# Understanding your Turbine Engine

You have bought that new engine and are looking at this $3000.00 piece of hardware that resides on your table at home. Man is this cool, you call your buddies over to look at it, hold it, and show it off at your field. You have just entered a new level in your hobby and with that comes new information and responsibility. This new piece of metal that includes more pieces than came in your last ARF, will take your hobby to a new level. The knowledge of its operation as well as how to handle and respect it will ensure many runs and flights with almost no hassle. New terms such as EGT, Compressor, T-Wheel, EGV, ECU, and the bad one FOD, are common to jet pilots, but what are they, and what do they do or mean.

Turbine powered jets bring a whole new facet to the modeling fraternity. Real sound and unbelievable performance are just a couple that come to mind, but with this new step you take comes a higher level of responsibility than most modelers have ever thought about in the world of aero-modeling. Wing loadings higher than 60 ounces per square foot (most sport models barely hit 20 ounces per square foot), more complex airframes with flaps, retracts, gear doors, speed brakes, and other features which are cool to use but equal a higher level of difficulty than previously seen. Larger fuel loads equal more complex fuel systems, multiple fuel tanks, and a fire potential that needs to be understood to not fear it.

After almost three years of servicing engines for JetCat USA, and over 18 years of service on full scale jet engines with the military, I have acquired a rather large knowledge base on the care and operation, as well as maintenance of micro turbine engines. Let’s start with the engine and then move onto the associated accessories. From there we will move into the operation and overall care of the engine. My information is based on the JetCat engine line, but I believe it could be followed by most all other manufacturer’s engines in general. If you find any information in this publication that differentiates from another brand of engines, please follow your brand specific instructions. Please understand that while these micro turbine engines provide a new level of power and performance for our model jets, they are not toys. They can fail at any time if misused or neglected. These engines are far more dangerous in the hands of carelessness or negligence than any other model aircraft power plant available today.

Most engines today are based on the following principles; a centrifical flow compressor, annular combustion can, and an axial flow turbine wheel. People want multiple stages of compression which would be nice, but the complexity and cost would over-weigh the advantages. The current engines available to us give a thrust to weight ratio better than 8 to 1 on average. Changing the compressor section without the ability to control the stages of compression would only lead to failed compressors, extremely high Exhaust Gas Temperatures, and failed internal parts on a scale none of us would want to deal with. Believe me we have the best design available today. Keep in mind there are still many full size turbine engines powering some of the corporate business jets with engines very similar to the ones we use in our models. The KJ-66 design as it is called has been used in full scale aviation with great success for over 45 years.

Our engines are made from a variety of materials; aluminum, incolnel, steel, and plastic. Tolerances inside must be maintained during all temperatures of engine operation. Open the tolerances up and you loose thrust and/or raise EGT. Both of these degrade performance to a level the expert jet modeler will not accept. These tolerances are designed into the engines from the start. However they must be maintained for the engine to continue to perform at the level desired during the purchase. The reason I say this is because most jet modelers buy based on thrust versus size. They want the most thrust in the smallest case. Take a look at the new engine Chevy drops in the Z06 Corvette. Would you find that engine in any other car in the Chevy line up? Probably not because it wouldn't last during daily driving by 15 million different drivers. Do those engines go 200,000 miles without maintenance, no they do not. They are performance engines designed to do one thing, deliver performance! This performance comes at a cost, and that is longevity. Your micro turbine engines are the same way. More thrust out of a smaller diameter routinely leads to a higher performance motor. It will require more maintenance over time because of its capabilities. Higher performance motors routinely sacrifice in the area of longevity, on the average.

Thrust comes to life from heat and the ability to move mass air, period. To say it comes to life any other way is mis-information. Low EGT's with mass air flow will result in lower thrust levels, but with a long life span. Higher EGT's with mass air flow will result in higher thrust levels, but with a possible sacrifice in longevity. The mass flow numbers from a particular design will be a determining factor in the statements above, but the basic statements should make sense. If you end up with lower mass air flow and high EGT's you end up with lower thrust because you do not have the correct amount of air passing through the motor as per the capabilities of the design. With this the engines run hot and sacrifice on longevity of the internal parts. There is a happy medium to every motor made. Please do not think that because a motor is larger in diameter or longer in length it will work "better" every time. This is not the case. EGT's average around 600 – 700 degrees for the standard class KJ-66 design motors. Your particular manufacturer can give you more accurate numbers on this.

It is not hard to get a turbine to run, what is difficult is to get one that provides both power and longevity, with reliable operation time after time. Multiple items can cause issues with how an engine runs. Compressor height clearance, damage to the compressor blades, compressor height to the diffuser, damage to the diffuser, fuel distribution inside the motor, fuel leaks inside a motor, combustion flow paths, exhaust guide vane flow paths, turbine wheel/Exhaust guide vane ring clearance, and exhaust nozzle diameter. This is only for the motor itself and does not include intake obstructions, bypass limitations, internal obstructions (non-bypass setup), tailpipe diameters, tailpipe lengths, as well as placement of the motor in between the intakes as well as the tailpipe. The number of factors can be overwhelming to say the least.

If we look at the items explained above in the motor itself, we can determine which ones the factory/service department can control, and the ones where you the user control. Compressor damage as well as diffuser damage arrives from one thing, FO (Foreign Objects). The result of FO going down a motor is FOD (Foreign Object Damage). This routinely will rip compressor blades. On rare occasions a bent blade is the result which when straightened (if possible), can return the motor very close to its original power capabilities prior to the damage. Compressor blades which have a small tear in them with the part still attached should be repaired immediately. Failure to do this will result in the small part being ingested and causing even more damage to the internals of the motor. The clearance between the compressor and compressor cover routinely on a JetCat engine is .0005" - .0015". That is from 5/ten thousandths to 15/ten thousandths of an inch. If you suck one item which most believe do no damage to the engine down the intake (GRASS) chances are good you have damaged your motor. I have seen guys ingest grass only to say "I'm fine because I got it all out". What about the grass that continued through the 50,000 rpm blender through the diffuser, only to clog a few of the air holes on the combustion chamber. The end result is the engine runs, and everything is fine, well not really. The engine has now acquired a hot spot, maybe small, maybe big, time will tell. Remember when we talked about flow path of the mass air that passes through the motor? Well you have changed it and the only thing that will happen is redistribution of heat inside the motor. The end result is an immanent failure point which could be seen by flameouts during certain throttle transitions, or the worst case, and catastrophic failure of the engine assembly. The moral of this story is if you ingest grass or some other soft FO and you can tell it went into the intake; return the motor to the manufacturer to be checked.

The other interesting point is the build up of the chloroform from the grass on the diffuser blades. This build-up changes the compression ratio and mass flow paths inside the motor. It needs to be cleaned off to ensure correct operation. It is a very lengthy process (routinely about 1.5 hours of hand work) to remove this film as it has been baked on during the moment of ingestion. This is one of those things that most modelers don't think about because they can't see it.

Other items which can cause damage to your engine but are not limited to are: bugs, rocks, screws, wire, fuel line, carbon cord, fiberglass, etc. I think you get the drift here. The item does not have to be a metal object to do the damage. Keep in mind what the kinetic energy is of a 1 – 2 ounce "June Bug" going down the intake during a 180 mph pass. It hits the aluminum intake blades which are spinning at close to 100,000 rpm. The end result is stuff gets bent or broke! FOD screens have become the norm to many jet modelers. Some believe the manufacturers should supply motors with them. Common sense says this will never happen. FOD screens can save many potential FOD repairs, but it is possible for them to cause some issues with the motor itself. If they are too restrictive they can cause a motor to run hot and we know what happens there. They routinely cause a reduction in thrust. Most of the time the reduction is small enough where the benefits out weigh the adverse effects of it not being installed. FOD screens are routinely made from kitchen or sink strainers. It is not cost effective for any manufacturer to develop a specific application unit for us. Turbine aircraft have been flown in the United States since the very early 1990's. Yes guys, 15 years. I believe even longer if you look towards Europe. We didn't need FOD screens before and did fine without them. Correct care and use of the motor will help you survive before a FOD screen will help. For the record I do not run FOD screens and never will. The minor effects associated with them inside the motor and thrust loss potential is enough for me to keep them off my engines.

So how do you keep an engine running season after season without any maintenance? First and foremost is a properly designed closed flow path system. This is the intake, bypass, and tailpipe. I will not run an internal engine in a non- bypass environment. Some will say it is because I am associated with Bob Violett Models. This is not the case. A completely closed system will eliminate 90% of the FOD potential that resides in an internal/open installation. Second is for fire suppression. Third is for engine temperatures, they run cooler in a bypass. If you have a fire, one small shot down the **INTAKE** and the fire will go out, I assure you. 18+ years of military training proved this to me on three different occasions on F-16 aircraft. The fire suppression agent will follow the same path the air flows when it goes in an intake. If you have a completely closed system with a properly designed bypass, the entire agent goes to the engine, which routinely is the source of the fire. **NEVER shoot down the tailpipe!!!**

Second is a properly designed tailpipe. Dual wall pipes are the norm these days and work very well. I am not an expert in tailpipe design and use tailpipes only from BVM or Tam Jets. I am not saying other pipes don't work, I only know which ones have worked for me. Both of these manufacturers have been producing tailpipes for many, many years with excellent results. They have failed with pipe designs in the past during testing and have used that information to bring you the best tailpipe designs on the market.

Runway choice can be another item which can lead to longer or shorter life span of your motor. Paved runways are or course your best bet for longevity of your motor. Finely manicured grass fields as found at Triple Tree Aerodrome/Joe Nall are another excellent example of runways. Rough grass fields are fine, but can have minor items which if ingested could cause damage to your engine. A FOD screen is almost a must with these fields. Dry lake beds are another good place to fly from. Whatever your runway is, make sure to protect your intake accordingly.

Let's get back to the internals of your motor and talk about **compressor stalls**. The compressor is designed to draw air into the motor. You will find the motors have aluminum covers placed over the compressor. This clearance is extremely tight and needs to be to ensure correct operation of the motor. If this clearance is too large, the engine will compressor stall during acceleration and an audible "bang, bang, bang" will be heard. If you hear this sound your have a problem and need to fix it. **Do not fly**, as the end result is a compressor stall in flight which will result in a flameout. I have seen pilots get this stall during a run up and have decided to fly because it will be fine in the air. Every time I have seen them fly, they have brought back a pile of airplane. They will say "it didn't do that last flight", or "it didn't do that at my home field". While this may be true, it is doing it now and will continue until the problem is corrected. Field elevation, outside air temperature, density altitude, barometric pressure, and humidity all play an important part in the world of compression. Possibly something inside has changed, or is damaged. Another reason is the weather is the culprit.

Full size jet engines have very complicated computers which control the intake of air into the engine and vary the compression during the first stages of compression to compensate for these conditions which change all the time. There are actual vanes which move over ranges of 40 degrees to change the compression rate ensuring the compressor section will not stall during acceleration or deceleration. We do not have this luxury with our fixed ratio compressors. For these reasons, if you get the "bang, bang, bang" noise from your engine during acceleration, abort the flight and fix the problem.

The next area to look at is a motor that is "hung" in operation. This is where the motor fails to accelerate beyond a certain point. Normally this is during a start, but can occur during normal engine operation. During normal operation it will routinely be associated with the compressor stall "bang". The difference between the two is with a compressor stall the engine routinely clears itself and continues through the transition. An engine that hangs and bangs and fails to continue to accelerate is hung and the EGT will only get hotter with every passing second. The best thing to do here is to reduce the throttle to idle and then shut the motor down. If this occurs, something internal is damaged and needs to be repaired. There is no field fix for this. This is a pretty rare occurrence in the micro-turbine world, but if it happens the motor needs to be returned for service. Another item which can hang a motor is high EGT. If you motor hangs, check the EGT during the operation. If it is getting very hot, the acceleration will be very slow. Shut the motor down and return it for repair.

The condition of the diffuser can have a very large effect on the above situations. Any damage to a diffuser and the engine will run hotter with slower acceleration times. If the acceleration scheduling inside the ECU is not changed, stalls will occur until the damaged area is repaired. The other area inside the motor which has an extreme effect on acceleration and deceleration is the combustion chamber. Certain motors have holes that are bent in certain directions, while others have holes that are not bent at all. These are designed from the factory to work with the scheduling of the motor for the best operation overall. The mass flow path inside the motor has an effect on these holes as well. Changing them one way or another can make the engine accelerate faster or slower, accelerate better at high altitudes or low altitudes. The combination is almost an infinite number. The chambers as they are in the motors from JetCat are designed for the best overall operation in just about any condition a pilot would fly in. Combine this with the fuel vaporization tubes and distribution of fuel into the chamber and another level of combinations comes to life.

If a combustion chamber becomes warped over time the engine will continue to run, but not as well as it did when it was new. Unless you monitor the temperatures during acceleration and deceleration during all operations of your motor, you will not be able to determine the chamber is warped until the repair guys tells you it is time to spend the money. The normal response is "but it was running fine" and the tech says "no it wasn't". Who do you believe in this case? As far as you know it was fine and he is just trying to pull more money out of the repair bill and your wallet. Not the case routinely, the tech wants your motor to be right, this way you don't call him and say "hey I just had my motor in and it's not running right". No company likes this phone call or the press associated with it on the internet forums or jet meets. They want your motor to be the best it can be, to perform correctly for you when you ask it to.

Combustion chambers can become cracked over time as well. The concept of cracks and warping comes with throttle management and flight style. If you love full throttle most of the time, the chamber will live a shorter lifespan. If you love those extreme tumbling maneuvers and high "G" maneuvering, your chamber as well as other parts will live a shorter lifespan as well. All of the combustion chambers in JetCat motors are made of incolnel. There is no stainless in them at all. Some manufacturers still use high quality stainless for combustion chambers, but the end result is they will not last as long. EGT's run in the 600 – 700 degree range during constant throttle settings. An engine can see temperatures up close to 800 degrees on the EGT during acceleration ramps. These temperatures are in Centigrade. The temperature inside the chamber is routinely 100 – 200 degrees hotter. Most people think the EGT is the actual temp of the motor. This is not the case. This is the temp of the exhaust, not what is happening inside. The combustion chambers are made from a very thin incolnel (.020") on average. They can only take so much.

Cooling air is the next item which comes to mind in the jet engine. This is what determines the life span of a motor. Take away the cooling air and the motor lives a shorter life. Ensure the engine has adequate cooling air and it lives a longer life span. Cooling air on the outside will have a quantifiable effect on the cooling air on the inside. If the case is running at a certain temp the cooling air on the inside is running at certain temp. Increase the case temp and the cooling air on the inside increases and the EGT increases as well, but without any increase in performance. An internally mounted engine without a bypass will always run hotter internally than an engine which is housed correctly (in a bypass) with cooling air being directed around it. This will result in a cooler running engine and more efficient engine as well. It has been shown that bypass motors live longer life spans as well. Externally mounted motors have proved to work well and live long life spans  The basic flame pattern on the inside of the motor never touches the outer perimeter of the inner combustion chamber.

The fuel manifold is another area of the motor that can make or break the way an engine operates. Routinely the manifolds are brass with either incolnel or stainless fuel needles brazed into place. JetCat only uses incolnel. These needles are less than .020" in total diameter. They require this to atomize the fuel inside the vapor tubes on the combustion chamber. These needles are very fragile. A small bend on a fuel needle one way or another can change the entire flame pattern inside the chamber. Over time these needles become annealed to a point that they will not hold their position inside the vapor tubes. When this happens the manifold needs to be replaced. Fuel manifold changes are costly due to the labor required to set the needle ends to maintain the flame pattern. Time and experience is all that works here. There is no set way to bend a needle to ensure proper operation. Once again, the condition of the combustion chamber can also dictate how the needles need to be bent.

The Exhaust Guide Vane (EGV) is what the combustion chamber fits over at the aft part of the motor. Some of you know this part as the NGV or nozzle guide vane. The term NGV is a hobbyist/micro turbine term and is not known in the full scale turbine arena. There is no reason to guide the vanes in the nozzle. The part guides the exhaust through a series of vanes, hence the term Exhaust Guide Vane assembly. This is cast from incolnel and is what the turbine wheel runs inside of. The pitch of these vanes, along with the pitch on the turbine wheel set the amount of back pressure the combustion can and engine feels during operation. To low of back pressure and the engine will run hot and produce less thrust. Too much back pressure and the engine will compressor stall during acceleration.

Over time and use the vanes begin to crack. Once this occurs, heat transfer is not controlled through the EGV, causing hot spot on the turbine wheel and EGV ring assembly where the turbine wheel sits. What begins to happen is this ring now becomes very hot in certain areas and will deform. During this deformation, the gap between the turbine wheel and EGV ring opens up. When this opens up the engine will run hot in that spot, cause a loss of thrust, as well as reduced back pressure. Once the deformation has begun the only alternative is replacement. The clearance set between the turbine wheel and the EGV ring on a P-120 is between .006" - .008" of an inch cold. Once the engine fires up and begins to run, the turbine wheel expands more than the ring; the end result is a gap of .002 - .003 during operation. This is the hardest clearance to set in the motor as it is done when the engine is cold (room temperature). It is impossible to be sure if the clearance is correct until you have seen close to 12 – 15 flights on an engine. Starting the engine is the hardest on this area. If you start and shut down a bunch of times to "see it work" you could be doing more to require re-machining of the EGV ring than you would like.

If you receive a motor back from repair or a new motor and the engines does the proverbial lock-up during start, it will probably need to go back to be re-machined and open the gap a thousandth of an inch. No real damage is done to the motor during the situation, it just sounds bad. It does no damage to the bearings or rotating parts of the motor. Over time carbon can build up in this area and cause a similar situation. At this time the engine will require service to clean the affected area. More than once this can be cured without replacement of any parts. Quality of fuel and oil, as well as age of fuel will determine the carbon build up of the motor. Quality of the burn and hot spots can also be determining factors of the carbon build up inside the EGV ring assembly.

The last part of the motor is the bearings and oiling system. All of the turbines in current production use the spent fuel/oil oiling system to lubricate the bearings. Should be a simple system right? Wrong! The variations of what is happening inside the motor can make the easiest of system become almost impossible to control during operation. The bearing tunnel is the main inner shaft of the motor and is constructed of aluminum. Some manufacturers use steel for this. Inside this tunnel the main shaft and front and rear bearings reside. A preload system is required as well to maintain the correct load on the bearings. If the preload is set too high, the motor will require more energy to rotate and cause premature bearing failure, hot EGT's, and lower thrust. Too low of a preload and you will see premature bearing failure. The bearings are a hybrid design of ceramic, nitrite coated balls inside stainless inner and outer races. There are no bearing retainers in these bearings. These bearings are capable of spinning at very high rpm's with minimal lubrication as long as they are clean. One speck of dirt is all it takes to get on a bearing and destroy the coating. Once that has occurred, bearing failure is imminent.

As fuel enters the front of the motor it is "tee'd" off to provide two things; fuel for the motor to run on and fuel for the bearing to receive lubrication from. Most all companies require the standard one quart of oil per five gallons of fuel mixture for operation. Less is definitely not recommended, and more won't hurt on occasion. Mixing fuel can be your life blood. Set up a standard in how you do it and never change! I personally will not fill a jug of fuel unless a quart of oil is already inside of it. This way if the jug has fuel, it has oil. Any turbine engine oil will work in the JetCat series of engines. Only use the type oil recommended by the manufacturer, nothing else. Fuel is another area to consider. K-1 Kerosene is a favorite as well as Jet-A, JP-4, JP-5, JP-8, and Jet-A1. Kerosene has no odor and burns clean but with a small amount of carbon build up. It is available at just about any hardware store and cost is around $5.00 per gallon. **Do not purchase Kerosene out of a ground tank.** Kerosene is notorious for attracting water as well as algae. If you use it regularly you won't have any issues. If it sits for periods of time, algae may begin to grow, and this will only clog up your fuel needles, filters, pump gears, etc.

Jet fuel is my choice. It will not grow algae over time as most people think. Adding Prist as people say to do, only gives you de-icing agents to ensure your fuel doesn't freeze in extreme cold. Prist is already in the military jet fuels. Jet fuel also carries additives which have some lubricating abilities. It smells worse, but I believe that bearing last longer over time using jet fuel over kerosene. Either fuel will work, the choice is yours. Jet fuel is routinely half the price of Kerosene as well.

Bearing lubrication, how does it work? After the fuel is tee'd off it must be sucked through the engine to get to the bearings. The mixture of fuel and oil is routed through a brass tube which is approximately 2 mm in diameter. It is then released at the beginning of the shaft tunnel just under the compressor. There it drips onto the front bearing which becomes entirely coated because of the vacuum in the shaft tunnel and high rpm of the bearing. The vacuum continues to pull the mixture towards the aft area of the shaft tunnel onto the front face of the rear bearing. After passing through the rear bearing, the mixture of fuel and oil hits the forward face of the turbine wheel and is vaporized in the exhaust. There are numerous clearances which are required to be set in the motor to ensure the correct vacuum exist to draw the fuel oil mixture through the shaft tunnel. Too much vacuum and the bearings will not get the correct amount of lubrication. Too little vacuum and the rear bearing never receives the fuel oil mixture.

If at any time bearing noise is heard, shut down the engine and send it in for service. Bearing noise routinely shows up first during a cool down mode. You will not hear it during operation.

That pretty much sums it up for the internal workings of a micro turbine engine. They are far more advanced than your average 2-stroke engines out there and require far greater care during operation. If treated correctly they will last you many flights and deliver awesome power. But if neglected or treated with carelessness they will fail. With their failure will come high expense and very serious safety hazards. Respect the engine and its capabilities at all times. Good flying.

John Redman