircraft engines;

– measures have been developed to minimize the influence of aviation engine tryout, operation and maintenance;

– gained the experience and selected the means and methods for engine thrust specific fuel efficiency improvements in order to satisfy strict noise and pollution requirements.

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