Power Augmentation of an Existing Gas Turbine Starter Unit for use on A High Thrust Military Turbofan Engine

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Abstract :- **This paper presents the study successfully carried out, along with experimental results, for augmenting the output shaft power of an existing gas turbine starter unit (GTSU), a single spool turbo-shaft engine, in order to meet starting characteristics of higher 120 KN thrust class turbofan engine.The main objective of the study was to boost the power of the existing GTSU designed for a 85KN thrust class turbofan engine so as to cater to the starting requirement of a 120KN thrust class turbofan engine while keeping overall engine dimensions unaltered. Experimental test results of GTSU units obtained at Rig level as well as at engine test bed level before and after power augmentation are presented.**

This study is a first round performance assessment for specified parameters, where detail designs of the components are not scrutinized. The GTSU which is expected to produce a shaft power of 95 HP is boosted to produce near about 18% more shaft power by increasing the fuel flow to the combustion chamber.The feasibility of the augmentation was then exercised and assessed with respect to the design limits of the existing GTSU units. The key test parameters were then critically reviewed in comparison with testing limits for each parameter. This critical analysis also could discover the available potential in the existing GTSU for producing high power output without any significant performance issues which will save company's time and money for building an entirely new engine from scratch. This will also serve as a fruitful solution for the requirement of the customer.

Keywords—shaft power; gas turbine starter unit, fuel flow; power augmenation;test results; power out put;

ABBREVIATIONS

τ1 = satrting time of the main engine
OEM = original equipment manufacturer
GTSU = gas turbine starter unit
PA = power augmentation
EGT = exhaust gas temperature
FCU = fuel control unit
SP = specimen
AAGB = aircraft accessories gear box
EAGB = engine accessories gear box

1. INTRODUCTION

Primary purpose of a GTSU of any aero engine is to provide power to start the main engines. The principle involved in the starting of a low by pass turbofan engine is relatively simple. It is merely necessary to rotate the main engine at a speed sufficient to provide adequate air volume and velocity for starting, provide high intensity ignition in the combustion chamber and introduce fuel through the fuel nozzles in an amount that will not produce excessive heat but will provide sustained combustion and further acceleration of the engine. [1]

The starting system has to overcome inertia of the compressor and friction loads, the system remains in operation after combustion starts and is disengaged once the engine has reached self-idling speed. [2] Smaller jet engines are usually started by an electric motor, while larger engines are usually started by a small turbo-shaft type gas turbine engine. Before engines are to be turned, the GTSU is started, generally by a battery or hydraulic accumulator. Once the GTSU is running, it provides shaft power to start the aircraft's main engines.

GTSU for the low by pass turbofan engines belongs to the free turbine, turbo-shaft category, which is one of the most common types of engines in the aviation industry. The GTSU transmits power to the main engine vide the Central Bevel Drive Unit of the main engine by engine gear box route. GTSU transmits power to the main engine till the attainment of its self sustaining RPM (i.e expresed in % of HP rotor RPM).

Purpose of any GTSU is as mentioned below:

a. To rotate the engine up to self-sustaining RPM during engine starting on ground.
b. To rotate the engine up to cranking RPM (20 + 3%) during cold/ dry cranking and preservation / de-preservation.
c. It provides basic electrical supply to power the instruments on an aircraft, so that pilots can carry our pre-flight checks when on ground.

At present the aero-engine factory of the company is in the licence manufacturing of two different thrust class low by pass turbofan engines of wet thrust 85 KN and 120KN respectively. The starter unit GTSU-95 used for the 85KN engine is capable of producing 95^{+5} HP shaft power which is specified in line with the starting power requirement of the said engine by OEM. Similarly another starter unit called GTSU-115 fire up the 120KN engine with a shaft power of 115^{+10} HP. In both the cases the free turbine arrangement allows the main engine to work flexibly at a constant shaft speed of 3000±50 RPM.

This is only made possible by a series of well-designed components working in quick succession. Power from GTSU is transferred from AAGB to EAGB through a transmission shaft connecting both the gear boxes as shown in Fig.1.

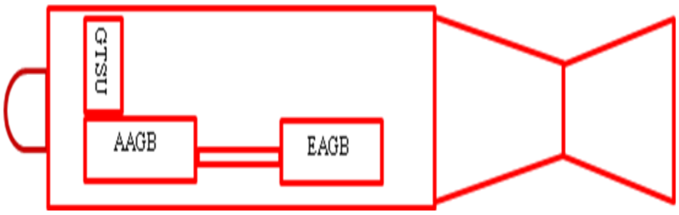

Figure-1 power transmission route /Lay out of GTSU on engines

Both the GTSUs are installed on to the AAGB of their main engines and secured with quick release clamp as shown in Fig.2.

Figure-2 Panel access/position of GTSU (indiacted by red arrow) on aircraft.

Both the GTSU units have a modular design, with the turbo-compressor module being one-shaft with centrifugal compressor and one-stage turbine. The reduction gear of the power turbine is executed according to the two-stage multi-flow scheme.

Free turbine power is transmitted via the reduction gear to the output shaft and further through a drive shaft to the engine gear box drive. Fig.3 shows the schematic lay out of a GTSU-95 used on the 85KN engine.

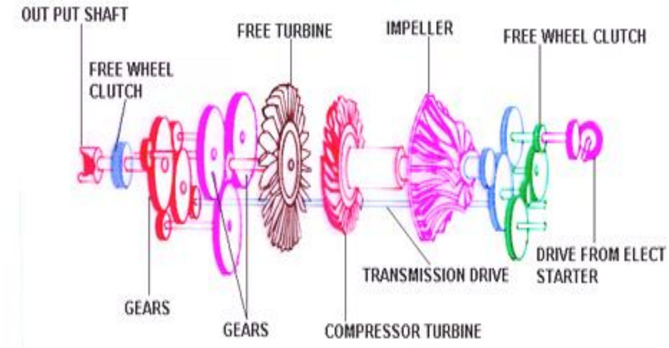

Figure-3 Schematic lay out of a GTSU-95

These GTSU engines are made in the form of two assembly modules. A cut section of the same is given at Fig.4:-

(a) <u>Turbine Compressor Module</u>

- (i) Accessory drive gearbox,
- (ii) Compressor,
- (iii) Combustion chamber,
- (iv) Compressor turbine.

(b) <u>Free turbine module</u>

- (i) Free turbine
- (ii) Exhaust pipe
- (iii) Reduction gear
- (iv) Output shaft.

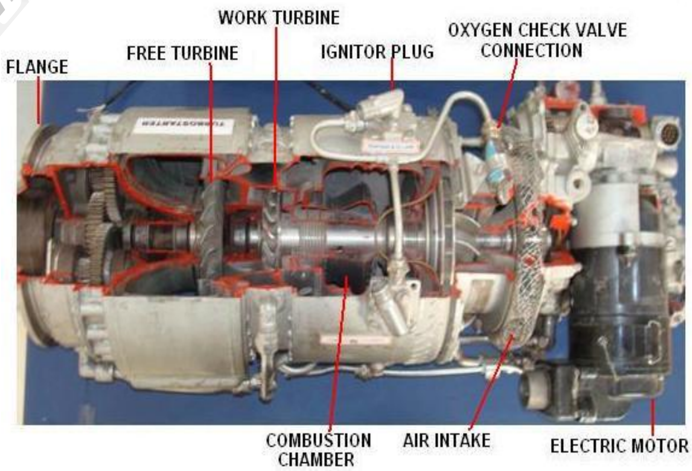

Figure-4 Cut section view of a GTSU-95

Coming to the issue, the starting time of the 120 KN engine for achieving its self-sustaining speed is 35 to 50 secs depending upon the ambient conditions. However the GTSU supplied by OEM for this engine which is capable of producing 115^{+10} HP though able to meet the starting requirements of the main engine was giving serious snags/defects during the in-service exploitation as well as during the in-house testing. The poor reliability of the GTSU -115 and growing customer dissatisfaction forced the factory to think for an alternate GTSU for the 120KN engine.

After significant brain storming and feasibility assessment of various options it was decided to check the feasibility of using the existing GTSU-95 which is having a good reliability history with the 85 KN engine, instead of going for an ab-initio GTSU design.

Before going for GTSU-95, it was felt that power of the same need to be increased to cater the starting time requirement of the 120KN engine as the starting load of the same would be more than that of the 85 KN engine. So the seeming potential for power augmentation was assessed from the rig level test data of twenty five no of successfully exploited GTSU-95 units. The observations made for potential realization purpose is mentioned at Table-I.

TABLE-I AVIALBLITY OF POTENTIAL MARGIN IN GTSU-95 FOR POWER AUGMNETATION

Parameters	**Design limit**	**Actual value(averaged for 25 units)**	**Potential margin available**
JPT (^{0}C)	715	645	70
Compressor shaft RPM	65000	62100	2900
Fuel flow	67	58	09
Compression ratio	2.6	1.9	0.7

From the above, it was realised that there is significant potential margin available with in the design limits for achieving higher shaft output from the existing GTSU-95 units.

Though it is well known that, increase in engine power cannot be achieved just by adding more fuel, as this would simply change the air to fuel ratio and result in un-burnt fuel being wasted and passing through the engine exhaust. [3]

But from the potential realization study it was observed that the Turbo-compressor is rotating usually at around 62100 rpm against the design limit of 65000rpm which shows availability of enough margin to increase the air mass flow by increasing the speed of the turbo-compressor vide fuel flow regulation i.e. increase in fuel flow will increase the shaft speed which in turn will increase the air mass flow within the available margin. More air and more fuel mean more power is developed by the engine which will significantly improve the power to weight ratio of the engine. The whole system may act like a forced air induction type. [3]

This was also supplemented by the fact that the turbo-compressor can tolerate the compression ratio up to 2.6 where it is usually utilized around 1.8 to 2.0. By this view, it can be said rich mixture formation can be avoided with the scheme based on fuel flow increase.Keeping this in view a scheme for power augmentation was developed.

2. METHODOLOGY ADOPTED FOR POWER AUGMENTATION OF GTSU-95

In absence of any reference standards it was decided to standardize the exact power setting requirement/or the potential of the present GTSU -95 units for producing higher power. It was decided, first to run the GTSU-95 units on 120KN engine without any power augmentation. Based on the above three specimen GTSU-95 were selected for this purpose. Details are given below:

The selected specimen GTSU-95 units are then mounted on to three different 120KN thrust engines and tested in the in-house test bed.

From the observations, it was found that the starting time of the 120KN engine is more than the allowable limits set by the OEM which is shown below in Table No. II

TABLE-II STARTING PARAMETERS OF ENGINE WITH GTSU BEFORE PA.

GTSU-95 units	**Starting time (in sec) of the120 KN engine up to self-sustaining rpm**			
	Ambient tempt. (^{0}C)	**Design limit**	**Actual value**	**delay**
GTSU-95 SP1	23.5	42	46.7	4.7
GTSU-95 SP2	23	41.8	46.3	4.5
GTSU-95 SP3	23.6	42.1	47.1	5

The above GTSU-95 units are set at power output of 95^{+2} HP at rig level. But, this delay in starting time could be resolved after replacement of GSTU-95 with GTSU-115, in all the three cases. This has shown that the power delivered by existing GTSU-95 was insufficient to provide necessary starting characteristics resulting in to higher starting time of the aero engine.

Hence in order to enable GTSU-95 to act as a prospective starter unit for the 120 KN engine, decision for power augmentation of the same was taken to achieve power output nearer to that of GTSU-115 without violating any of the design limitations set for the GTSU-95. Accordingly the three specimen GTSU-95 units reported with higher starting time were brought back to the testing rig for power augmentation. The increased power output of the GTSU-95 was aimed to achieve through least possible experimentation/modification and within quickest possible time so as to meet the urgency in the fleet requirement of the customer.

Keeping these constraints in mind, power augmentation was achieved by increasing the fuel flow to the combustion chamber by making suitable adjustments in the fuel control unit of GTSU-95 units. The power adjustment exercise at rig test level is shown in Fig.5.

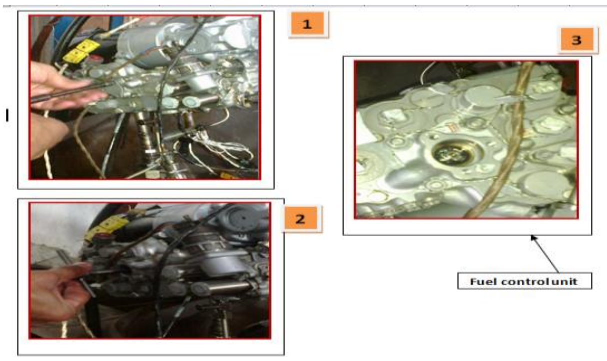

Figure-5 Adjustment of fuel flow in FCU of GTSU-95 at Test Rig.

These adjustments were done within the testing norms specified for the original GSTU-95 units. After successful rig testing, these three power augmented specimen GSTU-95 units were subjected to tests with main engine by fitting them with the same set of 120 KN engines in in-house testing facility as shown in Fig.6

Figure-6 In-house testing facility for the 120KN engine.

3. APPRECIATION/ANALYSIS OF TEST RESULTS

3.1. Test results of GTSU-95 before and after power augmentation at Rig Level Testing are analysed and placed in the following paragraphs.

3.1.1 *Exhaust gas temperature (EGT)*

The limit for exhaust gas temperature of GTSU-95 unit is 715°C .The values of EGT of the GTSU-95 units before and after power augmentation at test rig level are plotted in the Fig.7.

From the graph it is observed that after power augmentation, the EGT of all the three specimen GTSU-95 units increased by 15 to 30 °C, but all are found well below the prescribed limit of 715 °C.

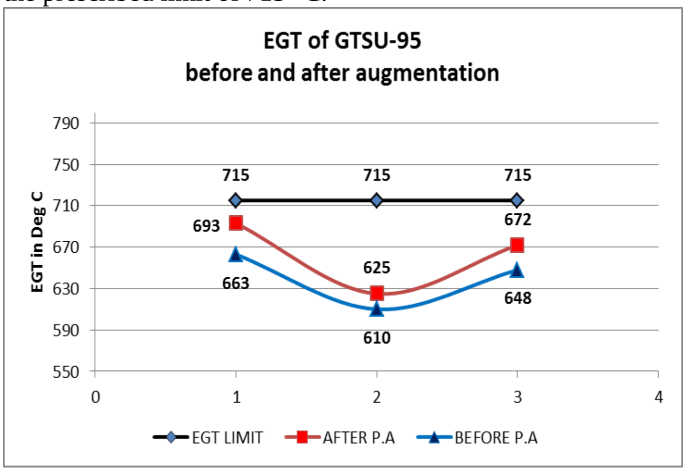

Figure-7 .(GTSU-95-SP1) 2. (GTSU-95-SP2) 3. (GTSU-95 SP3)

3.1.2 *Turbo compressor RPM*

From the Table-III, it can be observed that the there is no definite variation pattern with respect to turbo-compressor RPM of GTSU-95 units before and after power augmentation.

Further, it shows that the increased power could be achieved by keeping the turbo-compressor RPM well below the prescribed limit.

TABLE-III TURBO COMPRESSOR RPM OF GTSU-95 BEFORE & AFTER PA.

Type	Sl no.	POWER (Hp)	Turbo compressor (RPM) < 65000
GTSU-95 (B/PA)	SP-1	95	61987
	SP-2	95.5	62123
	SP-3	96	62324
GTSU-95 (A/PA)	SP-1	112	63223
	SP-2	113	63456
	SP-3	112.5	63567

3.1.2 *Fuel flow rate*

The fuel flow rate limit as per GTSU-95 testing technology is 67 kg/hr. Power of the GTSU-95 units is increased by subsequent increase in fuel flow vide adjustments in the FCU. The variations in fuel flow rate are plotted in Fig.8.

From, the given graph it is clear that the power augmentation could be achieved by keeping the fuel flow rate well below the technical limit.

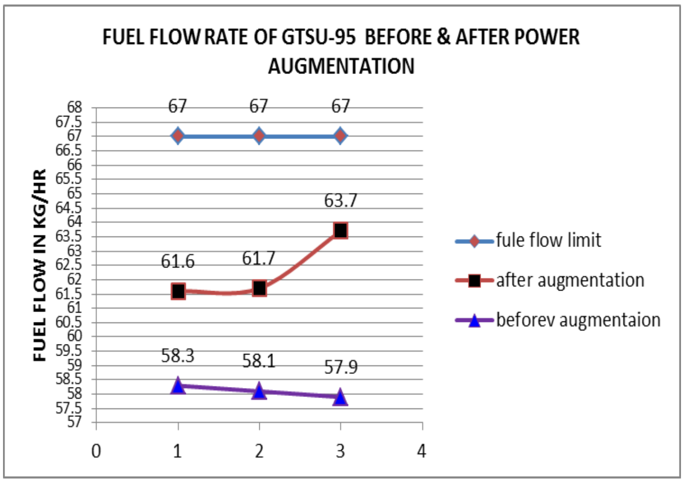

Figure-8 1.(GTSU-95-SP1) 2. (GTSU-95-SP2) 3. (GTSU-95 SP3)

3.1.2 *GTSU-95 starting time*

The allowable starting time (i.e. the time taken by the rotor of the turbo compressor to settle out at 98 % of the rotational speed of the steady starter mode, from the time when the start button is pressed, sec., max.) of GTSU-95 is 10 secs.

The Table. IV shows that the in all the cases the starting time of the GTSU-95 units was within the prescribed limit and there is no almost any variation observed in starting time before and after power augmentation**.**

TABLE-IV STARTING TIME OF GTSU AT RIG LEVEL BEFORE & AFTER PA.

Type	Sl no.	POWER (Hp)	Turbo compressor (RPM) < 65000
GTSU-95 (B/PA)	SP-1	95	8
	SP-2	95.5	8
	SP-3	96	8
GTSU-95 (A/PA)	SP-1	112	8
	SP-2	113	9
	SP-3	112.5	8

The above table shows that the in all the cases the starting time of the GTSU-95 units was within the prescribed limit and there is no almost any variation observed in starting time before and after power augmentation.

3.2. Test results of GTSU-95 before and after power augmentation with 120 KN engine are analysed and placed in the following paragraphs.

3.2.1 *Starting Time of 120KN engines with Power augmented GTSU-95 units.*

The Turbo-starter remains on for the duration required to attain the self-sustaining RPM of the engine (i.e. 55% of HP rotor RPM of engine) or by maximum 50 secs the turbo-starter will cut off automatically from engine drive. This time period is termed as τ_1.

The Table.V summarises the τ1 value of the engines with the specimen GTSU-95 units before and after power augmentation.

TABLE-V STARTING PARAMETERS OF 120KN ENGINE WITH GTSU-95 BEFORE AND AFTER PA.

Type	GTSU-95 SL NO	Power (Hp)	Amb. Tempt (Deg C)	τ1 (sec) limits	τ1 (sec) actual
GTSU-95 (B/PA)	SP 1	95	23.5	42	46.7
	SP 2	95.5	23	41.8	46.3
	SP 3	96	23.6	42.1	47.1
GTSU-95 (A/PA)	SP 1	112	23.5	42	39.76
	SP 2	113	23.5	42	39.50
	SP 3	112.5	23	41.8	39.25

From the above table, it is observed that after power augmentation the starting time **τ1** has been improved significantly and found well within the acceptable limits of 120KN engine testing technology.

3.2.2 *Vibration of power augmented GTSU-95 units during testing with 120KN engines.*

The vibration values of GTSU-95 units as obtained during engine testing are mentioned in Table.VI. The limit for all the 3 type of vibrations is 30mm/sec.

TABLE-VI VIBRATION VALUES OF GTSU-95 WITH 12OKN ENGINE TESTING BEFORE & AFTER PA.

Type of Vibration	GTSU-95 SP 1	GTSU-95 SP 2	GTSU-95 SP 3
VERTICAL	15	13	14
HORIZONTAL	17	18	14
AXIAL	8	10	9
LIMIT (mm/sec)	30	30	30

From the above, it is observed that the vibrations of all the power augmented GTSU-95 units are well within the acceptable limits of engine testing.

3.2.3 *Starting EGT of 120KN engines with Power augmented GTSU-95 units.*

The variations in the starting EGT values of 120KN engines when tested with GTSU-95 units, both before and after power augmentation are plotted in Fig.9.

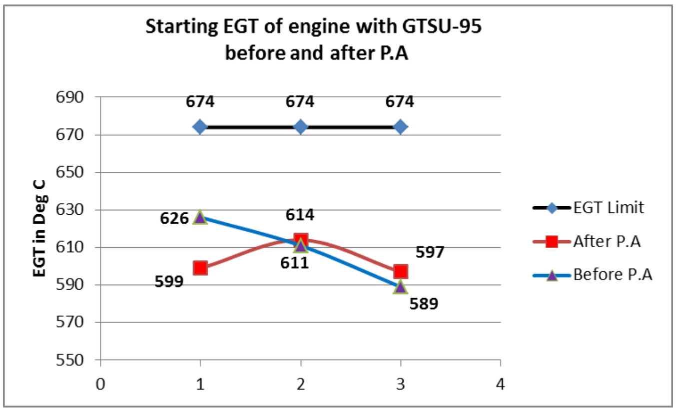

Figure-9 1.(GTSU-95-SP1) 2. (GTSU-95-SP2) 3. (GTSU-95 SP3)

Form the graph; it is clearly observed that the starting EGT of the 120KN engine is well within its testing limit when tested with the power augmented GTSU-95 units. However there is no significant trend set between pre and post augmentation EGT value.

4. CONCLUSION

From the test results, required level of power augmentation of GTSU could be achieved without any noteworthy change in the performance and life critical parameters like EGT, max speed and vibration, which was considered as an essential condition for the study.

Hence, the capacity of GTSU-95 units to achieve starting time within the testing limits of 120KN thrust class engine by power augmentation is established by this study within the following limits:

1. Rig testing parameters of GTSU-95
2. Test parameters of 120KN engine.

Further this exercise also demonstrated that power augmentation with a ratio of approximately 1.18 can be achieved from the existing GTSU without any physical modifications and only with a small additional fuel cost which will serve as a fruitful solution for the requirement of the customer as well as the company.

ACKNOWLEDGMENT

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