
Effects of components Deterioration on Helicopter operation in hostile environment

By

**Marcus Aul M., **Ibrahim Ali Kachalla, **Chikeluba Uchenna N and **Ohemu Monday Fredrick*

**Aircraft Engineering Department,*

***Electrical and Electronics Engineering Department,*

Airforce Institute of Technology,

Kaduna state, Nigeria.

Email: aulmarcus@yahoo.com

ABSTRACT

Operation of helicopter in dusty areas is capital expensive. Frequent engine maintenance is associated with consistent operation in such area. This amounts to high maintenance and operation costs which may lead the operator to operate by cutting corners. Consistent and prolonged operation in the hostile areas causes primarily blade and vane erosion as well as fouling. In this work a typical small helicopter engine (which have a service ceiling of 3810m) has been modelled and simulated at both clean, off design point and degraded conditions at different altitudes. The deteriorated engine performance which is indicated by lower shaft power output, reduction in engine acceleration, reduced compressor discharge pressure and possibly compressor surge is discussed in this work.

Key words: Engine Deterioration, Turbine Entry Temperature (TET) and Specific Fuel Consumption (SFC).

INTRODUCTION

Helicopter operation in dusty regions is faced with fundamental issues of component degradation due to relatively low altitude flight profile associated to helicopters. Operation of helicopter in such regions involved conveying passengers from one airport to another as well as taking oil workers from land to offshore for oil exploration. Such operations cause the helicopter gas turbine engine to ingest some airborne contaminants as it passes through layers of dust clouds. Operation of helicopters around the marine environment is also prone to ingest saltwater and some other evaporated marine contaminants as it operates closely over the marine water. Helicopter is also operated on charter basis where a business man or group of persons are conveyed to particular destination regardless of an approved airfield in such destinations. Landing and take-off at such airfields is very detrimental to helicopter gas turbine engine as sand particles dislodged from the ground is ingested into the engine through a process known as brownout. Aviation training schools are also not left out in helicopter usage. Training pilots flying helicopters prefer to fly at low altitude where dust layers are concentrated.

Helicopter gas turbine engine components such as compressor and turbine blades, vanes being relatively smaller are susceptible to erosion and corrosion during a prolonged and consistent operation in these hostile environments. Erosion and corrosion of such important gas

turbine components cause performance degradation of the engine. Rotor shaft engine degradation is indicated through one or more of the following;

1. Engine acceleration tends to be slower.
2. Erosion and corrosion during a prolonged and consistent operation in these hostile environments. Erosion and corrosion of such important gas turbine components cause performance degradation of the engine. Rotor Engine compressor may surge or stall.
3. Lower power output observed.
4. Loss of engine compressor discharge pressure.
5. Increased compressor discharge temperature.

REVIEW OF RELATED WORKS

Erosion Fundamentals

Erosion is described as a process whereby a metal surface is attacked by solid particles entrained in the air stream and cause wear to the metal surface. The study of erosion is of great importance to engineering application especially in the area of fast moving engine components. Erosion rate is determined experimentally by measuring the weight of the metal object (target surface) before and after the experiment and it is expressed in milligram of the eroded material per gram of impacting particle. The rate of material removal is primarily dependent on the impacting particle velocity and its diameter, as stated by the following equation;

$$W = kVaDb \quad [1]$$

Where W= eroded material by impacting particle

D = Diameter of impacting particles

V= Particle velocity

K,a, b are constant

Material removal is also a function of angle of impingement between the target material and the impacting angle. Study of erosion and its impacts on metal surfaces is carried out by many investigators. Some of these investigators' works will be reviewed in this work.

Compressor Erosion

The major engine components susceptible to erosion are compressor and turbine blades, with the compressor blading the most affected Tilly and Wendy, (1970). These components are exposed to impact of dust laden air which causes severe damages on the blades through continuous cutting and pitting of the metal surfaces. Erosion of compressor blades for helicopter operating in dusty region blade occur at all flight profiles, however is its more prevalent during vertical and short take off landing over unimproved airfields (Smeltzer et al., 1978). This condition is described as brownout. During this period the engine generates a downwash force which causes entrainment of dust and solid debris to be ingested in the engine. This is because the ground is loosely packed and hence can easily be dislodged by the rotor wash force. According to Smeltzer et al (1987), dust concentration at brownout condition increases by a factor of 3. A prolonged interaction between dust particles and compressor blades gradually cause erosion of compressor blades and vanes. This leads to a gradual decrease in blades chord with increase in flight hours

The damage caused by erosion of blades affect the compressor performance significantly. Three distinct effects that associate with blades erosion include

1. Increased tip clearance
2. Change in air-foil geometry
3. Change in air-foil surface quality.

Tip clearance occurs between rotor blades and the casing due to the centrifugal action on entrained sand which is ingested in the compressor. This action leads to the removal of the rotor blade tip as shown in figure 1 .Increased tip clearance results to a higher leakage of mass flow which reduces compressor efficiency (Rainer and Klaus, 2000). Increased tip clearance typically reduces the compressor pressure ratio .According to Rainer and Klaus (2000), increased in tip clearance recorded from 1% -3.5% of blade chord will result to 15% reduction in compressor pressure ratio. This reduction is as a result of the intensive mixing of both the primary flows and leakage flows, hence creating losses as well as reducing the effective through flow. According to Batcho, et al (1986), the severe effects of erosion on the compressor blade will lead to total pressure distortion in the radial direction and this effect will result to flow instability that could cause separation of flow boundary layer in the blade tip region. According to them this characteristics can cause stage performance degradation of compressor and could result to compressor surge. Surge occurs due to pressure distortion in the compressor, and its incapability to sustain burner pressure, hence small increase in the burner pressure by increase fuel flow will create a back pressure on the compressor to surge. In his work, (Hamed and Tabakoff, 2006), stated that, stall point drops significantly by 5% when the eroded blade chord is reduced by 10%. Furthermore, Hamed and Tabakoff (2006) stated that economically engine deterioration via blade erosion causes loss in shaft power as well as increase in fuel consumption.

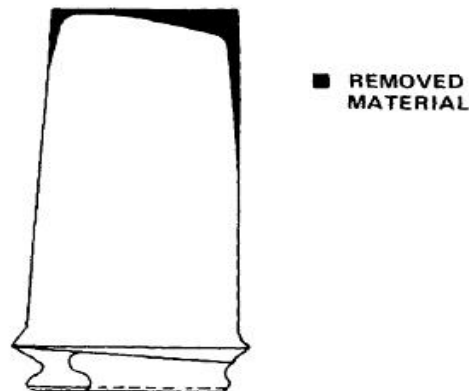


Figure 1: Erosion effect on rotor blade

Fouling

Fouling is caused as a result of particle adherence to blades and annulus surfaces of a gas turbine. The particle adherence is caused by the presence of saltwater and oil in the engine .Fouling is caused by particles which are typically smaller than 2-10 μ m.Rainer and Brun (2000,).Fouling is function of the following factors:

1. Gas turbine parameters
2. Operational environment
3. Atmosphere

According to Eliabet syverud *et.al* (2007), turbine blades are fouled when air impurities in form of solid and liquid pass through turbine passages and adhere onto the blades due to inertial impaction, turbulent diffusion impaction, Brownian diffusion, and thermophoresis

CT58-140-1 Engine Model

This work dwells more on performance analysis of CT58-140 engine model using Turbomatch software. Turbomatch is developed by Cranfield University. The engine model is used to analyse engine performance for clean condition (design and off design points) and deteriorated condition due to erosion and fouling effects. CT58-140 is a commercial version of the T58 (military engine) and it is the first American turboshaft to receive FAA certification. CT58-140 engine is comprised of 10 stage axial flow compressor, two stage chord axial turbines and a power turbine. CT58-140 is used on different civil helicopters such as Sirkorsky s-61, and s-62.

Performance model of GT58-140 Engine

Before the clean condition of the engine model is simulated, the engine model specifications were all known as shown in table 1

Table 1: CT58-140 Parameter specifications

Parameter	From Jane's	Engine model
Mass Flow(kg/s)	6.21	6.21
TET(K)	-	1150 (Guess)
Pressure Ratio	8.4	8.4
SFC($\mu\text{g}/\text{J}$)	105	90
Shaft Power (KW)	1044	1055

In Table 1, TET of the engine model was guessed because it was not given by Jane's aero engine. TET was varied in the model until the model produces shaft power close to that given by Jane's aero engine (original engine manufacturer rated power). TET was varied up to 1150K and a power of 1055KW which is very close to the original engine manufacturer rated power was produced by the model. After getting the required TET for the model, parameters such as mass flow, pressure ratio, and TET were input in the model and simulated to produce shaft power, specific fuel consumption as output parameters(dependent parameters). These parameters are considered to have been generated during sea level take off condition; hence they are assumed as design point parameters.

Compressor map shown in figure 2 is produced after the model is simulated at design point and it is used to describe the model performance at design point. The running line of the compressor map is plotted by running the model at different off design conditions by varying the model shaft speed.

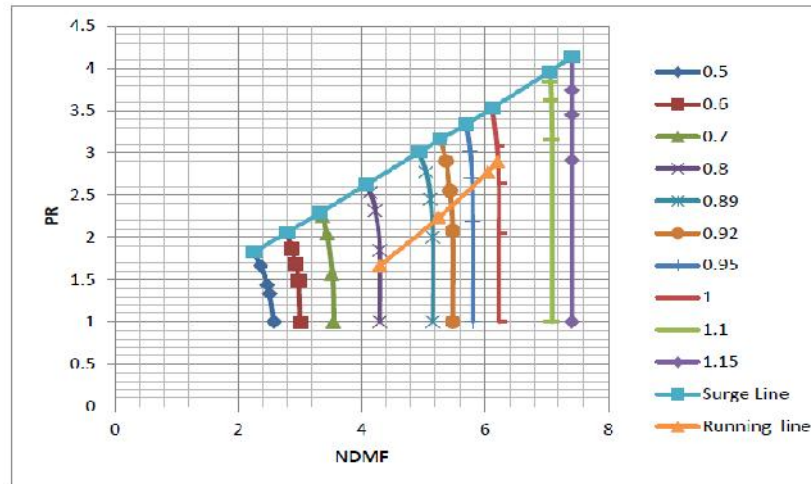


Figure 2: Compressor Map of GT58-140 Model

Effect of per Altitude on performance

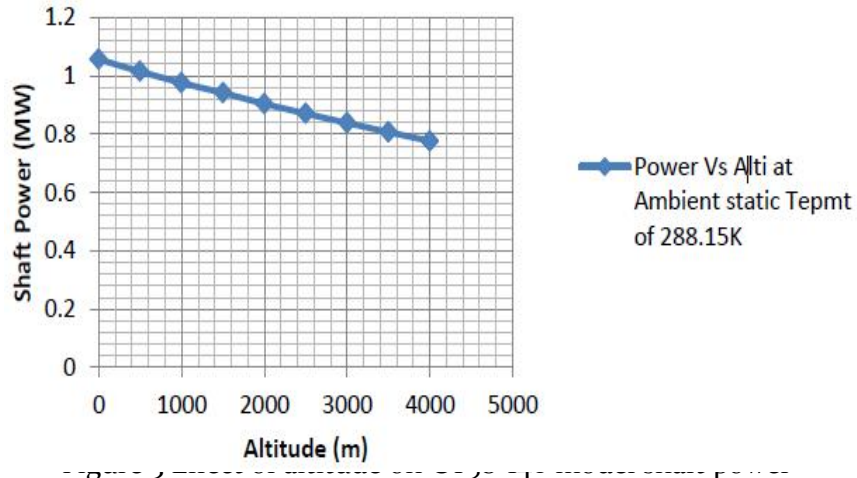
The model was stimulated at various altitudes with TET set as handle. The model service ceiling which is 3810 falls within the simulated altitudes.

With constant TET of 1150K from ground level up to 4000m a drop in shaft power is observed with increase in altitude as shown in figure 3.

At the service ceiling, the shaft power is reduced by approximately 25.2% (0.78MW). The gradual reduction in shaft power as the helicopter climbs to higher altitudes is attributed to drop in mass flow due to low air density and pressure at higher altitudes. However the low density is also beneficial to engine performance as the specific fuel consumption is observed to have significantly improved at high altitudes. For instance, the model's SFC at ground level is about 90.0957 $\mu\text{g}/\text{J}$ while that at 3500m is about 86.38.94 $\mu\text{g}/\text{J}$ which gives about 4.1% improvement of SFC at this altitude. SFC improvement at higher altitudes is due to low drag gas turbine engine encountered at higher altitudes.

Effect of ambient temperature on performance

Effect of ambient temperature was simulated in turbomatch software using various ranges of ambient temperatures with TET set as handle. At take-off condition; it is observed the model's shaft power drops gradually while the SFC increases as the ambient temperature increases. Figure 4 shows the effect of shaft power and SFC on helicopter operation in Nigeria, West Africa where ambient temperature is about 35 $^{\circ}\text{C}$. According to figure 53, at 35 $^{\circ}\text{C}$ (308K), the shaft power is reduced by 26% while the SFC is increased by 11%. Attempt to recover the lost power by increasing TET will be detrimental to the engine as increase in TET will reduce the creep life and consequently shortened the life of the engine. According to (Tendro, 2009) increase in TET by 25K will reduce creep life by half. Decrease in shaft power as a result of ambient temperature increase is due to significant reduction in mass flow and pressure.



In as much as lapse rate (rate of decrease in temperature with height, (i.e. 6.50C drop for 1000m) is observed as the helicopter climbs to higher altitudes, the effect of high ambient temperature is still noticed on the model shaft power as shown in figure 4 where shaft power at ISA condition and an ambient temperature of 350C both simulated at constant TET of 1150K were compared at various altitudes.

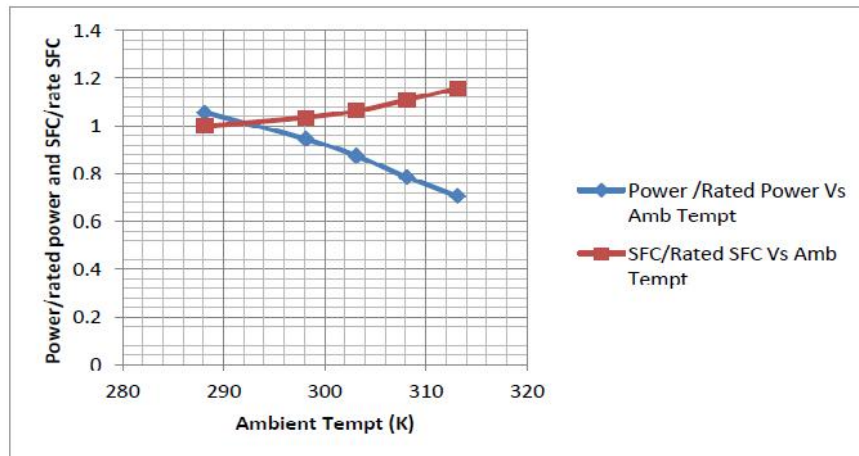


Figure 3: Effect of ambient temperature on power and SFC

Degraded performance analysis

The principle parameters that cause deviation on the degraded compressor map are mass flow and pressure ratio and components efficiencies. When the engine model is degraded due to erosion and fouling of blades, the mass flow, components efficiencies and pressure ratio are decreased as shown in figure 4. This reduction leads to decrease in shaft power. Figure 5 shows comparison between clean and degraded parameters at ISA conditions and a constant TET of 1150k, both the mass flow and pressure ratio are reduced by approximately 17% when the model is degraded. Similarly components efficiencies are also reduced by 31%. Reduction in these parameters lead to decrease in shaft power by 25%. Another performance parameter affected

when the model is degraded is SFC. Specific fuel consumption is however increased when engine is degraded.

Decrease in mass flow and pressure ratio as well as components efficiencies ratio for degraded engine is as a result of increase rotor tip clearance which cause flow leakages. According to Rainer Kurz and Llaus Brun (2000) increase in rotor clearance from 1% to 3.5 will cause reduction in pressure by up to 15%. Roughness on the other hand, causes premature flow separation which leads to significant losses in component efficiencies.

The fundamental effect of degradation is loss in shaft power. Of course the lost power could be recovered by increasing the TET, as demonstrated in the simulated model where 100K (increase in TET) as well as 15% increase in SFC are required to recover the lost power for the degraded model. However, this could jeopardize engine life as increase in TET by 25K decreases engine creep life by half.

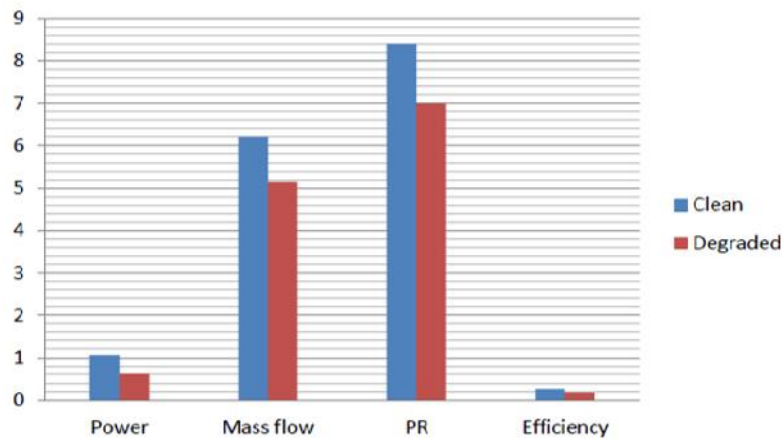


Figure 4: Indicators of degraded CT58-140 model

As earlier discussed in the previous chapters that operation of helicopter in dusty environment results to erosion of both the compressor and turbines and consequently, the engine performance is deteriorated. It is from this backdrop that the CT58-140 was degraded to understand the performance deterioration of parameters. Performance deterioration is understood with the aid of a compressor map shown in figure 5. The compressor graph is produced when the model was degraded by 4% and simulated at various altitudes with TET set as handle and PCN set to vary. In figure 6 the bold lines depict baseline performance whereas the dashed lines represent degraded performance of the model. In front of each bold line on the compressor map is a dashed line that shows deviation from baseline condition. Figure 6 also shows that operating line moves toward surge line when engine is degraded. Deviation in parameters demonstrated by the compressor map is basically an indication of change in performance parameters shown in figure 5.

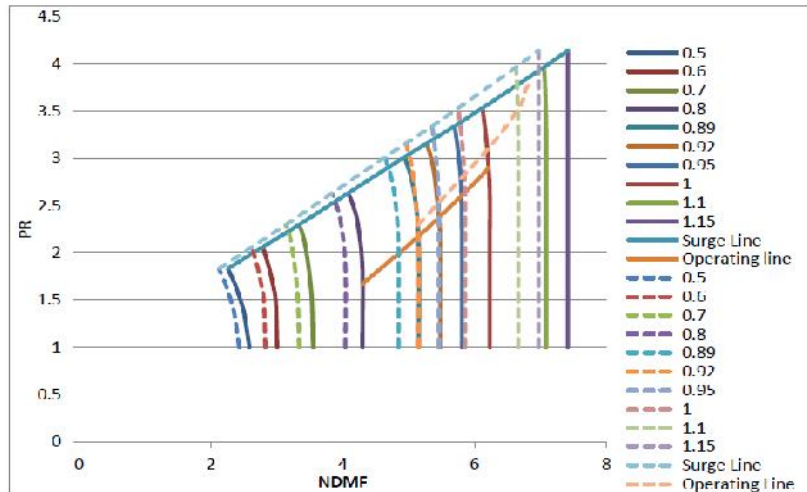


Figure 5: Degraded CT58-140 model of compressor map

Figure 6 shows comparison of degraded model and clean at various altitude. Figure 7 show a sharp decrease of shaft power by the degraded model with increase in altitude. The clean model shaft power also decrease with increase in power due to decrease in in pressure and density at higher altitudes. However decrease in the degraded shaft power is more than of the clean shaft power.

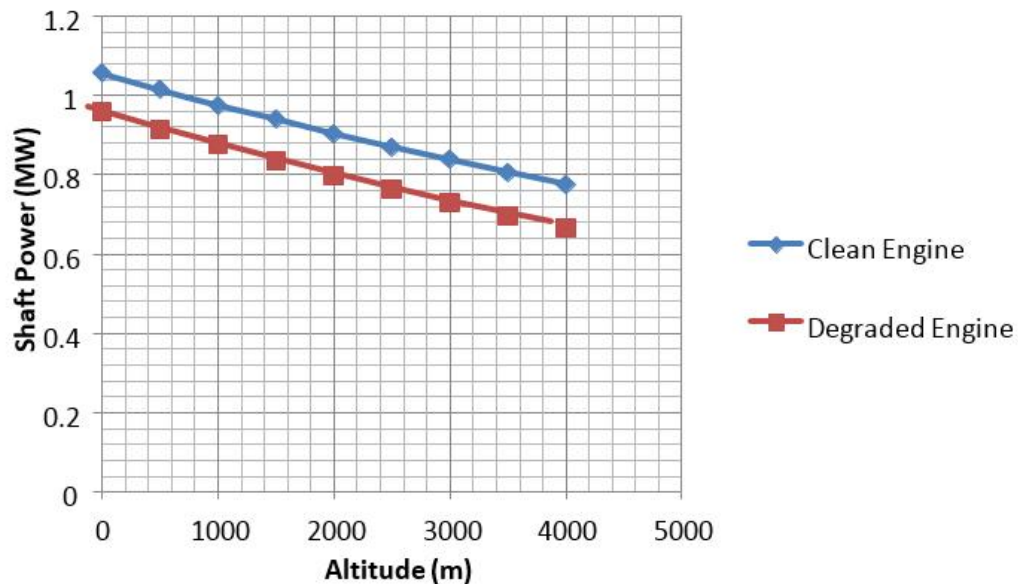


Figure 6: Comparison between degraded and clean model at various altitude

CONCLUSION

A model of CT58 -140-1 helicopter engine was stimulated using Turbomatch software to show effect of deterioration on the engine. The model was degraded by 4% and simulated at various altitudes with TET set as handle and PCN set to vary. Results for deteriorated and clean engine were obtained and compared, graphs and bar chat were used to present the results. According to the results, erosion of blades and vane lead as well as high temperatures and

altitudes cause significant decrease in shaft power, high tendency for surge to occur and increase in fuel consumption. This decrease is due deterioration of compressor blades which lead to reduction in pressure ratio, mass flow rate and components efficiencies. Decrease in the shaft power output and performance is also attributed to high temperatures recorded in the region of operation. Erosion effects pose threat to the entire engine as it reduces engine life due to reduction in creep life caused by increase in TET in order to recover power. Helicopter operation in this region is subjected to frequent maintenance much higher than recommended by the manufacturer. Thus operational cost in this region will be higher than that of unhostile region. Future work can be carried out to optimise the flight profile by analysing dust dispersion and distribution in the atmosphere.

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