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Performance Simulation of a Turboprop Engine for Basic Trainer

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A performance simulation program for the turboprop engine (PT6A-62), which is the power plant of the first Korean indigenous basic trainer KT-1, was developed for performance prediction, development of an EHMS (Engine Health Monitoring System) and the flight simulator. Characteristics of components including compressors, turbines, power turbines and the constant speed propeller were required for the steady state and transient performance analysis with on and off design point analysis. In most cases, these were substituted for what scaled from similar engine components' characteristics with the scaling law. The developed program was evaluated with the performance data provided by the engine manufacturer and with analysis results of GASTURB program, which is well known for the performance simulation of gas turbines. Performance parameters such as mass flow rate, compressor pressure ratio, fuel flow rate, specific fuel consumption and turbine inlet temperature were discussed to evaluate validity of the developed program at various cases. The first case was the sea level static standard condition and other cases were considered with various altitudes, flight velocities and part loads with the range between idle and 105% rotational speed of the gas generator. In the transient analysis, the Continuity of Mass Flow Method was utilized under the condition that mass stored between components is ignored and the flow compatibility is satisfied, and the Modified Euler Method was used for integration of the surplus torque. The transient performance analysis for various fuel schedules was performed. When the fuel step increase was considered, the overshoot of the turbine inlet temperature occurred. However, in case of ramp increase of the fuel longer than step increase of the fuel, the overshoot of the turbine inlet temperature was effectively reduced.

Key Words : Performance Analysis, Turboprop Engine, Characteristics

Nomenclature

A	: Area
C_P	: Specific heat at constant pressure
$D.P.$	: Developed program
FN	: Thrust of nozzle
$G.T.$	: GASTURB program
ΔH	: Enthalpy of reaction
I	: Moment of inertia
$M.D.$	: Provided data by Manufacturer
$M.N.$	: Flight Mach Number
$\dot{m}$	: Mass flow rate
$\dot{m}_a$	: Air mass flow rate
$\dot{m}_f$	: Fuel flow rate
N	: Rotational speed

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Ng : Rotational speed of gas generator
P_0 : Total pressure
PR : Pressure ratio
SFC : Specific fuel consumption
SHP : Shaft Horse Power
TIT : Turbine Inlet Temperature
T_0 : Total temperature
η : Isentropic efficiency

Subscripts

C : Compressor
CT : Compressor Turbine
C.F. : Centrifugal Force
$D.$: Design point values of scaled component
$M.$: Arbitrary map values
$M.D.$: Design point map values of original components
a : Air
g : Combustion gas
m : Mechanical
1 : Compressor inlet
2 : Compressor exit
3 : Compressor turbine inlet
4 : Power turbine inlet
5 : Power turbine exit

1. Introduction

A performance simulation program for the PT6A-62 turboprop engine, which is the power plant of the first developed military basic trainer KT-1 in Republic of Korea, has been required for more precise performance prediction and development of the EHMS and the flight simulator. However, because most performance analysis programs of engine manufacturers are proprietary, they are usually not provided to their customers. Therefore, most aircraft developers need their own analysis tools for detailed performance analysis and development of equipments related to the engine. The following literature reviews the historical background of gas turbine simulation.

A non-linear analog simulation of a J85-13 turbojet engine was developed by Seldner, et al. (1972). The study indicated that a mathematical representation using the dynamics inherent in the conservation equations and engine geometry will provide a better simulation than those using component representation and linearized dynamics (Seldner, et al., 1972).

In order to optimize the thrust response rate of a single spool turbojet, Saravanamuttoo and MacIsaac(1973) used a hybrid computer. The digital computer was better suited to store and access data such as compressor and turbine characteristics while the analog computer calculated the integration of net torque and numerous multiplication and divisions for the representation of thermodynamic variables (Saravanamuttoo and MacIsaac, 1973).

For simulating the steady state and dynamic performance of turbojet and turbofan engines, a generalized digital computer program, called DYNGEN, was developed by Seller and Daniele (1975). A modified Euler method to solve the differential equations, which model the dynamics of the engine, was used (Seller and Daniele, 1975).

Palmer and Yan (1985) developed a generalized modular digital computer code, called TURBOTRANS for the steady state and transient performance simulation of arbitrary gas turbine engines with arbitrary control systems. The control system of a given engine might consist of up to 4 control units, e.g. main fuel, afterburner fuel and both bypass and main nozzle area control units (Palmer and Yan, 1985).

TURBOCAL, a digital computer program that simulates the on-design, off-design and transient performance of arbitrary gas turbine configuration was developed by Douglas(1986). This program performed also rig-test analysis of three engines. In order to obtain numerical solution of the dynamic equations for the transient performance simulations, the modified Euler method was used (Douglas, 1986).

Schobeiri et al., (1994) developed a modularly structured simulation code, called GETRAN, which was capable of simulating the non-linear dynamic behavior of single and multi-spool core engines, turbofan engines, and power generation gas turbine engines (Schobeiri et al, 1994).

Since mid 1990's, a program of GUI(Graphical

User Interface) method has been increasing. Using SIMULINK, the dynamic non-linear model of a single- shaft industrial gas turbine was developed by Bettocchi, et al(1996). The model consisted of modular structure representing individual engine component and was carried out in simplified form (Bettocchi, et al, 1996). Also, lower case a 65MW heavy-duty gas turbine plant model was described using SIMULINK by Crosa, et al. (1998) (Crosa, et al., 1998).

GASTURB program of GUI method developed by Kurzke(1995) is updated as version 8.0 in 1999 and it is widely used as well-known program. GASTURB simulates most of the common engine types: mixed and unmixed turbofans with or without boosters, turboshafts with or without heat exchangers, and one shaft and two shaft turboprop engine. Also, GASTURB simulates afterburner and convergent/divergent nozzles in the turbojet and mixed flow turbofan engine simulation (Kurzke, 1995).

The developed program for steady state and transient performance analysis in this study was compared with the performance data provided by the engine manufacturer and the analysis result of GASTURB program to evaluate whether the developed program is acceptable or not.

The performance analysis was separately carried out at the design point, off design points in steady state and transient conditions. Efficiencies of individual components and the inlet temperature of turbine were selected by comparing with engine manufacturer's performance data.

The steady state off-design point analysis were performed with altitude variation between sea level and 10668m height, flight velocities between M. N. 0.0 (flight mach number=0.0) and M. N. 0.4 and partial load between 65% RPM and 105% RPM.

In the transient performance analysis, the step increase of fuel supply, which is needed to increase the rotational speed from idle to 100% RPM was considered. The overshoot of the turbine inlet temperature was compared with experimental data provided by the engine manufacturer. In addition, transient behaviors were analyzed at various simulated fuel schedules.

2. On-Design Performance Analysis

The PT6A-62 free-turbine turboprop engine is selected for performance analysis in this study. The station number and layout for analysis is shown in Fig. 1.

In the design point performance analysis, well-known thermo-dynamic relationships were used to calculate individual component's characteristics to meet the performance provided by the engine manufacturer.

Table 1 presents the performance data which were provided by the engine manufacturer as a reference.

Firstly, the compressor efficiency was determined using the compressor pressure ratio and the exit total temperature, and then fuel flow rate was calculated from S.F.C (specific fuel consumption) and SHP (shaft horsepower). The fuel flow rate was used to calculate the turbine inlet

Table 1 Performance data provided by engine Manufacturer

Variable	Data by Manufacturer
Atmospheric Condition	Sea Level Static Standard Condition
Mass Flow Rate (kg/s)	3.676
Compressor Pressure Ratio	8.25
Compressor Exit Temperature (K)	592.43
Shaft Horse Power (hp)	950
S.F.C (kg/kw·hr)	0.36588
Nozzle throat Area (m^2)	0.05806
Gas Generator Rotational Speed (100% RPM)	36200
Propeller Rotational Speed (100% RPM)	2000

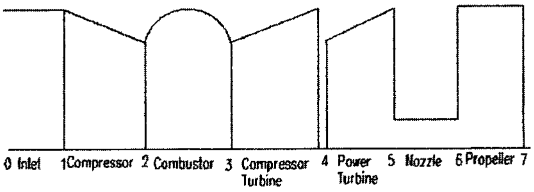


Fig. 1 Station No. and layout of the study engine

temperature, the turbine work and the power turbine inlet temperature at the design point. If the efficiency and the pressure loss of the combustor may be assumed from the data of a similar engine, the turbine inlet pressure can be calculated. Moreover the exit pressure of the compressor turbine can be calculated from the compressor turbine temperature ratio and the turbine inlet pressure. Since the nozzle of the PT6A-62 engine is not choked at the design point, the nozzle exit pressure must be the same as atmospheric pressure, and therefore the nozzle exit temperature can be calculated from the nozzle throat area. Finally, the power turbine pressure ratio and the power turbine exit temperature to satisfy the required shaft horsepower can be determined. Where isentropic efficiencies of the compressor turbine and the power turbine and mechanical efficiencies of rotor shaft bearings including windage losses were assumed from experimental data of a similar engine.

The design point performance analysis results, by both the developed program and the GASTURB are shown in Table 2.

As shown in Table 2, the results satisfied the performance data (Table 1) provided by the engine manufacturer and corresponded to the results analyzed by GASTURB, so that the design point was determined. In this case, the efficiencies of the combustor, the compressor turbine and the power turbine and the mechanical efficiency of the gas generator rotor shaft and propeller rotor shaft were assumed to 0.97, 0.92, 0.91, 0.94 and 0.892, respectively, and the combustor pressure loss was assumed to 3%.

Table 2 On-design performance data

	D.P. (Developed Program)	G. T. (GASTURB)	% Error [(G.T.-D.P.) /G.T.×100]
$\dot{m}_a$(kg/s)	3.696	3.696	0.0
P_{02}/P_{01}	8.250	8.250	0.0
P_{03}/P_{04}	3.0420	3.0424	0.018
P_{04}/P_{05}	2.5109	2.4609	1.991
T_{02} (K)	592.43	592.43	0.0
T_{03} (K)	1269.50	1269.50	0.0
T_{04} (K)	1000.04	1000.04	0.0
T_{05} (K)	820.626	817.86	0.337
$\dot{m}_f$(kg/s)	0.0720	0.07204	0.056
SHP (HP)	950.035	950.008	0.003
FN (kN)	0.56109	0.56035	0.132
SFC (Kg/Kw·hr)	0.36587	0.36606	0.052
A_7 (m^2)	0.05804	0.05801	0.052

3. Steady State Performance Analysis

In the steady state performance analysis for off-design point, the following assumptions and equations were considered:

The airflow passed through the intake, the compressor, the compressor turbine, and the power turbine must be constant. Therefore, the following flow compatibility equations can be applied to this type of the engine such as: (Cohen et al., 1996)

$$\frac{\dot{m}_a\sqrt{T_{03}}}{P_{03}}=\frac{\dot{m}_a\sqrt{T_{01}}}{P_{01}}\times\frac{P_{01}}{P_{02}}\times\frac{P_{02}}{P_{03}}\times\sqrt{\frac{T_{03}}{T_{01}}} \tag{1}$$

$$\frac{(\dot{m}_a+\dot{m}_f)\sqrt{T_{04}}}{P_{04}}=\frac{(\dot{m}_a+\dot{m}_f)\sqrt{T_{03}}}{P_{03}}\times\frac{P_{03}}{P_{04}}\times\sqrt{\frac{T_{04}}{T_{03}}} \tag{2}$$

The work done by the compressor and the turbine connected with the same shaft must be the same. Therefore work compatibility of the gas generator are presented as the following equation.

$$\eta_m C_{Pg}\Delta T_{034}=C_{Pa}\Delta T_{012} \tag{3}$$

The performance of the each component follows the scaled performance characteristic from the original component characteristics.

Since the engine manufacturer does not provide component maps for this study, the scaled component maps from a similar engine were used. The scaling equations used in this study are as follows (Seller and Daniels, 1975):

$$PR=\frac{PR_{D.}-1}{PR_{M.D.}-1}(PR_{M.}-1)+1 \tag{4}$$

$$\dot{m}=\frac{\dot{m}_{D.}}{\dot{m}_{M.D.}}\dot{m}_{M.} \tag{5}$$

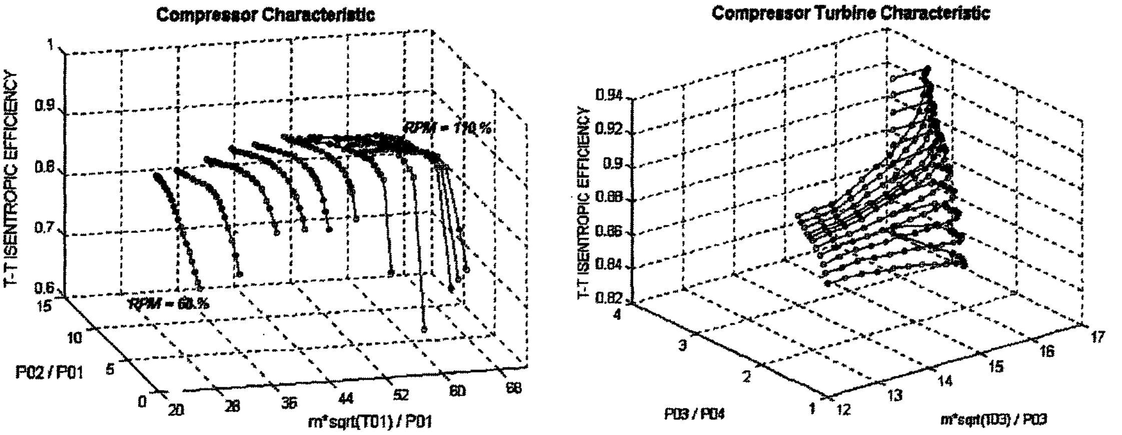
$$\eta=\frac{\eta_D}{\eta_{M.D.}}\eta_{M.} \tag{6}$$

The closer scaling factors ($([PR_{D.}-1]/[PR_{M.D.}-1]$, $[WA_{D.}/WA_{M.D.}]$, and $[ETA_{D.}/ETA_{M.D.}])$ are to 1.0, the simulated maps are much more reasonable. Conversely, not being close to 1.0 does not necessarily mean that the simulation must be poor since many maps have been typically scaled with a quite large range. In this study, because scaling factors were 0.795 to 1.2, it could be considered that the scaling component characteristics might be valid.

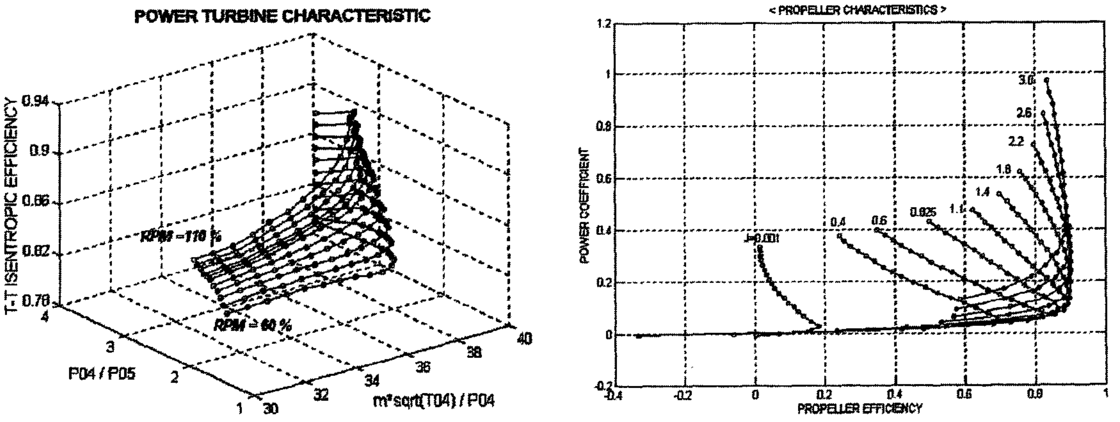
The performance characteristics of the compressor, turbine, power turbine and propeller were shown as Fig. 3.

Figure 4 shows the flow chart of the steady state program, which satisfies the above conditions. In this study, the steady state performance analysis is carried out with an uninstall condition.

In case of uninstall condition, the inlet pressure loss, bleed air take-off and the power take-off can be ignored. Not only flight conditions such as the flight speed and the altitude but also part load conditions were considered in this analysis. In this study, the maximum take-off condition, which are the design point and the off-design point conditions with various altitudes from ground to 10668m and various flight velocities from M. N 0.0 to M.N. 0.4 were analyzed. The part load performance analysis with the range between 65% RPM, the idle rotational speed of the engine rotor, and 105% RPM, the maximum rotational speed of the engine rotor, were analyzed as well.



(a) Compressor characteristic (b) Compressor turbine characteristic



(c) Power turbine characteristic (d) Propeller characteristic

Fig. 3 Component characteristics

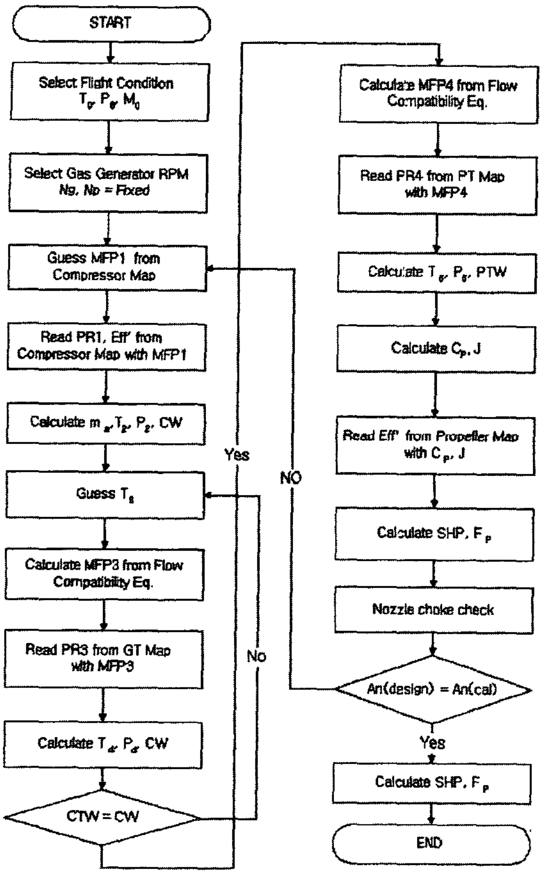


Fig. 4 Flow chart of steady state matching program

3.1 Maximum take-off performance

The maximum take-off performance at a design point has the sea level, standard atmospheric and static condition. The result by the developed program was compared with manufacturer's performance data and the analysis result by GASTURB program. The compared result is shown in Table 3.

The results compared with the results of the design point performance and GASTURB showed the maximum range of error within 0.2%. From these results, it was found that the scaling method of component maps and the algorithm of steady state performance analysis were reasonable.

3.2 Altitude performance

The performance analysis with the altitude range from ground to 10,668m, which is the operating range of KT−1, was carried out. If the altitude and the flight Mach number is changed, the component maps should be corrected in the standard condition.

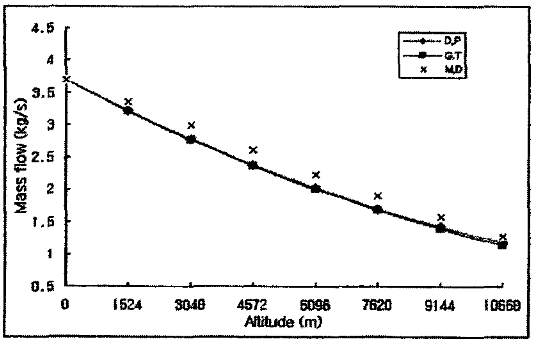
The performance analysis for considering altitude is carried out at zero flight Mach number

Table 3 Off design performance at take-off condition

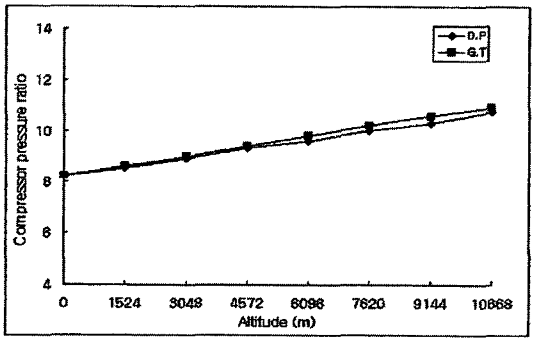
	G.T. (GASTURB)	D.P. (Developed Program)	% Error [(G.T.−D.P.)/G.T.×100]	M.D. (Manufacturer's Data)
$\dot{m}_a$ (Kg/s)	3.696	3.696	0.0	3.696
P_{02}/P_{01}	8.250	8.250	0.0	8.250
T_{02} (K)	592.43	592.45	0.003	592.43
T_{03} (K)	1269.50	1269.51	0.000	•
T_{04} (K)	1000.04	1000.06	0.002	•
$\dot{m}_f$(Kg/s)	0.07204	0.07200	0.055	0.072
SHP (HP)	950.008	949.399	0.064	950
SFC (Kg/Kw·hr)	0.36606	0.36611	0.014	0.36588
$A_7(m^2)$	0.05801	0.05794	0.121	0.05806

Table 4 Comparison of the GASTURB and the developed program as altitude variation

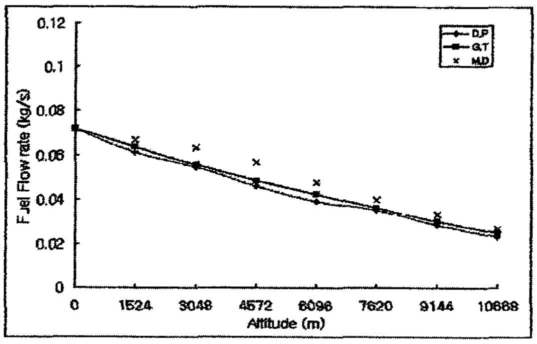
Altitude (m)	Variable	G.T.	D.P.	% Error [(G.T.−D.P.)/G.T.×100]
1524	$\dot{m}_a$(kg/s)	3.211	3.2293	0.270
	PR_C	8.621	8.5642	0.664
	$\dot{m}_f$(kg/s)	0.0636	0.0612	3.746
	SHP(hp)	855.096	832.041	2.696
4572	$\dot{m}_a$(kg/s)	2.368	2.3828	0.625
	PR_C	9.399	9.3367	0.662
	$\dot{m}_f$(kg/s)	0.0485	0.0461	4.910
	SHP(hp)	672.994	646.526	3.932
7620	$\dot{m}_a$(kg/s)	1.685	1.6953	0.610
	PR_C	10.211	10.027	1.806
	$\dot{m}_f$(kg/s)	0.0359	0.0350	2.507
	SHP(hp)	488.933	455.47	6.844
10668	$\dot{m}_a$(kg/s)	1.146	1.1362	3.508
	PR_C	10.942	10.776	1.515
	$\dot{m}_f$(kg/s)	0.0249	0.0236	5.482
	SHP(hp)	328.896	307.144	6.613



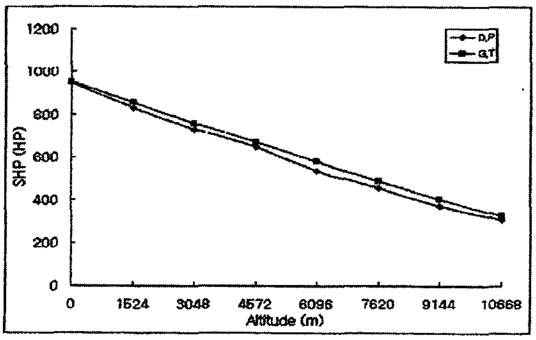
(a) Mass flow vs. Altitude



(b) Compressor pressure ratio vs. Altitude



(c) Fuel flow rate vs. Altitude



(d) SHP vs. Altitude

Fig. 5 Results of steady state performance analysis with altitude variation

and 100% rotational speed of the gas generator. It was compared with the performance data provided by the engine manufacturer and with GASTURB analysis results. Table 4 and Fig. 5 show the result of comparison between them.

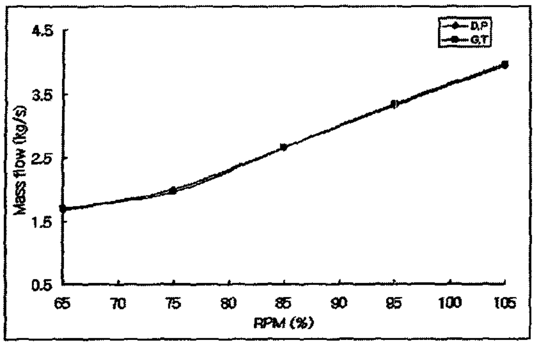
The airflow rate and the fuel flow rate were compared with the performance data provided by the engine manufacturer and with GASTURB analysis results. The former showed the maximum range of error within 8%, the later was lower. From these results, it was verified that the developed program is useful and the algorithm of steady state performance analysis was proper.

3.3 Part load performance

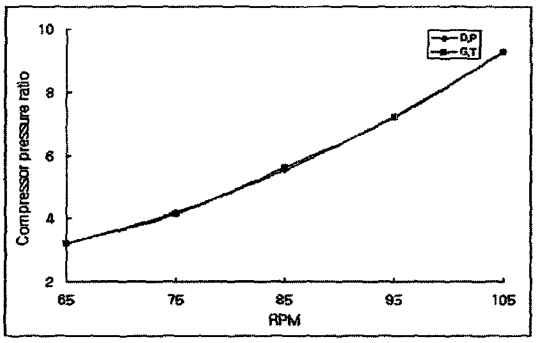
The part load performance analysis was done with the 10% RPM interval between 65% idle and 105% maximum RPM of gas generator at the sea level static standard condition. The analysis results compared with GASTURB are shown in Table 5 and Fig. 6.

Table 5 Comparison of the GASTURB and the developed program as rotational speed of gas generator

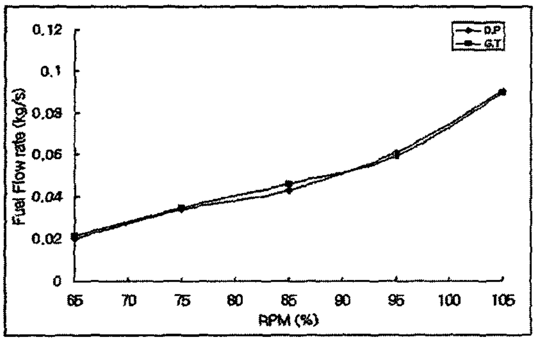
%RPM	Variable	G.T.	D.P.	% Error
75%	$\dot{m}_a$(kg/s)	1.702	1.6772	1.457
	PR$_C$	3.1936	3.1956	0.062
	$\dot{m}_a$(kg/s)	0.0212	0.0201	5.719
	SHP(hp)	147.183	149.89	1.839
85%	$\dot{m}_a$(kg/s)	1.967	2.0086	2.115
	PR$_C$	4.1449	4.1986	1.296
	$\dot{m}_f$(kg/s)	0.0347	0.034	2.146
	SHP(hp)	276.388	257.62	6.791
95%	$\dot{m}_a$(kg/s)	2.645	2.645	0
	PR$_C$	5.614	5.5274	1.545
	$\dot{m}_f$(kg/s)	0.0458	0.0431	5.769
	SHP(hp)	483.66	444.02	8.196
65%	$\dot{m}_a$(kg/s)	3.342	3.315	0.180
	PR$_C$	7.2232	7.2326	0.129
	$\dot{m}_f$(kg/s)	0.0593	0.0612	3.268
	SHP(hp)	735.989	732.926	0.416
105%	$\dot{m}_a$(kg/s)	3.965	3.935	0.762
	PR$_C$	9.2719	9.296	0.244
	$\dot{m}_f$(kg/s)	0.0894	0.0905	1.321
	SHP(hp)	1218.04	1205.89	0.997



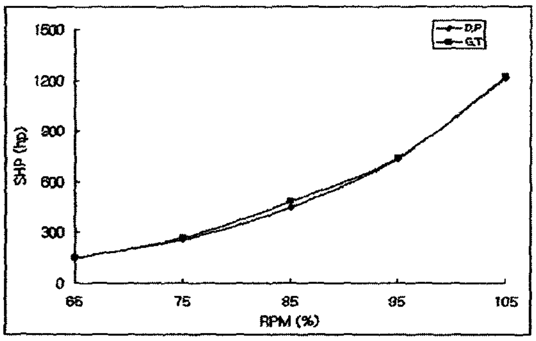
(a) Mass flow vs. RPM



(b) Compressor pressure ratio vs. RPM



(c) Fuel flow rate vs. RPM



(d) SHP vs. RPM

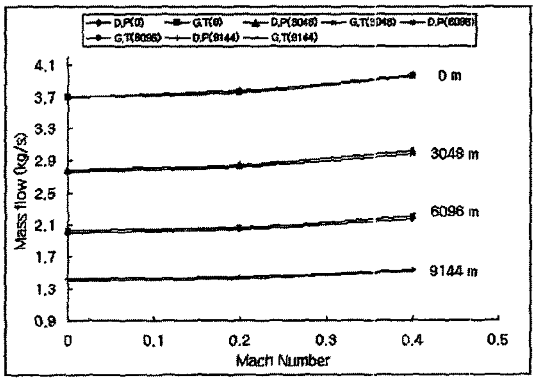
Fig. 6 Results of steady state performance analysis with gas generator rotational speed variation

The result showed that the developed program was proper for the part load performance analysis as the maximum range of error within 8%.

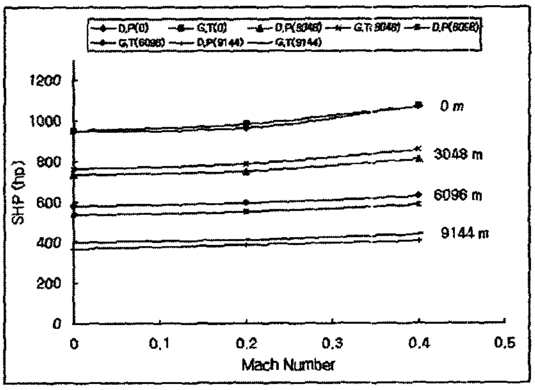
3.4 Effect of fight velocity

In order to examine the performance with the variation of flight Mach No., the performance was analyzed with the altitude range from ground to 10,668m, which is the operating range of KT-1, and with flight Mach number from zero to 0.4 at 100% rotational speed of the gas generator. It was compared with GASTURB analysis results. Table 6 and Fig. 7 show the result of comparison between them.

After carrying out the steady state performance analysis, the analysis results were compared with GASTURB analysis results. As a result, the range of error was about 1% at the design point but increased up to 8.15% away from the design



(a) Mass flow vs. Mach number



(b) SHP vs. Mach number

Fig. 7 Results of steady state performance analysis with flight Mach number

Table 6 Comparison of the GASTURB and developed program as altitude and flight Mach No. variation

Altitude (m)	Variable	M.N.=0.0			M.N.=0.2			M.N.=0.4		
		G.T.	D.P.	% Error	G.T.	D.P.	% Error	G.T.	D.P.	% Error
0	m_a	3.696	3.696	0.0	3.761	3.783	0.584	3.96	3.9705	0.265
	SHP	950.01	949.4	0.0064	979.837	963.645	1.652	1071.827	1071.825	0.000
	SFC	0.36606	0.36611	0.015	0.35986	0.3576	0.628	0.3425	0.35415	3.401
3048	m_a	2.767	2.7856	0.672	2.82	2.8502	1.070	2.983	3.01855	1.191
	SHP	761.63	733.4	3.706	784.548	749.886	4.418	853.636	807.69	5.382
	SFC	0.35303	0.35946	1.823	0.34715	0.342	1.483	0.33143	0.34247	3.331
6096	m_a	2.008	2.029	1.046	2.048	2.0683	0.992	2.169	2.207	1.751
	SHP	581.523	536.58	7.728	593.43	551.84	7.008	628.09	582.326	7.286
	SFC	0.34913	0.35124	0.606	0.34747	0.34406	0.981	0.34362	0.3441	0.139
9144	m_a	1.398	1.423	1.82	1.429	1.45	1.469	1.519	1.53357	0.959
	SHP	404.47	371.48	8.156	413.345	386.067	6.599	437.43	405.27	7.352
	SFC	0.36036	0.37	2.674	0.36004	0.36311	0.852	0.35991	0.3502	2.697

point. The reason is as follows, (Kurzke, 1999):

- In the developed program the performance maps of the compressor, the compressor turbine and the power turbine are used, but in GASTURB the compressor turbine flow rate, efficiency and pressure ratio are fixed and the compressor turbine map is not used.
- The constant pressure specific heat and the specific heat ratio are fixed at each hot section component in the developed program, but calculated as the function of temperature in GASTURB.

4. Transient State Performance Analysis

When fuel input is rapidly increased or decreased, the engine is in the transient state. In the transient state, the power output of the rotor shaft is surpassed or insufficient. Therefore, it would not be suitable for the required work balance between the compressor and turbine. Consequently, the engine is frequently beyond the operational range, which may damage the engine or shorten its lifetime. Above all, when the engine is operated during rapid acceleration, the overshoot of the turbine inlet temperature exceeds the limit. Therefore, it is very important that the dynamic characteristics of the engine should be correctly simulated or anticipated when improving the reliability of the engine during transient operation of an engine.

The CMF (Constant Mass Flow) method and the ICV (Inter-component Volume) method are primarily used in dynamic simulations. In the ICV method, work and flow mismatch during transient operation of an engine is assumed. The flow mismatch is used to calculate the rate of change of pressure at the various stations in the engine, by taking a value for inter-component volumes and applying the gas laws. Also, the work mismatch is utilized to estimate the variation of rotational speed by calculating the difference between compressor and turbine work during transient operation of an engine. (Kim, 1999).

The CMF method, the mass stored between components of an engine is ignored and the continuity of mass flow is used to calculate a performance.

In this study, the CMF method was utilized because of the advantages to reduce computational time and to perform the calculation for the change of a large rotational speed. In the CMF method, since the mass flow passing through the each component must be constant

Table 7 Steady state arrival time

Variable	Transient Simulation				Rig-test
$\dot{m}_f$	0.1 sec	0.7 sec	2.0 sec	4.0 sec	0.7 sec
Ng	3.0 sec	3.1 sec	3.9 sec	5.3 sec	3.0 sec
$\dot{m}_a$	5.4 sec	5.6 sec	6.3 sec	7.7 sec	•
TIT	5.9 sec	6.1 sec	6.8 sec	8.2 sec	
TIP	6.6 sec	6.8 sec	7.5 sec	8.9 sec	
SHP	4.7 sec	4.8 sec	5.7 sec	7.3 sec	5.0 sec

Table 8 Steady state value error

Variable	S-S analysis	S-S value	% Error
Ng (%RPM)	93.38	94.04	0.707
$\dot{m}_f$(kg/sec)	0.0566	0.0566	0
$\dot{m}_a$(kg/sec)	3.221	3.415	6.023
TIT (K)	1182.83	1132.46	4.258
TIP (bar)	6.809	6.955	0.472
SHP (hp)	688.35	698.8	1.518

an iteration process for matching mass flow is needed.

The work difference between the compressor and the turbine in the transient state can be expressed in the following equation (Sellers and Daniele, 1975).

$$\dot{m}_{CT}\Delta H_{CT}=\dot{m}_C\Delta H_C+\left(\frac{2\pi}{60}\right)^2 I\cdot N\cdot\frac{dN}{dt} \tag{7}$$

where moment of inertia for the rotor in this study is 0.9 kg-m^2.

For performance analysis of the transient state, the rotational speed's increase or decrease is calculated by integrating the surplus torque of the second term of the right hand side equation. In this study, the Modified Euler method was used for integration (William, 1992). Figure 8 shows the flowchart of the dynamic simulation program by the CMF method.

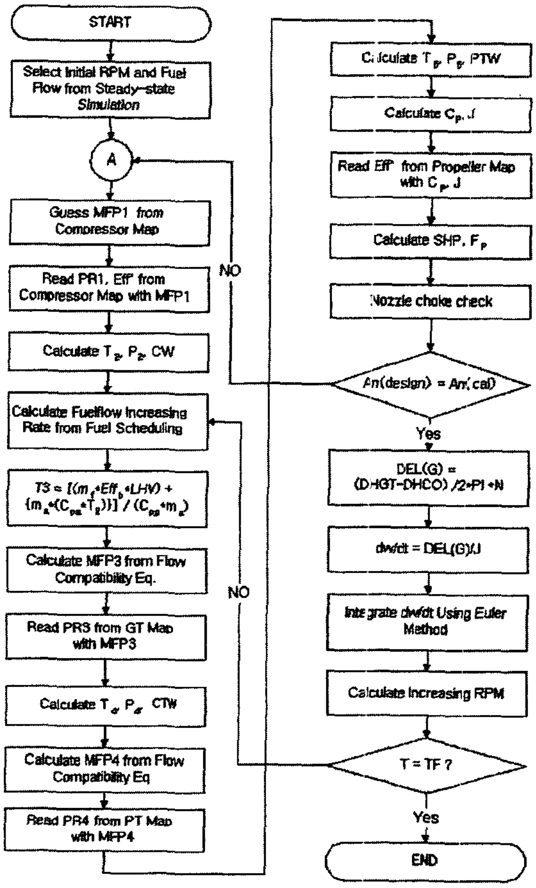
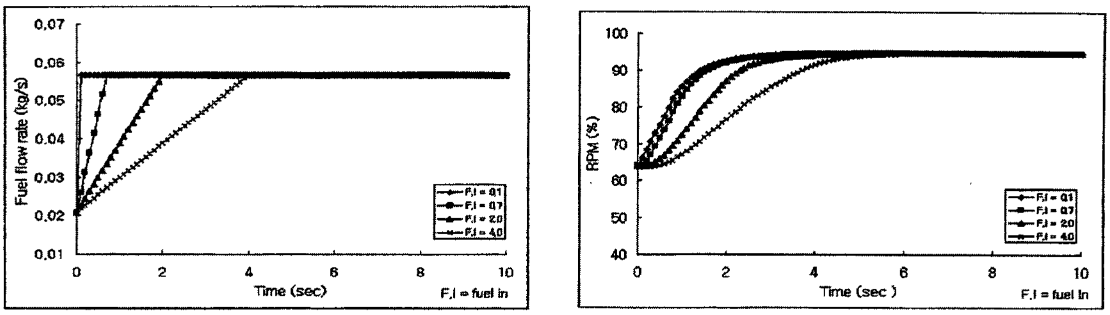


Fig. 8 Flow chart of transient analysis program

For performance analysis of the transient state, various fuel flow schedulings were assumed for acceleration from idle RPM(64%) to maximum cruise condition RPM(93.38%) of gas generator rotational speed. The fuel increase rates of 0.1, 0.7, 2.0 and 4.0 seconds were considered and 0.7 seconds was experimental condition. In case of 0.7 seconds, time that the rotational speed of the gas generator and the shaft horsepower reached the steady state was compared with the experiment result. Also, the value of steady state attainment was compared with the results of part load performance analysis at 93.38% RPM. The results of comparison show in Table 7, Table 8 and Fig. 9.

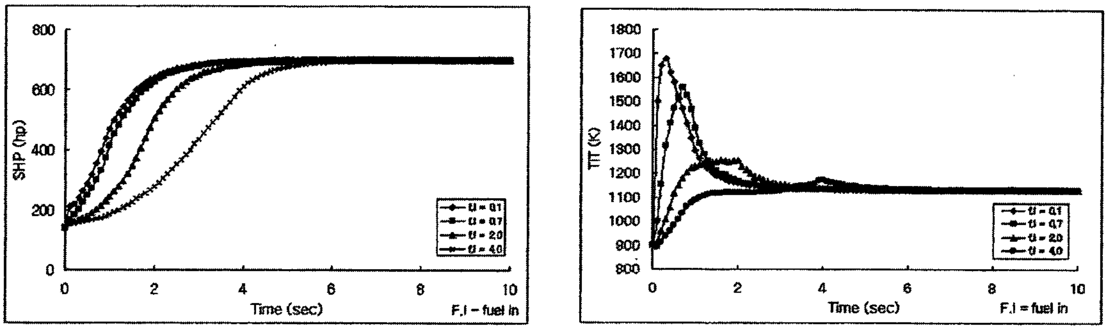
The developed program for transient analysis controls the fuel flow to keep the turbine inlet temperature of 1400K if it exceeds 1400K or beyond the bounds of operatable components' characteristics.

According to the analysis result, using the ramp fuel scheduling more than 4 seconds for acceleration from 64% RPM to 93.38% RPM can reduce the excessive overshoot, which can make failure of the turbine blades.



(a) Fuel flow rate vs. Time

(b) RPM vs. Time



(c) SHP vs. Time

(d) Turbine inlet Temperature vs. Time

Fig. 9 Results of transient performance analysis with fuel increase

5. Conclusion

A performance simulation program for the PT6A-62 turboprop engine, which is the power plant of the first Korean indigenous basic trainer, was developed. The design point performance parameters of PT6A-62 were determined by comparing with engine manufacturer's performance data. The developed program was evaluated by comparing with engine performance data and analysis results of GASTURB program, which is well known for the performance simulation of gas turbine. In the steady-state analysis, there were various cases such as take-off condition, flight conditions including variation of altitude and flight Mach number and part load conditions. In all cases, the maximum error was within reasonable value. For the transient analysis, the CMF Method was utilized, and the Modified Euler Method was used for integration of the surplus torque. In this analysis, there were two cases, such as the step fuel increase scheduling and the ramp fuel increase scheduling. In the case of step fuel increase, the analysis results were compared with the test results, and the excessive overshoot of the compressor turbine inlet temperature occurred. In order to eliminate the overshoot in the turbine inlet temperature, the fuel mass flow must be increased in ramp with the time interval over 4 seconds. However, the optimal control technique is required for safe operation and fast response characteristics of the engine. (Kong, et al., 1999)

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