THE IMPLEMENTATION OF POWERED GEARBOXES INTO TURBOFANS TO IMPROVE ENGINE EFFICIENCY

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Abstract—Recently, commercial airlines have been seeking more efficient aircraft technology. The International Civil Aviation Organization [ICAO] and the public have put pressure on them to reduce harmful emissions. To meet airline needs, aero-engine manufacturers are developing a revolutionary power planetary gearbox that will be implemented into the main shaft of commercial aircraft turbo engines. This gearbox will increase engine power while still conforming to new pollution standards. Almost all passenger jets today are running on standard turbofans, but they are quickly becoming outdated thanks to the new power planetary gearbox. Regular turbofans operate on a single shaft extending from the front of the intake fan to the compressor blades to the turbine. The new design will be improved upon by separating the intake fan from the shaft, compressor blades, as well as the turbine towards the rear part of the engine. The addition of the gearbox serves as a means to control the rotation speed of the various engines parts. Overall, the gearbox helps to optimize each part so the machine can function better as a whole. This innovation is groundbreaking because it not only benefits the airliner’s profit margin, but also benefits society as a whole due to reduced emissions and increased cabin comfort.

Key Words—Aircraft, Efficiency, Environmentally Friendly, Planetary gearbox, Turbofan, UltraFan,

PLANETARY GEARBOXES: THE FUTURE OF AERO-ENGINES

As an increased number of people opt for air travel each year, airliners and airplane manufacturers must find a way to boost flight efficiency. At the same time, they must use methods that are environmentally friendly and meet safety standards set by organizations such as ICAO. One invention, the planetary gearbox, seems to be paving the way for a new type of aircraft engine. Essentially, the gearbox allows the engine to run at optimal speeds while reducing the number of parts required to make the engine. Not only does it increase efficiency, but it also reduces fuel consumption which releases fewer harmful chemicals into the atmosphere. Geared turbofans are going to replace conventional turbofans due to superior efficiency, increased sustainability, and more prominent economic benefits.

A BRIEF INTRODUCTION TO AIRCRAFT ENGINES

The Wright Brothers’ initial flight during the early 20th century was a historic moment for mankind. It paved the way for future research regarding aircrafts and demonstrated that air travel would soon become a very real thing. Since that initial flight, the aerospace field has exploded and major advances have been made in every aspect of the industry. By 1930, the first jet engines were put into use, drastically decreasing flight times. Since then, aero-engine manufacturers have continued to improve upon engine designs. Their efforts brought the turbofan to the world of aerospace. The turbofan is currently the most up-to-date version of the basic gas turbine engine. However, further research has resulted in the geared turbofan, a more powerful and more efficient version of its predecessor. A key component of the geared turbofan is the planetary gearbox. This single piece essentially allows other parts of the engine to work at optimal efficiency. Only a few geared turbofans have been implemented into commercial aircraft; however, many companies, such as Rolls-Royce, are still in the development phase.

HOW DOES A TURBOFAN WORK?

Turbofans are complex machines but are easier to understand if each part is examined individually. For a turbofan to work, it must intake large quantities of air. This task falls upon the fans which are located at the front of the engine, located at the far right of Figure 1. Rotating titanium blades not only suck in the air but also split the air into two pathways. One pathway leads to the engines main core while the other travels just outside the core. The air that travels around the outside is known as bypass air. The role of the bypass air is to provide extra thrust, cool the engine as it compresses air, and blanket the noise produced by the exhaust. What may be surprising to some is that bypass air contributes more thrust than the air that travels through the compressor [1].

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2.10.2017
FIGURE 1 [1]
Diagram of basic turbofan engine

Air that does not bypass the engine core goes directly to the compressor. Contained within the compressor are a series of spinning, airfoil-shaped blades. As the air passes through these blades, it moves quicker and compresses. Each successive set of blades are slightly smaller, compressing the air even more. Between each set are stationary components, known as stator blades, that straighten the air flow before it enters the next group of rotor blades [1].

FIGURE 2 [1]
Diagram of combustor section of turbofan

Once the compression phase is over, the air moves into the combustor. As seen in Figure 2, the first component that the air passes is the diffuser. Its role is to slow down the air flow making it easier to ignite. Next, the dome and swirler cause turbulence within the air. The unsteady movement allows the fuel from the fuel injector to mix more easily with the air. The new, flammable mixture finally enters the combustion chamber through several holes in the liner. Once inside the chamber, the igniter lights the mixture and then shuts off. The constant flow of air mixed with fuel sustains the flame during a flight [1].

The last two sections of the turbofan are the turbine and nozzle. The turbine is connected to the same shaft as the fan and the compressor. As the air rushes past the turbine, the fan and compressor are forced to rotate and intake more air. The final stage is the ejection of the air through the nozzle. A key concept here is Newton’s Third Law which states that for every action, there is an equal and opposite reaction. So, as the air rushes out from the nozzle, it exerts a force on the plane. It is the force from this exhaust that helps propel the plane forward [1].

REGULAR TURBOFAN VS. GEARED TURBOFAN

The primary differences between the regular and geared turbofan are the fan blade diameter, reduced number of parts, and the addition of a planetary gearbox. Although each difference doesn’t seem significant on its own, the combined effect of them results in a much more efficient engine. Longer and wider fan blades allow the geared turbofan to intake increased volumes of air. The larger quantities of air are used to provide more thrust in the form of bypass air. One downside to larger fans is the bolstered engine size. The larger engine is necessary to accommodate larger fans and the increased volume of air passing through the turbofan. However, the geared turbofan weighs less than the conventional turbofan due to the reduced number of parts. The lesser number of components can be attributed to the planetary gearbox, which optimizes the speed of each part of the turbofan. The gearbox is inserted directly between the fan and the compressor blades. By optimizing both the compressors and turbine, it reduces the required number of blades [2].

Recently, Pratt & Whittney, a major turbofan manufacturer, struck a deal with Spirit Airlines. Spirit implemented Pratt & Whitney geared turbosfans and the results were quite remarkable. Jyri Strandman, vice president of flight operations at Spirit Airlines, had very positive first impressions. He stated that two things stood out immediately to him. He remarked that the engines were extremely quiet and that when he landed, he noticed that there was much more leftover fuel than expected. To be precise, on the 2000-mile flight from Detroit to Los Angeles, the new aircraft saved 422 gallons of fuel compared to the previous version of the aircraft [3]. Additionally, geared turbofan performance on other aircrafts confirmed that the Pratt & Whitney engine reduces fuel burn by 16 percent, cuts emissions by 50 percent and reduces the engine noise by 75% [3].

The Planetary Gearbox and Epicyclic Gears

The planetary gearbox (also known as the epicyclic gearbox) is the key component in the geared turbofan. Figure
3 shows the most basic layout of an epicyclic gear system. At the center is the sun gear which rotates in place. The three smaller circles are the planetary gears which are connected to the sun gear through the planet carrier. The final component is the ring gear encompasses the sun gear and all planetary gears [2].

Although, the mechanism used in the geared turbofan is more complex than the one shown in Figure 3, the underlying principle is still the same. First, a torque is applied to the central apparatus that holds each the gears together which causes the gears to rotate. However, they do not rotate with the same velocity. Each component of the system can move at a different pace, depending on how much torque is applied to the mechanism that forces the system to spin. These varying speeds contribute to the boosted engine efficiency of a geared turbofan. In a conventional turbofan, the fan, compressor, and turbine are connected to the same shaft [1]. Thus, they are forced to rotate at the same rate: one that is not optimal for each individual component. The fan wants to operate at a slightly slower pace to intake more air, but conventional turbofans could not allow for this because it would reduce performance in the engine’s core. With the addition of the gearbox, the fan would be able to spin at its optimal rate without compromising the rest of the engine [2]. This is because the gearbox separates the fan from the shaft that the turbine and compressor are on.

![Diagram of epicyclic gear](Image)

**FIGURE 3 [2] Diagram of epicyclic gear**

The specific number of revolutions of each gear compared to the other is known as the gear ratio. For instance, a ratio of 3:1 could mean that the planetary gears make 3 complete revolutions for every complete revolution that the sun gear completes. The teeth on each gear can impact the gear ratio as well. The general formula for calculating gear ratio is the number of teeth on the input gear divided by the number of teeth on the gear being driven. In the case of Figure 3, the ratio would be the number of teeth on each planetary gear divided by number of teeth on the sun gear [2]. So, if more planetary rotations were desired, manufacturers could add more teeth to each planetary gear. By varying the number of teeth and the torque applied, a maximum efficiency can be obtained.

### Bypass Ratio

One significant benefit of the gearbox is the improved bypass ratio. The bypass ratio is the proportion of air flowing around the core to the amount of air flowing through core [4]. Without the gearbox, turbofans could only achieve ratios around 9 to 1. Previously, aero-engine manufacturers attempted to lengthen the fan blades in order to increase air intake. At a certain point, the ends of the blades begin traveling close to the speed of sound. Such high speeds are dangerous because traveling at the speed of sound can create shockwaves that pose a serious threat to the plane’s structural integrity. With the use of the epicyclic gears, the fan can travel at the slower speeds necessary to intake large volumes of air using the larger blades [4]. The resulting bypass ratio is 12:1. This means that for every kilogram of air flowing through the core, 12 more flow around the outside. The amount of increased propulsion this provides is very significant because most of a turbofan’s thrust comes from bypass air.

**ROLLS-ROYCE ULTRAFAN**

One of the leading geared turbofan developers is Rolls-Royce. Rolls-Royce is one of the most prominent developers of geared turbofans and the company looks to be one of the leaders of aero-engine design. The British engine manufacturer currently has plans to release two new turbofans by the end of decade. The engines will be evolutions of the company’s current engine known as the Trent XWB. The first to be released is called the Advance. Though it is not a geared turbofan, it still boasts some impressive advancements. It is expected to possess a bypass ratio of 11:1 and burn fuel at 20% increased efficiency [5]. The more impressive engine, however, is the UltraFan which is set to be available for commercial flights by 2025. Unlike its predecessors, the UltraFan will have a planetary gearbox integrated into its design. Rolls-Royce projects that its geared turbofan will be able to create a bypass ratio of 15:1. If successful, it would be the most efficient ratio thus far. They are off to a strong start. In October of 2016, the Rolls-Royce team in charge of developing the planetary gearbox began its first tests. The gearbox will undergo several more tests that will lead up to the gearbox being able to provide over 100000 horsepower. This is the equivalent to the power produced by 100 Formula 1 cars [6]. The advancements on the UltraFan, especially the gearbox, will provide a 25% boost in fuel efficiency.

**UltraFan Power Gearbox**

The planetary gearbox is the center of attention in the upcoming UltraFan. Similar to the basic gear system discussed previously, the UltraFan’s planetary gearbox will
feature a sun gear surrounded by planet gears and a ring gear. Depending on which parts of the planetary gearbox are moving, it can either give a high torque low speed output, low torque high speed output, or a reverse output. The gearbox used in the UltraFan will feature a high torque and low speed output, letting the core operate at the optimal speed for fuel consumption, while allowing for optimum fan speed for minimal noise disturbance [7]. A planetary gearbox is used over a regular gearbox because the planetary gearbox evenly distributes the applied torque between planet gears.

FIGURE 4 [8]
Diagram of double helical planetary gear

The revolutionary planetary gearbox used in the UltraFan has five planet gears orbiting the sun gear. The planetary gears are oriented in a double helical style [7]. As depicted in Figure 4, the five planetary gears give superior control over the power inputted into the system. Furthermore, the five planetary gears give superior control over the power inputted into the system. Furthermore, the double helical gear provides increased stabilization due to its slanted perpendicular axis. This allows for continuous rotation between the teeth of the inner and outer gears. There would be a torsion problem if this design were only slanted in one way because the gears would slip past each other. Instead, there are two sets of teeth in reciprocating directions on the same gear to prevent slipping and eliminate axial load [6]. This design provides a superior advantage over the classic gear because there is never a surface not in contact with another gear at any time. This protects the metal by creating less impacts upon each rotation of the gears. It also smooths out the movements for a more controlled output, which is preferable for aerospace parts.

DISADVANTAGES OF THE GEARED TURBOFAN

The geared turbofan boasts some major advantages over the conventional turbofan. However, there are still some downsides that cannot be overlooked. As mentioned previously, the epicyclic gears allow the fans to spin at slower rates. The number of revolutions per second is small enough so that the blades can be produced with longer diameters. This increases the engine size which can cause difficulties mounting the engine onto current plane models [2]. Most commercial aircraft carry normal turbofans and are not designed to support a larger engine. However, airplanes do have a certain lifespan before they must go out of commission. As new airplanes are manufactured to replace the outdated ones, companies can rework their designs to accommodate larger engines. A second negative is the complexity of the gearbox. The gearbox incorporates several parts and may not be as easy to produce for mass distribution. Some aero-engine manufacturers may see the gearbox as too expensive for what it provides. After all, traditional turbofans have been able to reach a bypass ratio of 11:1, just a bit smaller than the Pratt&Whittney geared turbofan [5]. However, older turbofans seem to be reaching their limit while geared turbofans are on the rise. Rolls-Royce’s UltraFan will feature a 15:1 bypass ratio, significantly higher than anything that a conventional turbofan could achieve [6].

ECONOMIC BENEFITS OF THE GEARED TURBOFAN

Not only is the geared turbofan a more efficient version of its predecessors, but it also provides economic benefits for airlines. The commercial flying industry has experienced an exponential growth in the past century and continues to evolve each day. As aerospace technology improves, flight times will decrease and more people will opt to travel by air. Experts predict a 60% increase in the number of flyers from 2015 to 2030 [9]. Airlines must try to accommodate the rising demand of flights. At the same time, airlines are nothing but a business and are always looking for ways to save money and turn a profit. With the increased efficiency and reduced number of parts, the geared turbofan can help manufacturers, like Rolls-Royce and Pratt & Whittney, produce engines at a lower cost. Thus, planes are less expensive to produce and airlines can sell tickets at a cheaper price. Money saved on airplane production can be spent elsewhere such as better inflight amenities.

Fuel Efficiency

Fuel efficiency is one of the most important aspects of any method of transportation. Whether it be automobiles or commercial aircrafts, efficient fuel consumption is critical to staying competitive in the market. For drivers, it means more time spent traveling and less time spent refueling. This results in both time and money saved. The same can be said about commercial flights: efficient fuel consumption means less refueling time and more air time. If a larger number of flights take off in a day, an airliner will generate more profits. Furthermore, the fuel efficiency of aircrafts can directly influence the price of an airplane ticket. For example, a Boeing 787 Dreamliner has a life of around 40,000 cycles
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[10]. 1 cycle is considered the time takeoff to the time when it lands. With a price of 200 million dollars, this Boeing aircraft costs around 5,000 dollars per flight [10]. In addition, the cost of fuel for a transatlantic flight costs upwards of 15,000 dollars. Using these estimates, the cost of fueling is about three times as expensive as the plane itself. In the future, and engine like Rolls-Royce’s UltraFan could drastically reduce fueling costs thanks to its projected 25% increase in fuel efficiency.

**Engine Weight Reduction and Maintenance**

Another benefit of the planetary gearbox is its ability to drastically reduce the weight of a single engine. Normally, the addition of a new component would increase a machine's weight. The difference with the gearbox is that it removes the need for other parts of the turbofan. First off, the gearbox lessens the weight of an extended shaft that is concentric with the compressor turbine. Secondly, the gearbox allows each set of compressor blades to spin at optimal speed. Thus, fewer blades are needed to fully compress the air. In a standard turbofan, there are anywhere from 15 to 20 compression stages [11]. In a geared turbofan, approximately a third of those stages can be removed from the process [12]. The overall weight reduction is around 750 pounds off each engine which translates to 1500 total pounds on a typical twin engine aircraft [5]. This saved weight goes a long way; it equates to around 10 additional passengers flying “free”. In other words, ticket prices go down even further, resulting in more revenue for airliners and increased savings for passengers. Additionally, the lighter weight means less stress on the wing when the airplane is on the ground or in the air. Reduced stress adds longevity to other parts of the plane.

The gearbox not only saves weight on the plane but also plays a vital role in cutting down the maintenance time of planes. Since the turbofan reduces the number of compression stages, less parts have to be taken out and inspected. The compression blades are crucial in the turbofan as they are responsible for compacting the air before it enters the combustion chamber. Thus, it is important that each blade is carefully inspected during plane maintenance. To inspect a blade, it needs to be taken out, polished and, if necessary, repaired before being put back into commission. Each stage has two sets of blades with 100 to 200 blades per set [11]. This accounts for hours of labor dedicated to servicing engines and making sure they are fit to run. Any time not in the air or on the field for airlines is money lost. The reason these blades must be inspected so often is that there is no filtration in turbofans as that would drastically decrease the airflow and clogging would occur quite often. Clogging during a flight would be disastrous and lives could be lost. Therefore, the gearbox can help save hours, perhaps even days, of long, tedious inspection by reducing the number of blades that need to be inspected.

**ENVIRONMENTAL IMPLICATIONS OF THE GEARED TURBOFAN**

Global warming is becoming a more pressing issue as each day goes by. The growing population will only worsen the situation; therefore, it is essential that society finds ways to reduce pollution. As mentioned previously, experts predict a 60% increase in the number of flyer. Such a large increase will result in several million more passengers. With carbon emissions already a pressing issue, an increase in the number of planes could have devastating effects in the future. Airplanes are different from most other pollutant sources because they spew the harmful gasses directly into the upper atmosphere. The warming atmosphere is the key issue in today’s pollution because it is becoming filled with more greenhouse gasses each day. Our ability to cut these emissions will have a large impact on what will happen to our planet within the coming decades. Turbofan engines release a range of chemicals into the air, from unburnt fuel to carbon dioxide to various nitrogen oxides, all of which are very harmful to the environment [13]. Carbon dioxide is the largest contributor to the rising temperatures of the planet because it traps heat from sun. Nitrogen oxides are harmful in a different way. When there is sufficient moisture, nitrogen oxides will dissolve into the rain and form acid rain. Acid rain destroys crops by disrupting the pH balance in soil [13]. Moreover, acid rain slowly eats away at calcium carbonate, a main ingredient used in concrete. The result is weakened concrete structures such as bridges and skyscrapers.

The geared turbofan fights against the NOX Emissions and micro-particulate pollution by reducing the fuel consumption of turbofans by 30%, cutting emissions being released into the atmosphere. Along with the fuel reduction, the goal is to cut nitrogen oxide emissions by 90%, a drastic change [9]. New, low nitrogen oxide fuel injectors and mixers will achieve this, resulting in a cleaner and more efficient burn. This is crucial as the airplane injects the harmful particles directly into the atmosphere. A large decrease in the amount of these chemicals in our environment will help make a greener earth.

In addition to the decreased emissions, there are also other benefits that are enjoyed by both flyers and non-flyers. Noise is a huge issue in aircraft regulations, with certain restrictions on speed and the limitations on the maximum levels of noise in the cabin. Noise in today’s aircraft remain around 78dB in the cabin when cruising, and most of this noise is attributed to the engine producing high airspeeds and causing turbulence when meeting with the outside slower air. This is combatted in the new geared turbofans because the engines can burn at slightly lower temperatures resulting in slower exhaust gasses and therefore less noise turbulence. Another source of noise comes from the tips of the fan approaching supersonic speeds, creating mini sonic booms resulting in a “buzz saw” noise [14]. This noise is also heavily reduced by the geared turbofan design because the fan is now
running at a slower speed, eliminating the supersonic buzz saw noise. Also, the larger fans intaking more air generate more bypass air which can blanket much of the noise coming from the turbofan’s exhaust.

![Logarithmic Power vs. Decibel Graph](image)

**FIGURE 5**

Logarithmic Power vs. Decibel Graph

Overall, the noise is reduced by 65%, or by 15 dB [9]. It is only reduced 15 decibels even though it is a 65% noise reduction because the decibel scale is logarithmic. Figure 5 can help visualize this scale. In the graph, an extra 5 decibels, from 15 to 20, results in exponentially more power. This power is translated to how much air is pressurized against your eardrum and produces the sound that we hear. This reduction in noise is significant because it has the “noise equivalent to a Learjet 45, which weighs 25 times less and has 20 times less thrust [9].”

**PROVIDING SUSTAINABILITY**

Sustainability is currently a very pressing issue that countries around the world are trying to address. As civilization moves forward, humans will have to find ways to utilize resources in a more efficient and sustainable manner. Sustainable can mean have several different meanings. Regarding airplanes, it could mean making parts that will last longer, require less material, save fuel, and release less greenhouse gases. By being more environmentally aware, humans can create an ecosystem that does not compromise beauty of nature.

Airliners have recognized the need for change and are testing options to decrease their carbon footprint. The gearbox is one invention they are using which both uses less parts and cuts down on assembly time. This in turn saves a lot of energy that would be otherwise used to design, cast, and finish other components that have been replaced by the addition of the gearbox. These small processes add up and create a much more prominent effect.

**Reducing Fossil Fuel Emissions**

Fossil fuel usage and depletion are the largest contributors to the sustainability issue, as there is only a limited supply of fossil fuels left on Earth and the more we consume them, the more rare and harder they will be to get, not to mention the harmful particulates it emits as pollution. Carbon monoxide and carbon dioxide are often released with exhaust in engines that use fossil fuels as the main source of energy. CO is detrimental to the environment because of its tendency to rise into the upper atmosphere, trap heat and reflect infrared rays within the planet causing rising temperatures. CO2 emissions have a similar effect because it traps heat, further contributing to global warming. Global warming contributes to a number of problems such as rising sea levels, melting ice caps, disturbing the balance of entire ecosystems, and destroying coastal communities. Major airplane companies such as Boeing and Airbus are now asking their engine manufactures to adhere to these goals that the ICAO has set and reduce emissions by 28% by the end of 2030 [13] This is where the gearbox comes into play. As mentioned before, a Pratt & Whittney geared turbofan can reduce fuel burn by 16 percent and cut emissions by up to 50 percent [3]. Reducing fuel consumption not only cuts down emissions, but it also reduces the amount of fossil fuels that must be extracted to fuel commercial aircrafts.

**Impact on the Community**

As new components are being developed, not only are they benefiting businesses and environments by saving costs and reducing emissions, but also, they are positively impacting the quality of life of certain communities. The main concern is the noise “pollution” that is being inflicted upon the community, for both flyers and non-fliers alike. For flyers, the impact on them is obvious. Flyers would much prefer a quieter plane where they can rest easily. The gearbox tackles this problem by reducing fan speed. This reduced fan speed creates less noise because the blades are not rotating as fast, and the increased air intake blankets the noise caused by the engines exhaust. For the people that are not flyers, this will impact them too as the aircraft generates noise that is heard on that ground and that too will be reduced. The air flowing around the engine will be more streamlined and slower as to dampen the power of the sound.

**THE FUTURE OF AIRCRAFT ENGINES**

Overall, the introduction of the planetary gearbox has already begun to make an impact on aircraft design. Pratt & Whittney has proved that its engine can outperform older turbofans in various aspects such as fuel consumption, air intake, and engine weight. These improvements can be attributed to the addition of the planetary gearbox. Although there are definitely some disadvantages to the geared design, it is important to note that other companies, such as Rolls-Royce, are still in the development. It seems very likely that companies in the same situation as Rolls-Royce will be aware of the problems concerning geared turbofans. Therefore, they will compensate for these during the design and testing phases. However, past the initial bump of production, there
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will be significant benefits. These benefits include lower fuel cost, reduced pollution emissions, cheaper flight costs and quieter cabins. Aircraft engines are only going to get more advanced and more efficient. More specifically, the geared turbofan looks to be the next step for many airlines and airplane manufacturers.

**SOURCES**


**ACKNOWLEDGEMENTS**

Kevin Chang

I would like to thank my grandparents for instilling the basis for my love for aerospace and inspiring me to look up from a young age. I would also like to thank Rolls Royce for the extensive information provided on their UltraFan gearbox design, without which we could not have found inspiration.

Derek Sitt

I would like to thank Nate Carnovale for jamming to some sweet tunes with me while I worked on this paper. I would also like to thank Helen Yusko for keeping me company during the late night when trying to write this paper. Shout out to Alyssa Choboy and Mikayla Ambarian for letting me work in their room. Lastly, I would like to give a shout out to 8 Guize Burgerz and Two Friez. Let’s get that ‘W’.