International Journal of Engineering & Technology, 7 (2) (2018) 805-816

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET
doi: 10.14419/ijet.v7i2.12483
Research paper

In Tune with Times: Recent Developments in Theoretical, Experimental and Numerical techniques of Aircraft Engines

Armaan A [1], Srinivas G [2] *

[1] Under Graduate student, Department of Aeronautical & Automobile Engineering, Manipal Institute of Technology, Manipal, Karnataka, India. Pin 576104
[2] Assistant Professor (Sr. Scale), Department of Aeronautical & Automobile Engineering, Manipal Institute of Technology, Manipal, Karnataka, India. Pin 576104
**Corresponding author E-mail: srinivasle06@gmail.com*

Abstract

Today the aircraft engine designing and development work is increasing drastically. Especially aircraft engines play a vital role in order to decide the aircrafts speed and its performance. Broadly turbojet, turboprop, turbo shaft and turbofan engines comes under the category of air breathing engines. Every engine has its own purpose and application. But modern aircrafts require much more advancements. Designing a new aircraft engine has been a really challenging task to the researchers. But giving a complete holistic view of aircraft engines and research gap would definitely help a lot to the new designers. Once identified the drawbacks of engine performance can be corrected in the future. For any new design of aircraft engine researchers are suggested to take Theoretical, Experimental and Numerical approaches. Therefore present paper makes an effort to review complete recent Theoretical, Experimental and Numerical approaches which are followed till date. Under all the three approaches all the air breathing engines have been clearly explained and solicited. The effort is to identify the gaps between different approaches which are hampering the process of engine development. The paper also gives the research gaps that need to be incorporated for effective performance enhancement of the aircraft engines for aeromechanical features.

Keywords: *Aircraft; Approaches; Engine; Experimental; Numerical; Theoretical.*

1. Introduction

The human race is developing, evolving, learning and modernizing every moment. The flight by Wright Brothers lasted for only 12 seconds in the year 1903 but the curiosity of humans and urge to fly was such that within 70 years of that 12 second flight the humans were able to touch down on the moon. The underside portion of the first engine which was used by Wright brothers in 1903 can be seen in Fig.1. The oil pumps, cam shaft and rocker arms are clearly visible in the Fig.1. When one studies the timeline of the aviation industry it is clearly evident that aviation industry has seen tremendous and exponential growth compared to any other sector. Obviously the credit for such humongous growth goes to the technological development that has helped in the development of this industry.

The aviation sector has literally turned the world into a global village by reducing the distances between places far off from each other to just a matter of hours. Currently the aviation sector is seeing a boom in its demand and the increase in the number of passenger is due to a number of factors the major being cost reduction and the reliability the aviation sector provides compared to any other mode of transportation. With development in the technology the aircraft industry is able to cut down its operating cost. The development has resulted in the fact that today the difference between the cost of a rail ticket and an air ticket has come down. As this gap lessens the travel industry is going to see more number of people shifting to the air travel.

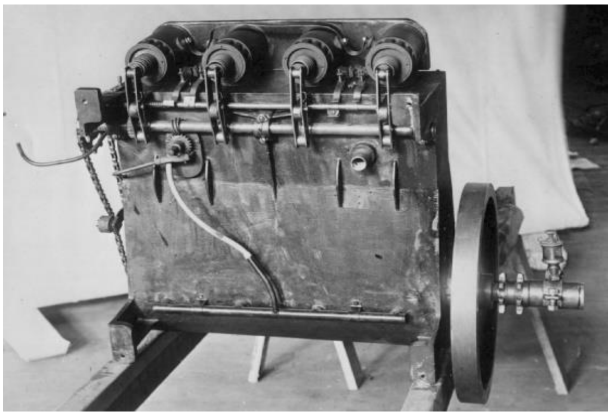

Fig. 1: 1903 Wright Engine Showing Underside Portion as Well as Oil Pump and Camshaft [46].

The negative of such tremendous growth is that all of this development comes at a cost of harming the environment. If this industry has seen the maximum amount of growth then this industry is also causing the maximum amount of damage to the environment. The increase in the use of aircrafts means that the engines of aircraft are going to require more and more amount of fuel considering the fact that even today fossil fuel is the most preferred fuel. The operation of engines also contribute to noise pollution and that to at an alarming rate.

Progress in the design and development of the engines have been very crucial in taking the aviation industry to the heights it has achieved. The journey of the gas turbine engines have been much of a roller coaster ride with each new engine being developed having some pros and cons in their applications.
One of the first engines to enter the world of aviation is the turbojet engine. A turbojet engine is basically a gas turbine engine that has inlet, compressor, combustor, turbine and exhaust in order. It starts by compressing the sucked in air and then sending this high pressure air to the combustor where combustion takes place and then the gas energy is used to run the turbines. Components of a turbojet engine can be seen in Fig.2. The engine basically converts the energy in the fuel to kinetic energy and thus producing the required level of thrust. The concept of the turbojet engine came into existence in the late 1930s. But as more developed engines came into existence the importance and the working radius of the turbojets started reducing. But because of some advantages which are still possessed only by the turbojet engines like small frontal area, high speed exhaust and the simplicity which they have compared to other engines make them the appropriate choice for medium range cruise missiles. Turbojets give very poor efficiency when operated at low speeds. It limits the use of turbojets in types of vehicles other than aircrafts and missiles.

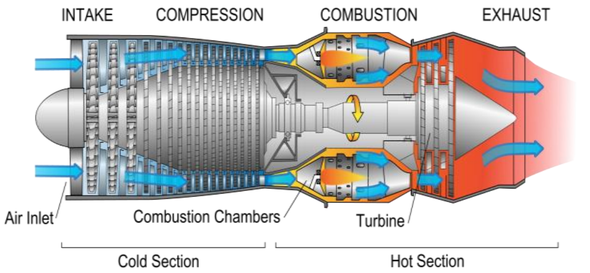

Fig. 2: Turbojet Engine [47].

The turboprop engine has intake, compressor, combustor, turbine and a propelling nozzle. These engines in their basic form drive an aircraft propeller and hence were given the name turboprop. The basic design of turboprop is shown in Fig.3. Unlike the turbojet engines these are not able to generate thrust at a very high rate because of the reason that most of the power is used to drive the propellers. Because of these reasons turboprops work most efficiently when the flight speed is below 725km/hr (390 knots) and need shorter runways making them good for operating in remote areas and harsh conditions. The turboprops have several advantages over the other engines major of them being that the turboprops are fuel efficient and cause less harm to environment in terms of greenhouse emissions produced. But at the same time they are uncomfortable to passengers during flight and have slower travel speeds. Hence even though the turboprops have some disadvantages they have been able to replace the turbojets in most areas of operation. For example in slower aircrafts the turbojets have been effectively replaced by turboprops because they have higher range specific fuel consumption.

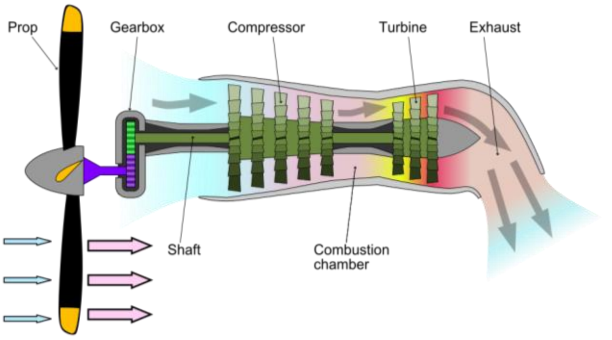

Fig. 3: Turboprop Engine [48].

A turboshaft engine can be safely said as the derivative of turbojet and turboprop engines but it resembles the turboprop more closely. The basic layout of the turboshaft greatly resembles that of a turboprop. The basic layout of turboshaft is shown in Fig.4. Many times a single engine can be sold as both the turboprop and the turboshaft. A turboshaft is actually a modified version of the jet engine where it produces the shaft power for driving the machinery instead of producing jet thrust. Hence the turboshafts generate very little or nearly negligible thrust. They are used in places and fields of operation which require small sized engine but the engine should be powerful, give high output power and be reliable and durable. The major applications include turboshafts being used in Helicopters (sometimes 2 or 3 turboshafts are fitted for heavy choppers), boats and auxiliary units of power. The only reason that the helicopters are able to have a vertical take-off, which is a very big advantage as they can be operated nearly at any place be it desert, sea or remote land areas where having a runway is impossible, is because of the design of the turboshafts which uses the shaftpower to drive a transmission which is in turn structurally attached to a vehicle (Here helicopter's body) thereby lifting the vehicle in air.

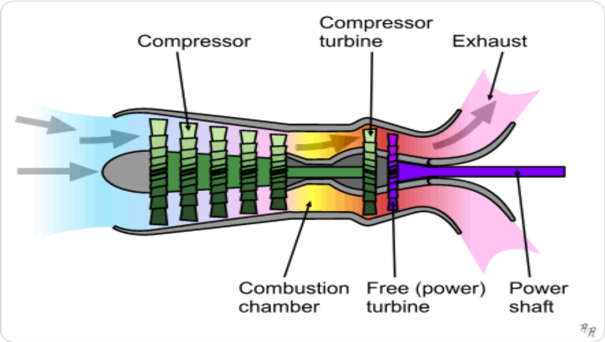

Fig. 4: Turboshaft Engine [49].

In the turbofan engine, the only major difference between the turbojet and turbofan engine is the presence of an additional fan in front of turbofan engine. At a first glance, this does not seem as a very big difference but this has far ranging consequences and gives the turbofan more advantages over the turbojet engine. In the turbofan engines, there is presence of a duct which bypasses the core and the fan present at the front of the engine accelerate the air through this duct thereby giving the turbofan huge amount of air mass flow rate compared to a turbojet engine. The components and design of turbofan engine is shown in Fig.5. Now this has several consequences and the major being that as the engine gives much higher mass per second as the output the thrust generated is tremendous and that to without extra fuel being used as the additional air is not to be ignited. Therefore, the combined effect of the fan and the core produces thrust, which has better fuel efficiency and the output, is larger than that the core could have produced alone. This also makes the turbofan engines quieter thus making them the most dominant engine being used for the medium and long-range airliners which have to take into account passenger comfort level. But the large frontal areas of the turbofan generate more drag which gives the turbofan a disadvantage while being used for supersonic military aircrafts. So in aircrafts of military, where factors like fuel efficiency, comfort and noise are less important while the need to reduce weight and drag is more, turbofans with less frontal areas are used or engine of completely different construction are preferred. Two types of turbofan engine exist namely low-bypass and high-bypass.

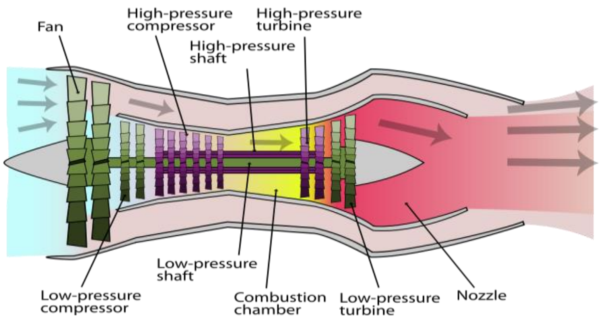

Fig. 5: Turbofan Engine: Low-Bypass [50].

With the recent advancements and developments in the field of engines, engineers have been able to the significantly increase a lot of factors involved like fuel efficiency, structural stability, durability and reliability. This review paper is aimed at conducting a review on the developments that are happening in the aircraft engines, the problems faced and the solutions required for having higher level of advancements in the field. This paper reviews the different types of methods which are being used for conducting the research in the field of air breathing engines. These methods include Theoretical approach, Experimental approach and Numerical approach. This paper will aid the researches in future in the field of air breathing engines development.

2. Recent developments of turbojet engine

2.1. Theoretical approach

Philippe Caisso et al aims at giving a general view or survey of how liquid propellant has changed the world of aviation by giving exceptional speed and range which could never be achieved by solid propellants. With the growing interests of the human race in space explorations it becomes immensely important that one knows all about the liquid propellants as much as one can starting right from its history, manufacturing, storage to the uses it serves. The paper has followed a theoretical based approach as it deals with the general overview on the usage of liquid propellants. The liquid propellant is much harder to produce than any other solid propellant owing to the fact that a lot of chambers like fuel and combustion would be needed. The paper starts from the scratch i.e. it starts by giving the history of rocket propellants, storage method for propellants, the engine cycles involved and the current status of liquid propellants. The paper also deals with the future the liquid propellants hold and the roadmap that could be developed for the effective use of the liquid propellant propelled engines [1].

Joosung J. Lee developed the aircraft systems so that the systems can be made more energy efficient for the world. The paper deals with the obstacles that are being faced in the development of energy efficient engines. The paper follows simple theoretical based approach dealing with the facts and issues related to development of energy efficient systems. The situation faced by the aviation sector currently is that demand exceeds supply. This means that the use of aircrafts is exceeding the rate of development of energy efficient systems. Even today one cannot exactly say how much effect does the use of aircraft for various purpose have on the environment but many scientists agree that the upper atmosphere of earth is being severely affected by the emissions from jet engines. The paper discusses about the methods that the aircraft industry has in place for measuring the efficiency of its systems. It deals with the fuels being used and how new environmental innovations can be induced in the aircrafts. Paper ends by giving recommendations for accelerating the growth of energy efficient systems [2].

G.D. Roy et al discussed the recent trends followed in the area of aircraft propulsion. The article focused more on present technology which is being followed in the advanced propulsion system. In the research, Pulse Detonation Propulsion (PDP) system current expectations, challenges and future prospectus which are being utilized in the field of aircraft industry were discussed in detailed [3].

Onder Turan discussed the design parameters of a small turbojet engine, used for unmanned vehicles, and it has been analyzed for energetic and exergetic performance. Exergy is an important tool for knowing the limits of maximum work for efficiency of any cycle. Theoretical based approach has been used in this article. In the case of complex power systems exergy based analysis was most widely used all over the world. In this work basically exergy efficiency of jet engines have been studied in terms of the turbine inlet temperature and compressor pressure ratio. It is already know by now that exergy analysis provides more knowledge on the system performances than the energy analysis. The use of exergy analysis provides researchers with the major locations of the inefficiencies. Exergy analysis needs a reference environment and hence one always has to provide it with the ambient environment as the system always operates in actual environment [4], [59].

Ernesto Benini et al studied in detail how to setup a 200N static thrust engine that can be used both for didactic and research activities. A large number of small sized turbojet engines are being developed from large turbojet engines by the scaling down procedures. Theoretical based approach has been used in this work. All this was done because of the capability of these engines to be used both for unmanned aerial vehicles and remote control planes. This is because of the high thrust-to-weight ratio these engines provide. The paper deals with all the phases that are involved in developing an engine which include manufacturing, designing and operation. The jet engine discussed here has a single-stage centrifugal compressor, a direct-flow annular combustion chamber and single stage axial turbine [5].

Runkai Zhu et al is aiming to solve the problem faced in selecting the correct engine for the design of the aircraft. Selecting an aero-engine which is in sync with the aircrafts design needs is the first and most crucial step in designing an aircraft. But often it is seen that this judgment is not very clear or is fuzzy. As the selection of engine is very crucial for the performance so it becomes very important that the selection is accurate and not fuzzy. The problem of selecting the correct aero-engine occurs because the current methodology is taking only one particular aspect at a time and hence is unable to reflect the overall performance. This leads to the issue that one becomes unable to select the engine accurately. So the paper takes into account materials and design parameters like bypass ratio, thrust-weight ratio etc. [6].

Leye M. Amoo aims to discuss and review the recent advances in the design and structural analysis for the fan blades of jet engine. The reason for this article being written is the crucial role the fan blades play in the performance of the turbine jet engines. Theoretical based approach has been followed as this is an advanced level study of the fan blade and the structural design these blades possess. With the recent developments and research that is going on in the field of fan blades there has been considerable advancements in the fan blade structural stability and durability. The performance of airplanes and flight vehicles was greatly affected by the aerodynamics and structural mechanics of the components. Among the many components that a jet engine possess the fan blades are especially the most important ones. Over the years development has been occurring in the use of modern materials and new manufacturing technologies. For the development of the fan blades it is important that many factors come together for getting the best output. This starts from selecting the material which is best suitable and also economical. Then comes the production processes that was used for manufacturing the blades. The process should be accurate and also maintain consistency so that the end product was as per the design requirements. If variation exceeds a certain limit then the fan blade produced will not perform as expected and also will certainly not have the structural durability as required [7].

Yousef S.H. Najjar et al aimed at analyzing the effect of parameter like compressor pressure ratio and turbine inlet temperature on the specific thrust and specific fuel consumption. The usage of gas turbine in aircrafts is increasing because of the advantage these have like being light and having high power-to-weight ratio. The main operating variables which include compressor pressure ratio and turbine inlet temperature affect the main performance parameters like specific thrust and specific fuel consumption. Theoretical based approach is the procedure followed in this paper. For the purpose of analysis a computer software called general algebraic modeling system (GAMS) was used. For turbojet engines the performance depends on the effective use of the cycle efficiency, specific fuel consumption etc. Now in the case of turbojet engines the working fluid was air and the thrust thus produced depends on the variation of the kinetic energy of burnt gases [8].

Meyer J. Benzakein focuses on what changes and developments need to be done in the coming future in the aircraft sector. The aviation sector has probably seen the maximum exponential growth since its inception. This can be clearly observed by looking at the history when in 1903 the first flight took off by the wright brothers and a meagre century from that time, thousands of flights take off and land daily covering more than thousands of miles and transporting people and goods from one place to other with extreme safety, accuracy and also economically. This article actually analyses the market of civil aviation by observing and trying to understand what are the expectations of the customer, what developments need to be done in the propulsion system and the flight structure and aerodynamics so that maximum efficiency can be obtained from it and at the same time it becomes economical. This paper discusses on how the improvement in the fuel burn can be brought. Analysis of specific fuel consumption have been going on continuously for the purpose of improving the fuel burn and increasing efficiency [9].

2.2. Experimental approach

M. Badami et al paper discusses the results obtained from numerical and experimental activity on the influence of different types of fuels on the performance of aircraft in terms of the emissions being produced. The aviation sector is growing today at an exponential rate. So one can easily estimate the amount of aviation fuel that must be being used to serve the thirst of engines of aircraft. But it is also not a hidden truth that the aviation sector is also having a severe impact on the environment. So the need to decrease the environmental impact of aviation sector is forcing the aviation companies to look for alternate aviation fuels which will have less impact on environment. The numerical and experimental analysis was conducted on a small turbojet engine having a thrust of 80N at 80,000 rpm. For the purpose of experimental activity the SR-30 turbojet was taken as the workbench (Fig. 6). For the position of sensors on SR-30 refer Fig.7. The experiments and analysis being required in any research activity couldn't be conducted on the real aircraft turbines as it would increase the complexity and cost. Hence, a small scale turbojet engine was used for this purpose. Three different kinds of fuels were tested (i) Traditional jet-A kerosene, (ii) Synthetic gas to liquid fuel and (iii) Blend of 30% jatropha methyl ester(JME) and 70% jet-A [10, 60].

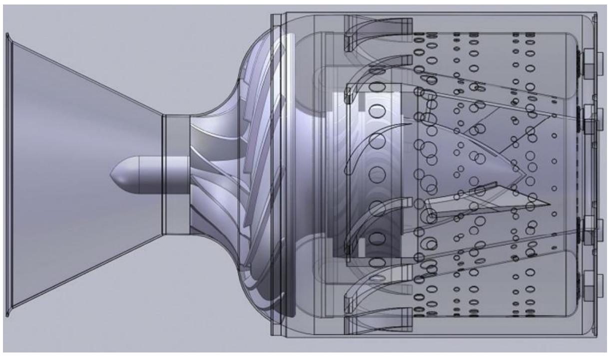

Fig. 6: Turbojet SR-30 Engine [10].

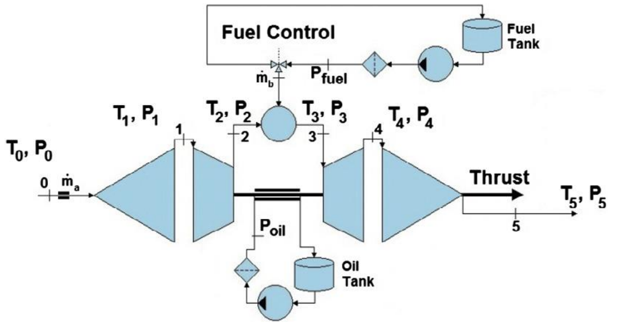

Fig. 7: Layout of the Installed Sensors Showing Bench and the Parameters Measured [10].

Tetsuya Saton et al discussed and analyzed a precooled turbojet engine produced by Japan Aerospace eXploration Agency (JAXA). The precooled engine which was named S-engine is used for the hypersonic aircraft and space vehicles. The thrust and weight of the S-engine are 1.2kN and 100kg. Configuration of S-engine can be seen in Fig.8. The need for such analysis occurs because of the need of reliable, economic and reusable jet engines which can be used for space explorations. This paper follows experimental based approach. As humans explore deep into space it becomes crucial for one to explore the propulsion system being used. New innovations need to be done for high reliability, low cost and the system needs to be such that humans have easy access to space. For such needs the precooled turbojet engine has been introduced to be used as the reusable hypersonic propulsion systems [11].

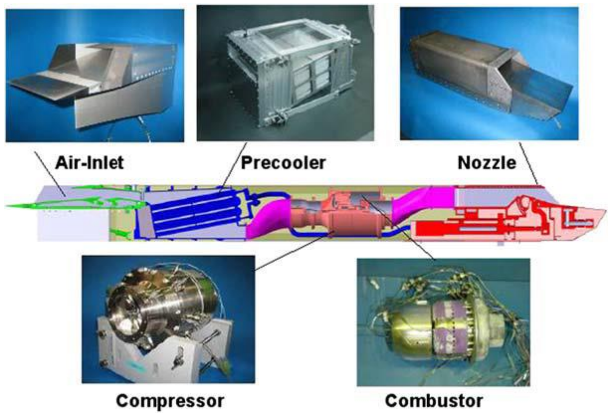

Fig. 8: Arrangement of S-Engine [11].

Tetsuya Sato et al is aimed at discussing the developmental studies happening for a precooled cycle turbojet engine in the first stage of two-stage-to-orbit (TSTO) space vehicle. In today's world where the importance of propulsion system is increasing day by day because of the need to venture into space, a turbine based combined cycle system comes out as a good option for propulsion system. It is so because of the low cost and reliability it may provide. Hence analysis of such an engine becomes crucial. As soon as the design and development of all the components was finished their aerodynamic performance was analyzed and studied with the help of wind-tunnel tests and CFD analysis. These components included the inlet, nozzle and pre cooler. Then a prototype model was developed for the diagonal-flow compressor for further analysis. The method followed here is experimental based approach. The article starts from the description of an S-engine and analyzes a full-scale engine with the S-engine. The manufacturing of small size S-engine no doubt possess great difficulties due to the complicated structures. The S-engine is analyzed over a wide range of flight starting from sea-level-static to Mach 6. Each and every part of the S-engine starting from inlet pre cooler to afterburner and connecting ducts have been analyzed separately in this paper [12].

Airo Watanabe et al is focusing on alternative, more developed and advanced methods for improving the overall engine control. The paper describes the method of designing experimenting a fuzzy logic controller. When an engine enters into service it faces real life critical condition which test its durability and sustainability. The working environment shows no leniency on the engine and gives problems like vibrations. All these problems faced by the engine urges the researchers to go on and seek alternative solutions to control of engines, mitigation and anomaly detection. The use of experimental based approach has been done. The fuzzy logic controller will be used for regulating and controlling the thrust output of the turbojet engine while one continuously keeps on changing the fuel throttle valve. Here a three term fuzzy controller and a linear PID controller are designed and tested. The PID controller functions both as the initial test case and also acts as he starting point for the fuzzy controller design. Block diagram of both engine and controller is shown in Fig.9. Now both of these fuzzy and PID controllers were integrated with the S-engine and tested, and analyzed the results obtained [13].

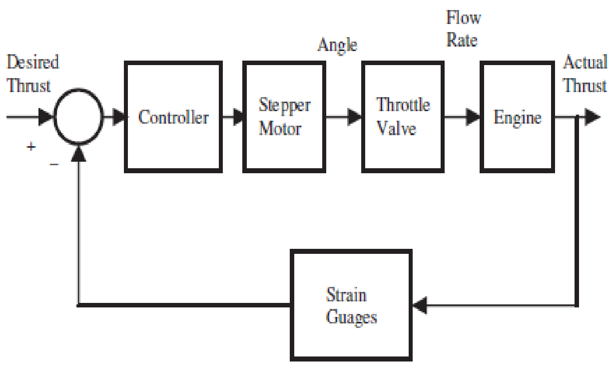

Fig. 9: Engine and Controller Block Diagram [13].

2.3. Numerical approach

Jorge Sousa et al aims at providing a numerical tool that will help in accurately evaluating the thermodynamic and non-isentropic processes that happen across the whole pressure gain combustion engine. Pressure gain combustion is the latest technology that is being researched upon. These have the capacity to give a performance increase of more than 20% compared to any currently being used state of the art technology. Numerical based approach has been used here in this article. But assessment of the overall engine performance is very difficult and new ad-hoc tools need to be developed for the performance analysis of these new combustors. The rotating detonation chamber is in fact a type of pressure gain combustion. Here one or more detonations are moving continuously around an annular channel. The problem being faced for using such a pressure gain combustor is that it operates under very critical and extremely harsh conditions. Also the combination of combustor with the turbo machinery gives unexpected and unknown aero-thermal-structural challenges [14].

3. Recent developments of turboprop engine

3.1. Theoretical approach

Megan S. Ryerson et al is trying to establish the fact that if the regional jets are replaced by turboprops then it will not only be economical but also environment friendly for China. In most of the parts in China regional jets are being used because of their good quality service and the fast speeds at which they travel. But on the other hand turboprops give higher fuel efficiency compared with regional jets which will reduce the cost for carriers and also have lesser impact on air quality and climate in a region where air quality and greenhouse gas emissions are a serious concern. A theoretical based approach has been used here. To analyze the current scenario China airport data has been collected for scheduled flights and then an analysis has been performed on them. With the increase in demand for flights the need is arising for the airports to be opened in remote locations and difficult terrains. There are certain advantages that the turboprops provide in such places. Firstly, turboprops need shorter runways (1400 m compared with 2000 m for jets), offering the possibility of serving more challenging terrains hence turboprops offer enhanced expansion opportunities. Secondly, turboprops are more fuel efficient compared with regional jets. But all this comes at a cost of passenger level of service. Turboprops have slower speeds and are also uncomfortable as compared to jets. Hence, turboprops present challenges compared to regional jets [15].

Hakan Aydın et al studies better understanding of sustainability performances of a turboprop aircraft. This paper aims to create a relation not well established till now, between the exergy and the sustainability of turboprop. If one want to address environmental issues along with sustainability and thermodynamics then there are 2 methods available (i). Energy analysis using the first law of thermodynamics and (ii). Exergy analysis using the first law of thermodynamics. As a general consensus among the scientists it is believed that the exergy analysis is the best way for evaluation of thermodynamic performance. There isn't any doubt that the passenger and cargo traffic in the aviation sector is increasing every day and this leads to the growing concern for the environmental impacts the use of aircrafts has on the environment. The environmental concern are making us shift towards the use of turboprops in increased numbers. Turboprops use less fuel and are very economic for short distance flights. This paper is basically a literature review kind of article. It can be safely said that this paper has a theoretical based approach as it is doing the exergy analysis of the engine with the help of second law of thermodynamics. As already said before, the paper is presenting the exergo-sustainability indicators of the turboprop engine with the help of data present in literatures. The paper aims to find the exergo-sustainability indicators for the turboprop as a function of the shaft torque. For all this the different phases of flight have to be taken into consideration. There are figures and graphs present that show the variation of exergy efficiency with the different phases of flight. At the end the paper concludes by writing the different indicators of exergo-sustainability of the engine some of which are waste exergy ratio, exergy efficiency etc. [16].

Pierluigi Della Vecchia et al discovered new guidelines, for future regional turboprop aircraft with capacity of 90 passengers, in the aerodynamic design and optimization. In the coming years there will be a huge demand for the turboprop engines keeping in mind the increase in environmental hazards due to the aviation sector. Hence new guidelines need to be presented for the aerodynamic design relating to the regional turboprop carrying 90 persons. The software like Matlab and Non-Uniform Rational B-Splines (NURBS) have been used for analyzing critical aircraft components in terms of aerodynamic drag contribution. The use of software have helped in analyzing the design of a typical regional turboprop aircraft. Because of this analysis the new design improvement guidelines came into existence. The studies conducted in past, in the field of aircraft design aimed only at reducing the drag and the parts that these studies usually focused on are wings and the designs of lift surface with special attention to the airfoil design. But at high speed a very important factor for reducing the total drag and improving flight performance is the design of fuselage. In an aircraft the fuselage plays a pivotal role in reducing the drag and hence increasing the aircraft performance. Now the most important part in the aerodynamic design of a fuselage is the junction between the wing and the body. This junction between the wing and body becomes very important because of the fact that it is the place where interaction between components takes place such as the boundary layers [17].

Ozgur Balli aimed at conducting an advanced analysis of the turboprop engine used in the aircrafts. To develop an eco-friendly and cost effective aviation system it is necessary that the formation cost and the impact engines have on the environment be reduced and at the same time the efficiency of the system needs to be held at its maximum. For analyzing the performance of aircraft engines thermodynamic methods of energy and exergy have been widely used. But the energetic analysis methods have a short coming that though they can detect the thermodynamic inefficiencies they do not provide exact details of the losses occurring and the location at while they occur. Exergy analysis method was then used. Exergy analysis method is one of the best methods to identify location, source and type of thermodynamic inefficiencies in the engine system. In this article a new method called exergo-economic analysis has been used, this method is a combination of exergy analysis and economics. In order to attain the objectives it is important that the engine be operated at is optimum mode of operation which includes the selection of best quality fuel, low fuel consumption rates etc. The aim of the exergoeconomic analysis was to make the inclusion of both exergetic values and the cost figures involved in the designing [18].

Megan Smirti Ryerson et al aims to conduct the evaluation of three representative aircraft on the basis of operating and passenger preference costs while taking a total logistics cost approach. The need for such a study was felt because in order to help the aviation industry in aviation systems planning it was required that for similar fleet of all aircraft category are compared over a range of fuel prices for finding the operating and passenger cost which is incurred. After doing this the fleet which was operating at minimum cost would be determined. The cost of the aviation fuel increased by more than thrice the amount between 2004 and 2008 and then suddenly it again dropped down to the price levels of 2004. Because of these actions modest efficiency growth was seen during these years. It has been observed that whenever the prices of aviation fuel increases the turboprop engine operates at the lowest cost per seat on wider distances flight. As a conclusion of this article it was observed that the aircraft which operates at the minimum expenses is the most affected when a change in prices of fuel is seen [19].

Benoit G. Marinus et al conducted a comparative and analytical review of the aircrafts that are presently being used for military purpose. Problem is that the designs of aircrafts that are proposed for civilian aircraft cannot be directly used for military aircraft unless and until they have undergone some changes. Now the data that is available for the military aircraft is actually obsolete and hence cannot meet the latest requirements of military. Data pertaining to tail and wing surface, mass, aerodynamic figures etc. of nearly 43 military aircrafts are being analyzed in this article. The data collected from the database of nearly 43 aircrafts that are being used over airforces all over the world ranging from small attack jets to large carriers are being analyzed. Use of statistical methods like mean and median have been done to compare the values [20].

Ozgur Balli et al discussed and analyzed about T56 turboprop engine at various operating conditions. With the world becoming a global village it is highly important that people and countries become interconnected and such a connection is only possible with highly effective means of transportation. For the analysis of engines the most preferred method was the thermodynamic analysis which includes energy and exergy analysis. Theoretical based approach has been used as the entire engine has been analyzed using thermodynamic laws. This will help people and goods travel and traverse with increased safety. In achieving such development a major role is played by the propulsion systems of aircrafts. As it is already known that exergoeconomic or thermoeconomic is that branch which simultaneously considers thermodynamic analysis, that are based on exergy analysis, and the principle of economics so that such a design can be found which is not only operational but also economical. The methodological approach of the exergoeconomic analysis has been used to develop exergoenvironmental analysis method. This method analyses the environmental impact which happen along with the energy conversions [21].

3.2. Experimental approach

Hyunbum Park's aim of the article is to put focus on the propeller blades of a turboprop aircraft. In this article the propeller blades have been analyzed on the basis of both structural and aerodynamic design. The aircraft industry produces about 3 to 5% of the total carbon dioxide emission in the world making it one of the most CO_2 producing industries among all. So a need has arrived to develop an eco-friendly engine which along with giving high fuel efficiency and good aerodynamic performance also reduces the carbon dioxide emission. The blade element theory and the vortex theory both have been used for the aerodynamic analysis and design of the propeller blades. Fluid-Structure interaction analysis have been done for the selection of structural design load. The propellers are subjected to a number of crucial forces, like centrifugal force, vibration, aerodynamic bending, vibration etc. while operating. The aerodynamic design result for the propeller is shown in Fig.10. In the final stage to finalize the proposed propeller design a prototype was made and compared with the results of structural analysis [22].

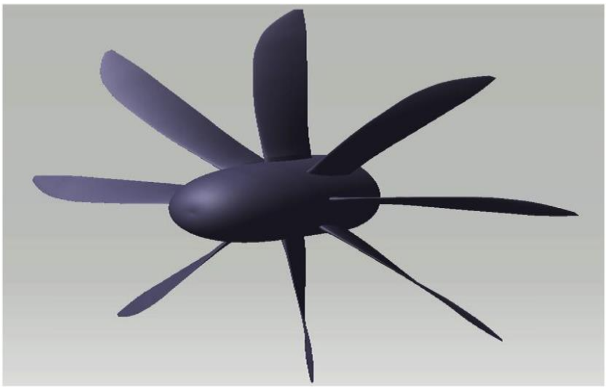

Fig. 10: Result of 3D Aerodynamic Design of Propeller Blade [22].

3.3. Numerical approach

Guangqiang Chen et al has focused and analyzed the equation of control of Multiple Reference Frame (MRF) as the propeller calculation model. The article shows that the MRF was able to precisely predict the aerodynamic interference encountered by an aircraft. In this method the stream traces that are there on the V-tail surface was deflected. Also the pressure distribution on the tail surface was changed. It was found that the slip stream had minimum effect on the aircrafts wing. When the UAV is about to take off the propeller slipstream has maximum influence on the aerodynamic performance of the UAV. In Fig.11 the stream trace of UAV wing is shown for both with and without propeller case. This effect decreases as the UAV climbs and this is reduced to its minimum when the UAV is cruising. Also as the propeller thrust is increased the effect of propeller slipstream is enhanced [23].

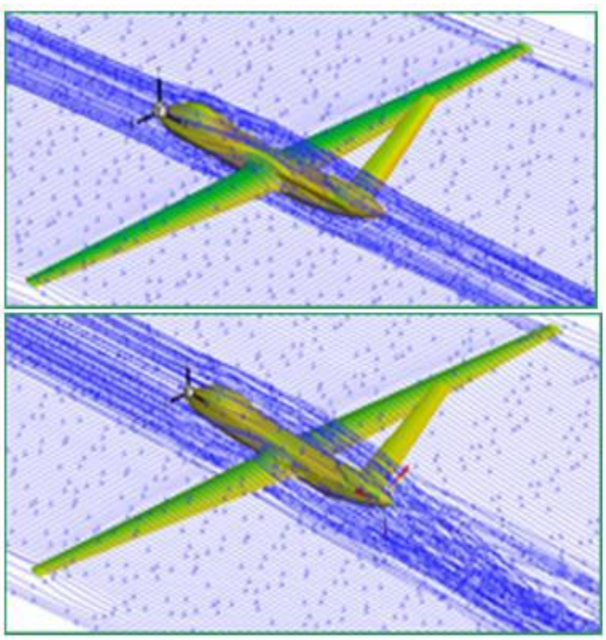

Fig. 11: Comparing the Stream Trace of Both with and Without Propeller UAV Wing [23].

L. P. Ruiz-Calavera et al conducted a study to investigate the feasibility in predicting the vibration and loading environment if Computational Fluid Dynamics (CFD) was coupled with CSM (Computational Structural Mechanics). A step by step approach was taken in order to identify the different effects involved in accessing the capabilities of the CFD coupled with CSM methodology. For the purpose of study Airbus military A400M was taken into consideration. In military transport aircrafts like A400M the high speed propellers are already used. The use of high speed propellers for civil purpose is being thought over. The high speed propellers when at an incidence to the incoming flow are capable of generating in-plane static loads on propeller shafts (called 1P forces). Also generated along with 1P forces are oscillatory loads on individual blades. The loads like 1P and oscillatory depend basically on the aerodynamic design of propeller and the structural features of the blade. In Fig.12 installed propeller aerodynamic mesh can be seen. A precise and early prediction of these loads is necessary because of the strong impact the loads can have on the propellers. Till now the method being used was weak coupling of isolated propeller aerodynamic methods, Finite Element Model (FEM) and CFD calculated flow-fields for the interference of aircrafts. This article aims at predicting this type of loads with the use of CFD coupled CSM technique without assuming simplifying assumptions [24].

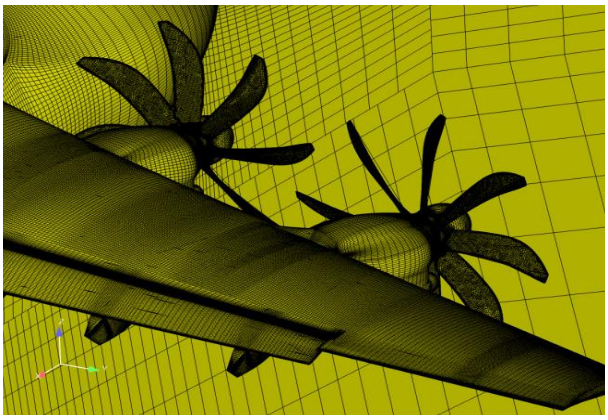

Fig. 12: Aerodynamic Mesh of Installed Propeller [24].

Hairuniza Ahmed Kutty et al discusses the numerical prediction method for determining small scale propeller performance. This study was conducted using computational fluid dynamics (CFD) solver, FLUENT. To determine the discrepancy of the thrust coefficient, power coefficient and efficiencies the numerical results were compared with the experimental data for an advanced precision composites (APC) slow flyer propeller blade. The design of a basic propeller has minimum two blades which are attached to the central hub. By conversion of rotating power from engine shaft required thrust was generated for pushing the aircraft forward. Because of Bernoulli's principle, as the airflow was accelerated it leads to reduction of static pressure in front of blade. At the same time the propeller in its back experiences high static pressure. A thrust force was created because of difference in pressure between the front and back of the propeller. For analyzing the performance of a propeller different methods are available. Three-dimensional CFD simulation was adopted in numerical analysis method using the Reynolds-average Navier-Stokes (RANS) equation. Very less literature was available for work done on small-scale propellers and low Reynolds number. The propellers which are in general used for the Unmanned Aerial Vehicles (UAVs) possess small diameter and low Reynolds number [25].

4. Recent developments of turboshaft engine

4.1. Theoretical approach

Antonio Filippone et al aims to develop technologies for air particle separation that can be used not only for helicopter turboshaft engines but for other machinery also which operates in dirty environments. It was known that helicopters use turboshaft engines. The major advantage of helicopters over any other aircraft is their ability to land anywhere and everywhere, even in the roughest of terrains. Because of this ability of turboshaft a major problem comes and it is that the engines are always operating in unclean environments and these leads to the vulnerability of turboshaft engine to the ingestion of foreign material especially dust and sand. Ingestion of such foreign particles and that to at such high concentrations can cause serious problems for the engine, including compressor blade erosion and combustor wall glazing. Well sand ingestion doesn't seem to be the end of our problems, and while operating in marine conditions an engine may be vulnerable to corrosion and flame-out as a consequence of saltwater consumption. There are certain operating fields like places having vegetation, dusty deserts where the presence of foliage clogs the passage of air intake resulting in flow distortion and losses of high pressure. Also very frequently the presence of rocks, birds, ice chunks (If operational area is glaciers) hamper the compressor blades resulting in a series of problems for the engine. While studying this paper it was clear that this was a theoretical based approach and all through the paper the three types of particle separators are discussed in detail. Because of the above cited problems the use of air-borne particle separation becomes essential. The use of these particle separators has its own side effects which include the increase in weight and drag, power requirements to operate the new system and what not else. The three main technologies discussed here are Vortex tube separators, Inertial particle separators and Inlet barrier filters. While analyzing a turboshaft engine whose inlet is fitted with a particle separator it was found that the key performance parameters are the rate of separation, the inlet pressure loss and the loss of inlet mass flow rate. The residual particles can still cause damage to parts of the engine, but indirect damage may also occur as a consequence of contaminated lubricant, fouling of controls, clogging of small passages and other factors. One of the fundamental problems is to decide which particles to filter. Sufficiently small particles, once lifted from the ground, stay aloft for a considerable time, larger particles would tend to fall under the effect of their own weight. Thus, although the ingestion of larger particles can be more damaging, their occurrence is less likely [26].

4.2. Experimental approach

Kahraman Coban et al tells that as the global demand for energy increases it is leading to an increase in the environmental impact which is being caused due to the use of energy systems. So engineers today are striving to improve the efficiency of energy systems which will give one better output and also lead to a decrease in the environmental impact being caused. This article presents the energetic and exergetic analyses of a turboshaft engine which is used for military helicopter at various load values. The main objective of this study is to assess the performance of the engine and to calculate the amount of exergy destructions in the components of the engine. The calculations were performed at four different load values (284 N-m for test No.1, 436 N-m for test No.2, 547 N-m for test No.3 and 579 N-m for test No.4). The exergetic performance parameters, such as the relative exergy destruction, the fuel depletion ratio, the productivity lack and the improvement potential were also investigated. Experimental engine ground test data along with theoretical thermodynamic performance evaluation has been done. The analysis of the performance of an 'energy conversion system' can be done thermodynamically using the concepts of energy and exergy. The energy analysis takes into account the quantity of energy, the exergy analysis deals with the quality of energy. As exergy unveils the degradation of energy, which causes the inefficiency of the system, exergy analysis was very helpful in defining the type, location and magnitude of the destructions. This allows us to focus on the components where the greatest exergy is destroyed and accordingly modify the design of the energy system. Therefore, many engineers and scientists suggest that the evaluation of thermodynamic performance is best done by exergy analysis as it provides more insights and is more useful in efficiency improvement efforts than energy analysis [27].

4.3. Numerical approach

Narjes Ahmadian is focused on the study of twin spool turbo shaft engine driving a variable pitch propeller. The aim is to develop a multiple model adaptive control method for gas turbine engine. The diagram of turboshaft is in Fig.13. The model of a twin spool turbo shaft engine driving a variable pitch propeller include various operating points and a variation in fuel flow and propeller pitch inputs will produce different operating conditions because of which the controller has to adopt itself rapidly. Here a multi-input multi-output (MIMO) version of second level adaptation using multiple models was developed. At last the proposed method was compared with two conventional first level adaptation. Stability analysis using Lyapunov method is presented. In section 2 of the paper i.e. physics-based model of the turbo-shaft engine the problem statement a physics based model of a twin spool turbo shaft engine was described. The spool dynamics was presented using Newton's second law and the gas turbine engine's nonlinear differential equations are described. The subsequent sections do numerical based research on various objectives of this paper like model reference adaptive control (MRAC) control strategy is described for MIMO systems [28].

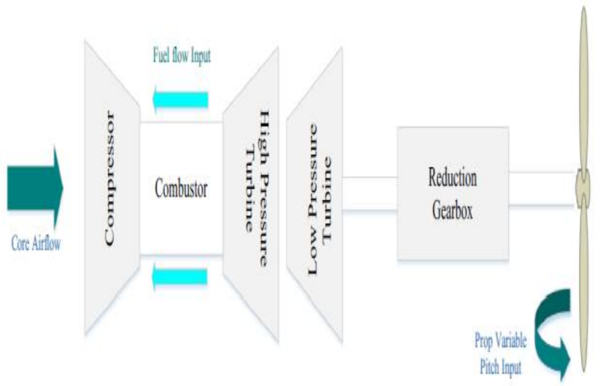

Fig. 13: Turboshaft Engine Diagram [28].

Onder Turan et al studied to have a deeper knowledge of the energy and exergy use throughout turbo shaft engine and its components, so that a more efficient engine can be developed which also reduces the environmental impact caused by the use of gas turbines. One is well aware of the facts that the with the tremendous increase in world's energy and air transportation need, the number of aero gas turbines and turbo shaft engines increases every year. Because of the increase in the energy demand engineers are facing the ultimate challenge of minimizing the environmental impact which is caused because of the use of gas turbine engines. The challenges faced in the task include the reduction in noise pollution use less energy. The fuel efficiency of the aircrafts also a major concern because the availability of fuel is limited and with the increased use the fuel sources are diminishing rapidly. So it becomes extremely important to have a better knowledge of energy and exergy use throughout turbo shaft engine and its components. In this study energy and exergy-based computational approach has been applied to a turbo shaft engine and its components. In this paper numerical based approach has been taken to get to the desired results. The starting of the approach was from the consideration of first and second laws of thermodynamics. For gas turbine engines traditional design procedure is thermodynamic first law analysis and it is energy-based approach. But the exergy is based on entropy generation minimization. The main target of exergy destruction is finding the actual magnitudes of exergy destruction and their precise location and help improve the system performance [29].

5. Recent developments of turbofan engine

5.1. Theoretical Approach

Yasin Sohret et al has aimed to conduct an exergy analysis using thermodynamic laws of a turbofan engine which is the power unit for an unmanned aerial vehicle. As the world is advancing towards modernization the demand for energy is increasing tremendously. Even today fossil fuel serve as a better and more sought after fuel instead of the renewable sources of energy. Hence this puts pressure on the scientific community to develop more efficient energy systems. For this a pivotal role is played by energy engineering. The exergy analysis has two parts. Namely, the first and second law of thermodynamics. The work of the first law is to deal with conversion of energy while the second law has the work of telling the limitations which a system will possess when it is under actual operating conditions. There are very few research papers available which deal with the exergy analysis of the turbine engines used in UAVs. So the progress will come only when one focuses their attention towards it and it will start by investigating from exergy point of view. In this article each component has been analyzed based on exergy parameters [30].

Ozgur Balli conducted an exergy analysis in order to evaluate the level of sustainability of a high by-pass turbofan engine. The objective for such an analysis again boils down to the fact that with the increase in the number of flight everyday the aviation sector is doing the job of making the world a global village by connecting the people across the world. It is also at the same time affecting the environment adversely and also bringing down the quality of atmosphere with the emissions and noise generated by the engines. Trends have shown that as development in the technologies used in the engines increases the emissions are coming down by good numbers. Hence developments and research need to be increased so that one can create aviation sector that is eco-friendly. The production of high bypass turbofan engine have been going on since 1984 and was started by Pratt and Whitney. The engine being taken for analysis in this paper is PW4056. This engine produces a thrust of 249.1kN and is set up on the commercial aircraft of Boeing specifically 747-400. The turbofan engine used here was made up of single stage fan, four stages axial-low pressure compressor etc. Full technical specification has been provided in the paper [31].

Onder Turan aimed to come up with a new methodology which will show the way to apply exergetic metric in order to map the exergy flow happening via a high bypass turbofan engine when it is at its maximum thrust, to conduct sustainability assessment of the engine. With time and development air transportation is quickly becoming the backbone of the economy. Hence it becomes important that this method of transportation is made as eco-friendly as possible so that humans can have sustainable development. Now for analyzing the sustainability and durability of the airplanes and engines exergetic sustainability method has proved to be an effective way. The engines of aircraft are able to convert the chemical energy stored in the aviation fuel and use this energy for propelling the aircraft. Out of the total energy generated from the fuel only $1/3^{th}$ is used in propelling the aircraft while the rest is expelled as waste heat from the exhaust. For creating green aircrafts the researchers and engineers are trying to optimize the energy saving thus creating eco-friendly engines. It is a general conscience among the research community that the thermodynamic performance is best evaluated using the exergy analysis. In the exergy method of system analysis the second law plays a very crucial role as it includes the reversibility or irreversibility of processes [32].

Tolga Baklacioglu et al article aims to successfully conduct a comprehensive dynamic modelling of the turboprop engine with the use of hybrid GA-ANN strategy (Genetic Algorithm-Artificial Neural Network). For the purpose of improving the output of energy systems and the power cycles, minimizing the entropy generation comes as a powerful tool. But for this a number of factors need to be accessed at the same time like thermodynamics, environment, energy and obviously the economy. The components of a turboprop engine includes compressor, combustor gas and power turbine. In the GA-ANN method 5 independent engine variables are taken into account and then these dynamic variables are used as inputs in the ANN while exergy efficiencies of the system become the output parameters. The task of optimizing the design of energy system is not an easy task. It involves making changes in the system structure and the parameters of component design. These changes will be done keeping in mind one or more specific design objectives. In a design process many objectives are involved like thermodynamics, economics, environmental effects etc. [33].

Sangjo Kim et al aim of the paper is to show that the combined use of variable guide vanes and bleed air is effective for the thermodynamic performance of aircraft engine. For the past century a number of literature have been published to analyze the effectiveness of variable guide vanes and bleed air. Bleeds possess the ability for achieving a greater mass flow through front stages of compressor [51-52], [55-56]. The paper is a theoretical based approach. This leads to a decrease in the relative flow angle at rotor leading edge because of the increase in axial velocity. The task of VGVs on the other hand is to redirect the air towards the rotor so that the incidence angles of the rotors have a good range away from the stalling incidence. This paper basically conducts a comparative study of the performance of the aircraft engine with variable guide vanes and bleed air, both separately and simultaneously. The use of genetic algorithm has been done to reach and know the optimized schedule of VGVs and bleed air. Well the results obtained in this article are able to show that the additional use of bleed air increases the compressor's efficiency hence achieving the target of optimizing engine performance [34].

Sangjo Kim et al aimed at improving the performance of turbofan engine with a set surge margin by conducting a full engine cycle analysis in order to know the schedule of variable guide vanes in a multi-stage axial compressor. We need a full engine cycle analysis because most of the time while in the process of scheduling of VGVs the engineers and scientists assume the operating line of the compressor. But now it is known that the performance of compressor is affected by the angle of VGVs. So the variation in performance of compressor affects the engine. Hence a full cycle analysis is needed to take into account the effects of VGVs on a turbofan engine. Theoretical based approach has been used. In order to do the performance prediction of a multi-stage axial flow compressor with VGVs one uses 1D meanline analysis. For considering the performance variation of engine with the application of VGVs the engine simulation program is coupled with compressor performance prediction tool. The scheduling algorithm of inlet guide vane and stator vane that has been proposed is adjusting the vanes angle to have minimum loss incidence angle at all rotor blades [35].

Andr´es Marcos et al this paper is aimed at discussing the applications of robust identification approach to turbofan engine. In the aerospace industry in order to increase their reliability and optimize the maintenance schedules the usage of aircraft engine anomaly and Fault Detection and Isolation (FDI) is very important in terms of cost minimization also. All of the approaches done for FDI give us the analytical redundancy with the help of a model obtained from first principles. An important alternative to such an approach was the robust identification. The identification approach used here takes into account together the parametric identification for the nominal and fault models and uncertainty characterization. This particular combination of nominal and model error model identification is called Robust Model Identification Approach [36].

Charlie Svoboda in the year 1996 did the compilation work of a large number of turbofan engine was done. The minimum bypass ratio of all the engines in the database was 2. In this article the graph of key parameters like dry weight, cruise thrust etc. were plotted mostly as a function of take-off thrust. In preliminary airplane design the engine can be quickly defined with the help of resulting plots. These plots are a very good source of information in such cases. Theoretical based approach is the approach taken in this paper. Simple result plotting has been done with the help of database collected in the year 1996 [37].

Yasin Şöhret paper was aimed at giving detailed explanations of methods which involve exergy based analysis. Among the two types of analysis which thermodynamics provides us, namely energy and exergy it is known that exergy analysis is a better method for analyzing systems and so is more preferred. Exergy Analysis is not only a method which helps one to study energy consumption but also a useful method for optimization of the thermal systems. Two laws of thermodynamic helps analyze the system and make it more efficient. The first law of thermodynamics talks of conservation of energy and tells us that energy can change from one form to other bit the total energy always remains constant. Whenever a system is analyzed with the help of first law it tells us how the energy is consumed in the system or let's say how the energy changes its form. Now in an aircraft engine exergy is destroyed and entropy is generated. Hence the assessment of the engine based on exergy become crucial. Exergy analysis also tell us precisely the locations where energy is lost. This paper tells necessity to perform state of the art exergy analysis [38].

A general aircraft is needed to operate under various non-design environment conditions like sudden pitch up, sudden pull down, sudden rolling, and sudden yawing motions. During these conditions aircraft engines may undergo huge turbulence which finally leads to low performance. Murat Yasar et al developed a theory for functioning of the aircraft twin engines under different operating conditions. So that without any side force problems aircraft reaches the mission objectives. To accomplish more thrust in the twin turbofan engines, author developed a language measure based Discrete Event Supervisory (DES) control system. With the help of proposed DES control system one can improve the quality of aircraft engine performance by operating in different operating conditions [39].

Cesare Tona et al evaluates the global performance of a turbofan engine and its components with the help of Exergy Analysis. The aviation industry has always aimed at reducing the cost and increasing the performance and efficiency of aircraft and engines. It has also been successful in doing so because this sector has with time developed extremely complex aircrafts and engine systems. But more advanced tools and methods are needed for further analysis and design of energy conversion systems. An aircraft is a very complex system in itself because it is made up of huge number of even complex systems and components which are themselves subjected to harsh operating conditions while in flight. While developing new systems in aircraft design it is important that there is a common basis for comparing different alternative design. Hence the use of exergy analysis shows us a new way in which the comparative study could rely. A complete exergy analysis of an aircraft allows us to analyze the exergy efficiency, destroyed exergy rates and the distribution of irreversibilities among the systems [40].

5.2. Experimental approach

Didier Henrion studied linearized models of aircrafts that have been derived from the standard engine simulators with the help of experiments. With the advent of the era of high bypass turbofan engines in both the civil and military aviation the pressure on control laws increased along with the expectations on performance. When operating in normal conditions the turbofan of an aircraft experiences extreme changes in ambient temperature and pressure, Mach number etc. and as a result of this the dynamics of engine changes in nonlinear manner when designing the control laws it should be noted that mechanical, aerodynamic limitations of the turbo machinery are taken into account [41].

Aircraft engine undergoes huge turbulence while operating under non-design environment conditions. Due to this non design environment conditions the engine may undergo huge vibrations and this also further leads to unexpected noise. In today's aircraft industry one of the challenging research area is acoustic and vibrational problems. S.M. Li et al developed an experimental setup in order to estimate the modern turbofan supersonic engine inlet during take-off and landing conditions. The experiment was suitable for these two conditions, therefore one can go for further research in other phases of flight envelop [42], [57], [58].

5.3. Numerical approach

Dilip Prasad et al studied the effects of inlet duct liner on the acoustics of a high bypass ratio turbofan rotor in this paper with the help of Numerical investigation technique. With the increase in the aviation traffic day by day the noise being produced is creating problems at an environmental level. Numerical based approach has been applied in this paper. Now in an aircraft the major source of noise is the propulsion system. Hence a good amount of attention is being given to the design of propulsion system. In past the studies conducted on inlet tone noise have focused only on linear waves and hence these studies are insufficient for studying the noise generated because of shock. The evolution of the shock system was studied here using method based on computational fluid dynamics [43], [53], [54].
Luc Reberga et al studied a military turbofan engine simulator and was aimed at describing the application of quasi-LPV modelling techniques to it. Even today the improvement of control policies for the turbofan engine is a challenge. The target is to reduce the manufacturing cost and increase the performance when in flight. The difficulties faced by researchers include lack of good and reliable analytic models for the turbofan engines. Recently a new modelling framework has been developed called Linear Parameter Varying (LPV) models. This method provides one with theoretical framework in order to ensure stability, performance and robustness of the control system. All this was done by this method with the help of convex optimization over Linear Matrix Inequalities (LMI) [44].
C. Priyant Mark et al main aim of this paper is the design of the annular combustion chamber in gas turbine engines. The position of the combustion chamber is between compressor and turbine. The designing of the combustion chamber needs to be based on enthalpy addition process and constant pressure. The method that was used for obtaining results in this article is numerical based approach. With time and development in the field of aviation the gas turbine engine emerged as the most efficient propulsion system and a critical part also. Currently it is being used in all the civil aviation aircrafts but with slight variations. With more technological development the military aircrafts even at supersonic speeds started using low by pass turbofan engine because of the advanced capabilities it has and the efficiency and reliability it provides. Having fuel efficiency is very important for both civil and military aircrafts. For improving the efficiency the designing of an efficient combustion chamber is very crucial because the answer for better efficiency lies in the combustion chamber. The most often used and preferred combustion chamber is the fully annular combustion chamber as it has separate combustion zones and a continuous casing called the annulus [45], [55].

6. Conclusions

The increasing demand for the aircraft services puts an increased pressure on the scientific and research community to develop engines that can be made more and more environmental friendly. The development is not going to be a cake walk because of the difficulties that testing and research work provides. First being the high economic costs that such research incurs because the operating conditions of the engine while in flight completely differ from that when it is being tested in a lab. So for simulating conditions of an actual flight state of the art technology and devices are required which are expensive. This is the reason that maximum number of literature and research paper that are available on the development of engine are based on Theoretical and Numerical approaches instead of Experimental approach and this can be clearly seen in this paper. In many cases even though the eco-friendly engines have been developed they cannot be put to use because of the fact that either their usage is not economically feasible for the industry or it will sacrifice the comfort of the passengers on board. Even though turboprops are a better choice over most of the jet engines (because it give higher fuel efficiency over regional jets, have lesser impact on air quality, need shorter runways to operate) these cannot be used everywhere effectively because of slower speed and are uncomfortable to passengers also as compared to regional jets. Through the literature it was found that the Theoretical, Experimental and Numerical approach taken for the research in the field of air breathing engines are facing many drawbacks among themselves. As the Theoretical approach does not take into account the operating conditions in which an engine works. The problem of taking into account the operating conditions is taken care when an experimental approach has been taken into consideration. Nowadays most of the approaches which are being taken by researchers do not take into account the speed levels like transonic (Mach speed 0.8 to 1.2) and supersonic (Mach Speed > 1) at which the engine operates in the aircrafts.
The aviation industry and the researches in this field are facing obstacles because of the requirement of optimizing a number of factors like customer satisfaction, reliability, safety of the flights, economic feasibility etc. The aim of the studies and researches is to develop an eco-friendly and cost effective aviation system with the condition that the formation costs and the impact these engines have on environment is reduced and at the same time the efficiency of these systems be held at maximum. One needs to keep looking for alternative, more developed and advanced methods for improving the engine in terms of efficiency, less emissions, reliability, durability etc.

7. Future scope in aircraft industry

If one starts studying the economics and the world economy for the coming future it shows that the world is going to see a significant growth in Gross Domestic Product (GDP) and this would obviously result in an increased demand for commercial aircraft all over the globe. Not only for commercial and civil use but if one takes a peek into other sectors like defense and space explorations then also there is an eminent need to develop the aviation sector because now humans need to go beyond the moon and this would happen with advanced aircrafts and space vehicles. The new demand of aircrafts will bring with itself an additional focus on more fuel efficient and more environment friendly aircrafts. Looking beyond the horizon one will find new aircraft designs, developed propulsion systems, greater efficiencies of engines etc. Studying the present ongoing research and development works one can predict that the new system will give nearly 40% more fuel efficiency. But there is also some precautions and care which need to be taken for the future. The ever increasing demand for aircraft travel has actually outpaced the rate at which the research work for energy improvements of aircrafts systems is going on. The exponential increase in the total energy consumption and the emissions by the aviation industry is increasing the need for a more operational and technical innovations. As it is said to create a better solution it is very important that you first understand the problem in a better way. Knowing the problem is winning 50% of the war! So there is a need to better evaluate, understand the effect of aviation on the environment. Hence it is very important that the world comes together for the sustainable development of this sector so that one can accumulate knowledge and then disperse this knowledge among firms and other stakeholders creating an environmental friendly and conscious market.

Acknowledgment

I would like to express special thanks of gratitude to my guide and supervisor Srinivas G. (Assistant Professor Sr. Scale) whose good guidance and instructions helped in completing this paper. Besides his guidance, he sacrificed his precious time to help the author explore various fields of knowledge to enhance the quality of the paper. I would like to thank Amma for the support she has provided and Nanu for the belief he had in me over the years. I dedicate this paper to Amma and Nanu. This paper would have never been completed without hearing the sweet voices of encouragement from my siblings Parth and Anish who via video calling kept urging me to achieve more. I would like to thank my mother Renuka, Jaya and

Rashmi for the thankless job of caring for me they have done all over these years.

References

[1] Philippe Caisso, Alain Souchier, Christophe Rothmund et al, "A Liquid Propulsion Panorama", Acta Astronautica, 65, 2009, 1723–1737. https://doi.org/10.1016/j.actaastro.2009.04.020

[2] Joosung J. Lee, "Can we accelerate the improvement of energy efficiency in aircraft systems?",Energy Conversion and Management, 51, 2010, 189–196. https://doi.org/10.1016/j.enconman.2009.09.011.

[3] G.D. Roy, S.M. Frolov, A.A. Borisov et al, "Pulse detonation propulsion: challenges, current status, and future perspective", Progress in Energy and Combustion Science, 30, 2004, 545–672. https://doi.org/10.1016/j.pecs.2004.05.001.

[4] Onder Turan, "Exergetic Effects of some design parameters on the small turbojet engine for Unmanned Air Vehicle Applications", Energy, 46, 2012, 51-61. https://doi.org/10.1016/j.energy.2012.03.030.

[5] Ernesto Benini and Stefano Giacometti, "Design, manufacturing and operation of a Small Turbojet-Engine for research purposes", Applied Energy, 84, 2007, 1102–1116. https://doi.org/10.1016/j.apenergy.2007.05.006.

[6] Runkai Zhu, Qianchao Liang and Haiyang Zhan, "Analysis of Aero-engine Performance and Selection Based on Fuzzy Comprehensive Evaluation", Procedia Engineering, 174, 2017, 1202 – 1207. https://doi.org/10.1016/j.proeng.2017.01.283.

[7] Leye M. Amoo, "On the design and structural analysis of jet engine fan blade structures", Progress in Aerospace Sciences, 60, 2013, 1–11. https://doi.org/10.1016/j.paerosci.2012.08.002.

[8] Yousef S.H. Najjar et al, "Optimization of gas turbines for sustainable turbojet propulsion", Propulsion and Power Research, 4(2), 2015, 114–121. https://doi.org/10.1016/j.jppr.2015.05.004.

[9] Meyer J. Benzakein, "What does the future bring? A look at technologies for commercial aircraft in the years 2035–2050", Propulsion and Power Research, 3(4), 2014, 165–174. https://doi.org/10.1016/j.jppr.2014.11.004.

[10] M. Badami, P. Nuccio, D. Pastrone and A. Signoretto, "Performance of a small-scale turbojet engine fed with traditional and alternative fuels", Energy Conversion and Management, 82, 2014, 219–228. https://doi.org/10.1016/j.enconman.2014.03.026.

[11] Tetsuya Saton, Hideyuki Taguchi, Hiroaki Kobayashi et al, "Development study of a precooled turbojet engine", Acta Astronautica, 66, 2010, 1169–1176 https://doi.org/10.1016/j.actaastro.2009.10.006.

[12] Tetsuya Sato et al, "Development study of precooled-cycle hypersonic turbojet engine for flight demonstration", Acta Astronautica, 61, 2007, 367 – 375 https://doi.org/10.1016/j.actaastro.2007.01.012.

[13] Airo Watanabe et al, "Soft computing applications on a SR-30 turbojet engine", Fuzzy Sets and Systems, 157, 2006, 3007 – 3024. https://doi.org/10.1016/j.fss.2006.05.011.

[14] Jorge Sousa et al, "Thermodynamic analysis of a gas turbine engine with a rotating detonation combustor", Applied Energy, 195, 2017, 247–256. https://doi.org/10.1016/j.apenergy.2017.03.045.

[15] Megan S. Ryerson et al, "The role of turboprops in China's growing aviation system", Journal of Transport Geography, 40, 2014, 133–144. https://doi.org/10.1016/j.jtrangeo.2014.03.009.

[16] Hakan Aydın et al, "Exergo-sustainability indicators of a turboprop aircraft for the phases of a flight", Energy, 58, 2013, 550-560. https://doi.org/10.1016/j.energy.2013.04.076.

[17] Pierluigi Della Vecchia et al "Aerodynamic Guidelines in Design and Optimisation of New Regional Turboprop Aircraft", Aerospace Science and Technology, 38, 2014, 88–104. https://doi.org/10.1016/j.ast.2014.07.018.

[18] Ozgur Balli, "Advanced exergy analyses of an aircraft turboprop engine (TPE)", Energy, 124, 2017, 599-612. https://doi.org/10.1016/j.energy.2017.02.121.

[19] Megan Smirti Ryerson and Mark Hansen, "The potential of turboprops for reducing aviation fuel consumption", Transportation Research, Part D, 15, 2010, 305–314. https://doi.org/10.1016/j.trd.2010.03.003.

[20] Benoit G. Marinus et al, "Data and design models for military turbo-propeller aircraft", Aerospace Science and Technology, 41, 2015, 63–80. https://doi.org/10.1016/j.ast.2014.12.009.

[21] Ozgur Balli et al, "Energetic and exergetic analyses of T56 turboprop engine", Energy Conversion and Management, 73, 2013, 106–120. https://doi.org/10.1016/j.enconman.2013.04.014.

[22] Hyunbum Park, "Advanced turboprop composite propeller design and analysis using fluide structure interaction method", Composites, Part B, 97, 2016, 111-119. https://doi.org/10.1016/j.compositesb.2016.04.054.

[23] Guangqiang Chen et al, "Numerical Simulation Study on Propeller Slipstream Interference of High Altitude Long Endurance Unmanned Air Vehicle", Procedia Engineering, 99, 2015, 361 – 367. https://doi.org/10.1016/j.proeng.2014.12.548.

[24] L. P. Ruiz-Calavera and D. Perdones-Diaz, "CFD based aeroelastic calculation of propeller loads", 28TH International Congress of the Aeronautical Sciences (ICAS 2012).

[25] Hairuniza Ahmed Kutty et al, "3D CFD Simulation and Experimental Validation of Small APC Slow Flyer Propeller Blade", Aerospace 2017, 4, 10. https://doi.org/10.3390/aerospace4010010.

[26] Antonio Filippone et al, "Turboshaft engine air particle separation", Progress in Aerospace Sciences, 46, 2010, 224–245. https://doi.org/10.1016/j.paerosci.2010.02.001.

[27] Kahraman Coban, C. Ozgur Colpan and T. Hikmet Karakoc "Application of thermodynamic laws on a military helicopter engine", Energy xxx, 2017, 1-10. https://doi.org/10.1016/j.energy.2017.07.179.

[28] Narjes Ahmadian, "Adaptive control of a jet turboshaft engine driving a variable pitch propeller using multiple models", Mechanical Systems and Signal Processing, 92, 2017, 1–12. https://doi.org/10.1016/j.ymssp.2017.01.023.

[29] Onder Turan and Hakan Aydın, "Numerical calculation of energy and exergy flows of a turboshaft engine for power generation and helicopter applications", Energy, 115, 2016, 914-923. https://doi.org/10.1016/j.energy.2016.09.070.

[30] Yasin Sohret, Ali Dinç and T. Hikmet Karakoç, "Exergy analysis of a turbofan engine for an unmanned aerial vehicle during a surveillance mission", Energy, 93, 2015, 716-729. https://doi.org/10.1016/j.energy.2015.09.081.

[31] Ozgur Balli, "Exergy modeling for evaluating sustainability level of a high by-pass turbofan engine used on commercial aircrafts", Applied Thermal Engineering, 123, 2017, 138–155. https://doi.org/10.1016/j.applthermaleng.2017.05.068.

[32] Onder Turan, "An exergy way to quantify sustainability metrics for a high bypass turbofan engine", Energy, 86, 2015, 722-736. https://doi.org/10.1016/j.energy.2015.04.026.

[33] Tolga Baklacioglu, Onder Turan and Hakan Aydin, "Dynamic modeling of exergy efficiency of turboprop engine components using hybrid genetic algorithm-artificial neural networks", Energy, 86, 2015, 709-721. https://doi.org/10.1016/j.energy.2015.04.025.

[34] Sangjo Kim, Changmin Son and Kuisoon Kim, "Combining effect of optimized axial compressor variable guide vanes and bleed air on the thermodynamic performance of aircraft engine system", Energy, 119, 2017, 199-210. https://doi.org/10.1016/j.energy.2016.12.076.

[35] Sangjo Kim et al, "A Full Engine Cycle analysis of a Turbofan Engine for Optimum scheduling of Variable Guide Vanes", Aerospace Science and Technology, 47, 2015, 21–30. https://doi.org/10.1016/j.ast.2015.09.007.

[36] Andr´es Marcos, Dinkar Mylaraswamy and Gary J. Balas, "Robust Model Identification Application to a Turbofan Engine", Elsevier IPAC Publications.

[37] Charlie Svoboda, "Turbofan engine database as a preliminary design tool", Aircraft Design, 3, 2000, 17-31. https://doi.org/10.1016/S1369-8869(99)00021-X.

[38] Yasin Şöhret, "Exergy as a useful tool for the performance assessment of aircraft gas turbine engines: A key review", Progress in Aerospace Sciences, 83, 2016, 57–69. https://doi.org/10.1016/j.paerosci.2016.03.001.

[39] Murat Yasar and Asok Ray, "Hierarchical control of aircraft propulsion systems: Discrete event supervisor approach", Control Engineering Practice, 15, 2007, 149–162. https://doi.org/10.1016/j.conengprac.2006.05.011.

[40] Cesare Tona, Paolo Antonio Raviolo, Luiz Felipe Pellegrini et al, "Exergy and thermoeconomic analysis of a turbofan engine during a typical commercial flight", Energy, 35, 2010, 952–959. https://doi.org/10.1016/j.energy.2009.06.052.

[41] Didier Henrion, "Linearization and Identification of Aircraft Turbofan Engine Models", Elsevier IPAC Publications.

[42] S.-M. LI, C. A. Hanuska and W. F. Ng, "An Experimental Investigation of the Aeroacoustics of a Two-Dimensional Bifurcated Supersonic Inlet", Journal of Sound and Vibration, 248(1), 2001, 105-121. https://doi.org/10.1006/jsvi.2001.3731.

[43] Dilip Prasad et al, "Dispersion, dissipation and refraction of shock waves in acoustically treated turbofan inlets", Journal of Sound andVibration, 352, 2015, 46–62.

[44] Luc Reberga, Didier Henrion, Jacques Bernussou et al, "LPV Modeling of a Turbofan Engine", Elsevier IPAC Publications.

[45] C. Priyant Mark et al, "Design and analysis of annular combustion chamber of a low bypass turbofan engine in a jet trainer aircraft",

Propulsion and Power Research, 5(2), 2016, 97–107. https://doi.org/10.1016/j.jppr.2016.04.001.
[46] 1903 Wright engine link :- http://www.wright-brothers.org/Information_Desk/Just_the_Facts/Engines_&_Props/Wright_Engine_&_Props_images/1903-Wright-engine-underside.jpg
[47] Turbojet image link :- https://en.wikipedia.org/wiki/Turbojet#/media/File:Jet_engine.svg
[48] Turboprop image link :- https://en.wikipedia.org/wiki/Turboprop#/media/File:Turboprop_operation-en.svg
[49] Turboshaft image link :- https://en.wikipedia.org/wiki/Turboshaft#/media/File:Turboshaft_operation.png
[50] Turbofan image link :- https://en.wikipedia.org/wiki/Turbofan#/media/File:Turbofan_operation.svg
[51] Srinivas G "Numerical Simulation of Centrifugal Compressor" ARPN Journal of Engineering and Applied Sciences, ISSN 1819-6608, 9(5), 2014.
[52] Praveen kumar Akula, Balbir Singh, Manikandan.M, Srinivas.G "Influence of Tip clearance on the turbulent aerodynamics of axial flow fan under off design conditions" Journal of advanced materials research, 232, 2012, 223-227.
[53] Srinivas G, Madhu Gowda B P "Aerodynamic Performance Comparison of Airfoils by Varying Angle of Attack Using Fluent and Gambit" Journal of advanced materials research, 592-594, 2014, 1889-1896.
[54] Srinivas G, Srinivasa Rao Potti "Computational Analysis Of Fighter Aircraft Wing Under Mach Number 0.7 For Small Sweep Angles" *Applied Mechanics and Materials Vols. 592-594 (2014), 1020-1024.* https://doi.org/10.4028/www.scientific.net/AMM.592-594.1020.
[55] Srinivas G, Raghunandana K, Satish Shenoy "Recent developments of axial flow compressors under transonic flow conditions" IOP Conf. Series: Materials Science and Engineering, 197 (2017) 012078 https://doi.org/10.1088/1757-899X/197/1/012078.
[56] Srinivas G, Bhupal Rakham "Experimental and numerical analysis of convergent nozzle" IOP Conf. Series: Materials Science and Engineering 197 (2017) 012078 https://doi.org/10.1088/1757-899X/197/1/012081.
[57] Srinivas G, Raghunandana K, Satish Shenoy "Flow blockage in a transonic axial flow compressor: Simulation and analysis under distorted conditions" International journal of Engineering and Technology (UAE), 2018, 7(2.21), 43-49.
[58] J K Ajay Kumar, R Vishnu Bharat, Srinivas G "Recent Trends in Theoretical, Experimental and Numerical Techniques of Axial of Flow Compressor in Aircraft Industry" Journal of Advanced Research in Dynamical & Control Systems, 10(3), ISSN 1943-023X, 75-88.
[59] Chandrakant R Kini, Satish Shenoy B, and N Yagnesh Sharma, 2017, "Effect of grooved cooling passage near the trailing edge region for HP stage gas turbine blade - A numerical investigation", Progress in Computational Fluid Dynamics, An International Journal, 17(6), 397-407. https://doi.org/10.1504/PCFD.2017.088778.
[60] Chandrakant R Kini, Satish Shenoy B, and N Yagnesh Sharma, 2011, "A Computational Conjugate Thermal Analysis of HP Stage Turbine Blade Cooling with Innovative Cooling Passage Geometries", Journal of Lecture Notes in Engineering and Computer Science, Volume: 1, Issue 2192, 2168-2173.