A STUDY ON GENERATION OF GAS TURBINE COMPONENT MAPS USING PERFORMANCE TEST DATA

Changduk Kong*, Semyeong Lim*, Keonwoo Kim*
*** Department of Aerospace Engineering, Chosun University, Gwangju, Korea**
(Tel : +82-62-230-7188; E-mail: cdgong@mail.chosun.ac.kr)

Keywords: *Inverse map generation, Compressor map, Experimental test data*

Abstract

The gas turbine engine performance is greatly relied on its component performance characteristics. Generally, acquisition of component maps is not easy for engine purchasers because it is an intellectual property of gas turbine engine supplier. In the previous work, the maps were inversely generated from engine performance deck data. However this method is limited to obtain the realistic maps from the calculated performance deck data. Present work proposes a novel method to generate more realistic component maps from experimental performance test data. In order to demonstrate the proposed method, firstly the NI data acquisition device with the proposed LabVIEW on-condition monitoring program monitors and collects real-time performance data such as temperature, pressure, thrust, and fuel flow etc. from a micro turbojet engine of the test setup which is specially manufactured for this study. Real-time data obtained from the test results are used for inverse generation of the component maps after processing by some numerical schemes. Realistic component maps can then be generated from those processed data using the proposed extended scaling method at each rotational speed. Verification can be made through comparison between performance analysis results using the performance simulation program including the generated compressor map and on-condition monitoring performance data.

1 Introduction

The performance simulation of gas turbine is a very important activity not only to estimate performance at various operating conditions and to design the engine control and health monitoring system in development phase but also to enhance availability and reliability through monitoring the engine condition in operation phase. In order to perform this performance simulation, component maps, engine component characteristic maps are needed. Generally, because these component maps are obtained by engine manufacturer through experimental test of each component in development phase, they are not provided to purchasers or operators. Therefore engineers, who want to develop performance simulation program, engine control or health monitoring system without the experimental component maps, has generated those maps using Scaling Method. The most widely used scaling method can generate the component maps from the scale factor which is obtained through comparison between the design point component characteristic value of the simulated engine and a existing similar component map[1]. However this method has a drawback that the generated map has a considerable error if the scaling factor would be far from 1 or at off-design points[2]. Moreover acquisition of a similar component map with the study engine component is not easy.

Therefore, in this work, an inverse map generation method is proposed using experimental performance data with the following procedure. Firstly, experimental performance data are acquired from performance tests at several throttle positions of a micro gas turbine using performance test equipment including data acquisition system. Secondly, scaling factors are obtained at tested rotational speeds, and finally the component map is generated by multiplying these scaling factors to the existing similar map at same rotational speed lines.

The proposed method is verified through comparison between performance simulation using the generated maps and the experimental performance data.

2 Experimental Test Setup

For this work, a micro turbojet engine, I-Jet 130 of I-Complete Company has been used. This engine has 137.2N maximum thrust at sea level static condition, and it is composed of 1 stage central compressor, reverse flow annular combustor, 1 stage axial turbine and convergent exhaust nozzle shown as Fig. 1 [3]. In addition, it has a fuel pump, a fuel filter, an ignition plug, an electrical starter and an ECU(Electronic Engine Control Unit). Propane gas is used in the starting phase for easy starting and kerosene is used as main fuel in the normal operation phase. Table 1 shows the specifications of I-jet 130 engine.

Table 1 Specification of I-Jet 130

Type	Turbojet
Compressor	1 stage centrifugal
Combustion Chamber	Reverse flow annular
Turbine	1 stage axial
Thrust (max.@126000 rpm)	137.2N(30.86 lbf)
Exhaust Gas Temperature(max.)	893 K
Fuel Consumption	330 g/min
Fuel	Kerosene, Jet A1
Start Gas	Propane
Lubrication Oil	Mobil Jet2, Exxon 2380
Fuel-oil Mixing Ratio	20:1
Dimensions	108 mm ∅ x 250 mm

In order to measure inlet air flow velocity, total temperatures and total pressures of compressor and turbine, a Pitot tube, thermocouples and pressure transducers are installed in the engine through holes for sensors shown as Fig. 1.

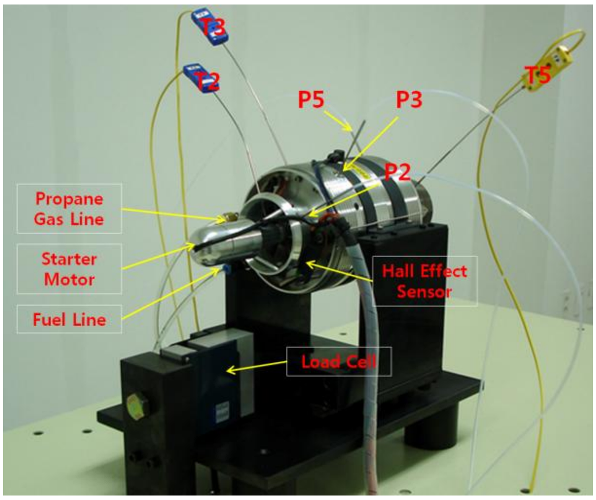


Fig. 1 Engine Test Stand with Measuring Sensors

The complete engine test setup of I-Jet 130 tubojet engine is composed of three compartments such as upper compartment with test stand for fixing the engine and measuring thrust, test section, FOD preventing screen, air intake and exhaust duct system, center compartment with on-line monitoring system, data acquisition system, sensor and power supply system and an electronic engine controller and lower compartment with fuel and gas tanks and data logging system[4].

Figure 2 shows a completely manufactured test setup of I-Jet 130 turbojet engine.

Fig. 2 Complete Test Setup of I-Jet 130 Engine

3 Performance Data Monitoring and Acquisition System

Performance data monitoring and acquisition system uses LabVIEW developed by NI(National Instruments). LabVIEW is a flexible, adaptable, intuitive understandable GUI(Graphic Use Interface) type language because it is optimized in control and measurement using computer as well as developed in graphic environment.

Location of the real-time monitoring system screen is arranged at the center compartment by which operator can easily monitor the real-time performance data. Performance data acquired by the monitoring system are temperatures and pressure at inlet and exit of compressor and turbine, fuel flow and thrust. Figure 3 shows the real-time monitoring system screen of the test setup front panel using LabVIEW.

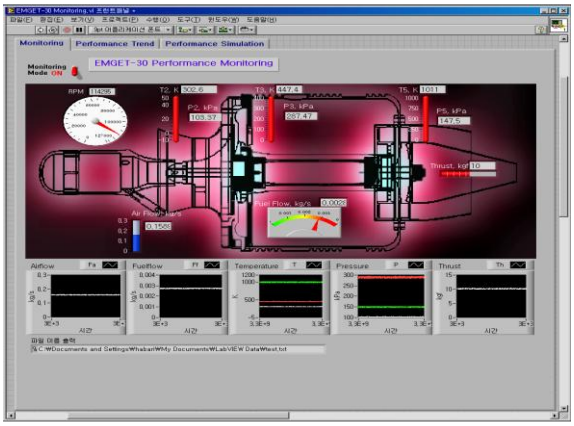


Fig. 3 Data Monitoring System Screen

Data acquisition system uses NI CompactDAQ hardware due to convenient application of data logger, low cost, high performance as a module type instrument and flexibility. Moreover this system can measure fast and accurately analog signals monitored by the test setup by simple plug and play of USB[6].

Figure 4 shows layout of signal line of data acquisition system using NI CompactDAQ. This figure shows briefly the layout diagram to collect experimental test data measured from fuel flow meter, load cell, pressure and temperature sensors.

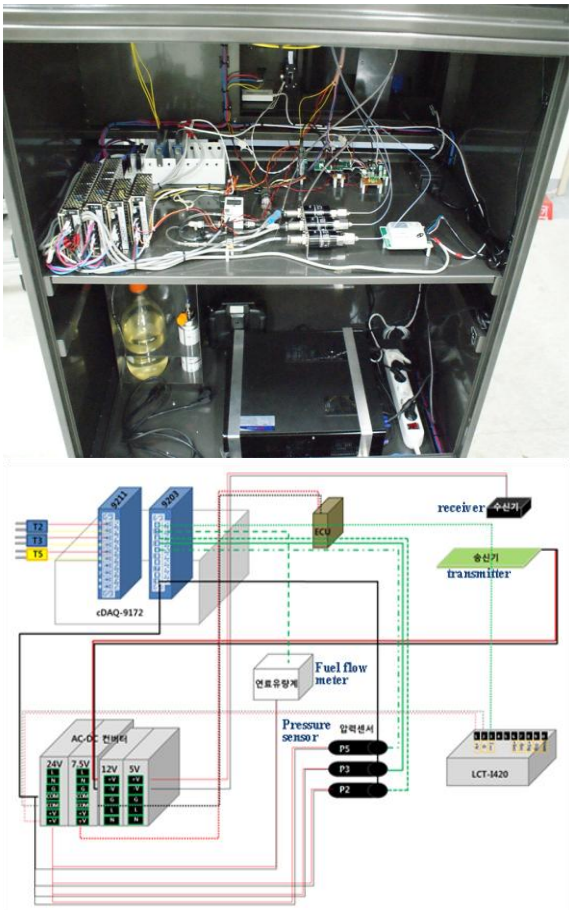


Fig. 4 Layout of Signal line of Data Acquisition System

Table 2 shows physical channel, device name and measuring type of measuring signals in data acquisition system. Table 3 expresses specifications of NI9211 and NI9203 devices

Table 2 Physical channel, device name and measuring type of measuring signals

Channel Name	Physical Channel	Device Type	Measuring Type
T2	cDAQ1Mod1/ai0	NI9211	Thermocouple(vol)
T3	cDAQ1Mod1/ai1	NI9211	Thermocouple(vol)
T5	cDAQ1Mod1/ai2	NI9211	Thermocouple(vol)
P2	cDAQ1Mod4/ai3	NI9203	Electric Current
P3	cDAQ1Mod4/ai4	NI9203	Electric Current
P5	cDAQ1Mod4/ai5	NI9203	Electric Current
Wa	cDAQ1Mod4/ai0	NI9203	Electric Current
Wf	cDAQ1Mod4/ai1	NI9203	Electric Current
Thrust	cDAQ1Mod4/ai2	NI9203	Electric Current

Table 3 Specifications of NI9211 and NI9203 devices

	NI9211	NI9203
Channel	4	8
Resolving power	24bit	16bit
Input Range	$\pm 80mV$	$\pm 20mA$
Transformation Time	70ms	5 μs (min)

4 Generation of Component Maps Using Experimental Test Data

Experimental tests of I-Jet 130 turbojet are carried out at 50%, 60%, 70%, 80% and 90% gas generator rpm, respectively. Data acquisition is performed during 30 seconds with 10HZ at each % rpm.

Flow chart of the component map generation using experimental test data is illustrated in Fig. 5. Performance data acquired by experimental tests at each % rpm are used to calculate the exhaust nozzle exit velocity, C_j and air mass flow, W_a using the equations (1) and (2)[7].

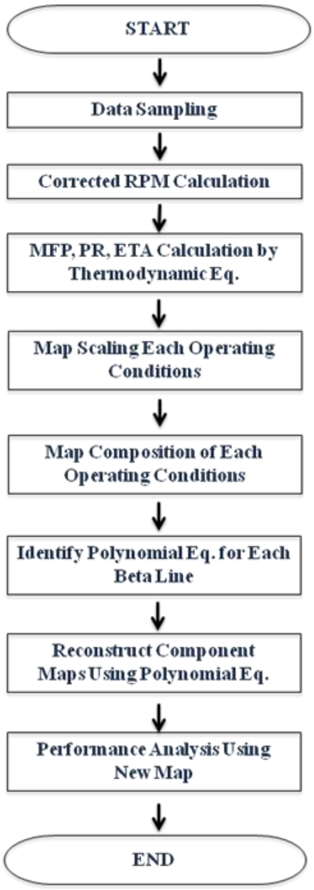


Fig. 5 Flow of component map generation using experimental test data

$$C_j = \{2c_p \eta_i T_5 [1 - (\frac{1}{P_5 / P_a})^{\frac{\gamma-1}{\gamma}} \tag{1}$$

$$F = W_a[(1+f)C_j] \tag{2}$$

Where: C_p specific heat at constant pressure, η_i : nozzle efficiency assumed as 0.98, T_5 : turbine exit temperature, P_5 : turbine exit pressure, P_a: ambient pressure, γ : specific heat ratio, f : fuel air ratio, F : thrust.

Air mass flow, W_a calculated by the above equations are used to obtain pressure ratio PR, mass flow parameter MFP and isentropic efficiency ETA of compressor and turbine using inverse approach calculated with well known thermodynamic equations[2]. Figure 6 shows performance parameters of compressor at 80% gas generator rpm which are obtained from the proposed inverse procedure.

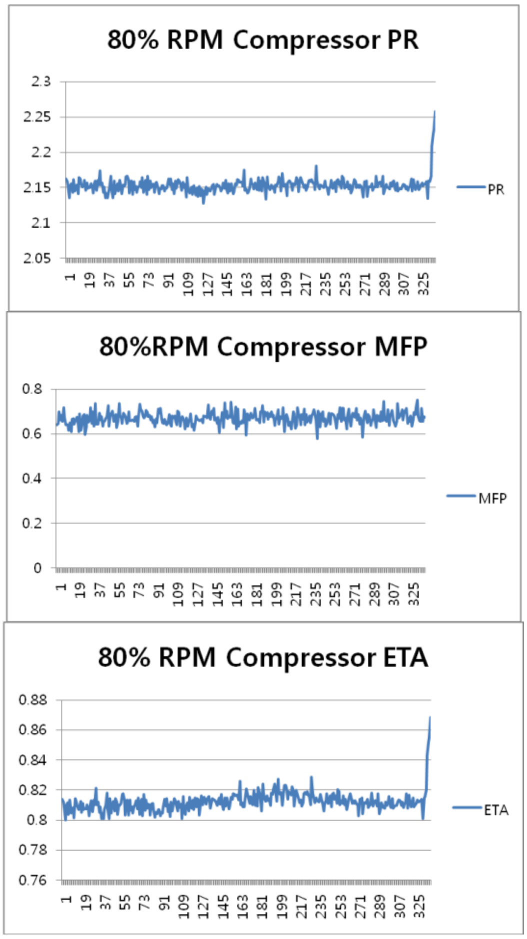


Fig. 6 Performance data of 80% RPM Compressor

These time dependant values of component performance parameters at each gas generator rpm are processed by a numerical technique as a representative value at each gas generator rpm considered. The proposed numerical technique uses an averaging method as follows. Firstly the component performance parameter data obtained at each rpm is divided into five intervals between maximum and minimum. Next, the most concentrated interval is selected from the above. Finally, an average value is obtained in the selected interval for removing noise as well as taking a representative value.

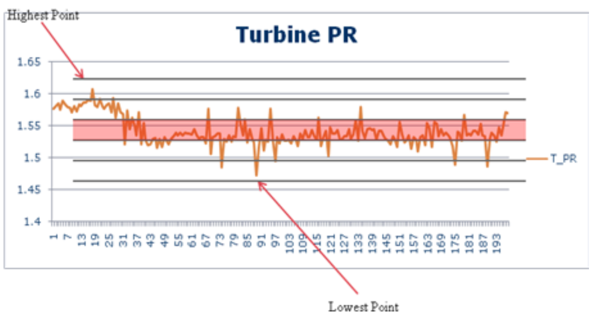


Fig. 7 Numerical technique

Table 4 shows performance parameter values of compressor and turbine at 5 gas generator speed conditions by the above proposed procedure.

Table 4 Performance parameter values of compressor and turbine

	RPM	50%	60%	70%	80%	90%
Compressor	PR	1.38111	1.59784	1.82956	2.14715	2.51732
	MFP	0.28153	0.43770	0.55305	0.66590	0.74716
	ETA	0.88376	0.87287	0.85212	0.80921	0.78778
Turbine	PR	1.23557	1.35727	1.50442	1.66064	1.79238
	MFP	0.40982	0.54162	0.59095	0.62968	0.62410
	ETA	0.55344	0.56185	0.59867	0.61593	0.63509

In the next step, the scaled pressure ratio PR, mass flow parameter MFP and isentropic efficiency ETA of compressor and turbine at each gas generator speed considered are obtained using the following scaling equations (3), (4) and (5)[7].

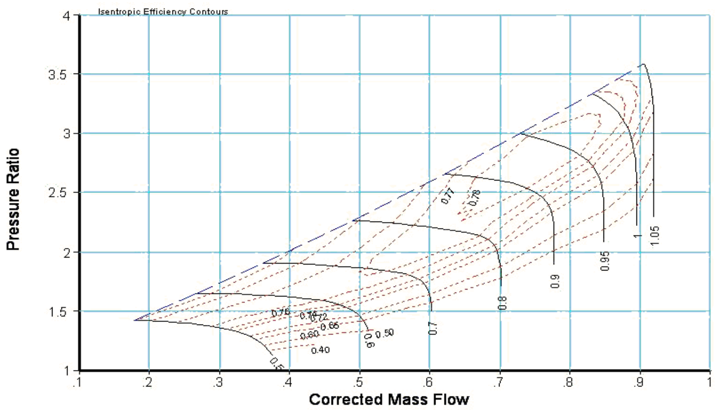
$$PR = \frac{PR_{(desing)} - 1}{PR_{(mapdesign)} - 1} \cdot (PR_{(map)} - 1) + 1 \tag{3}$$

$$MFP = \frac{MFP_{(desing)}}{MFP_{(mapdesign)}} \cdot MFP_{(map)} \tag{4}$$

$$MTA = \frac{MTA_{(desing)}}{MTA_{(mapdesign)}} \cdot MFP_{(map)} \tag{5}$$

Where, the subscript 'design' corresponds to the value at design point or representative point at different gas generator speed considered for the experimental test and the numerical approach. The subscript 'map design' corresponds to the design point or representative point considered at different gas generator speed of an existing component map. The subscript 'map' corresponds to the value at off-design points or off-representative points at different gas generator speed of an existing component map.

Therefore the 5 sets of scaled component performance parameter values at five gas generator speeds are obtained using the above mentioned equations. If these scaled component performance parameter values are extended to other gas generator speed conditions, the following maps of compressor and turbine are generated as shown in Fig. 8.



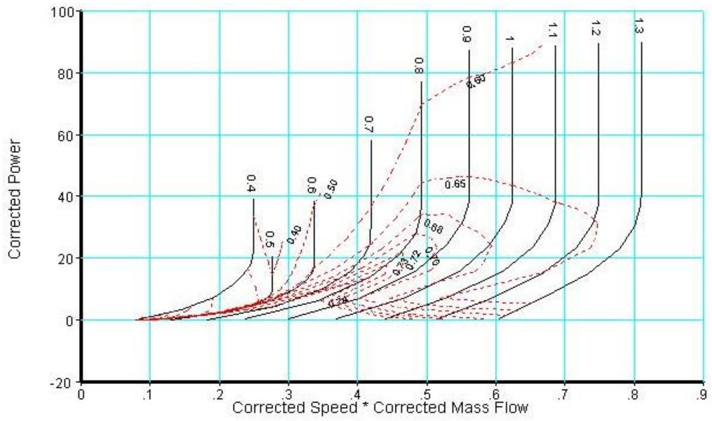


Fig. 8 Generated maps of compressor and turbine

5 Validation of Generated Component Maps

In order to verify accuracy of the generated component maps, the performance analysis result using the component maps generated by the newly proposed method (NM) in this work is compared with the validation experimental test data (VD). An engine performance simulation program for this purpose is coded using C^{++}. Figure 9 shows the flow chart of the performance simulation program.

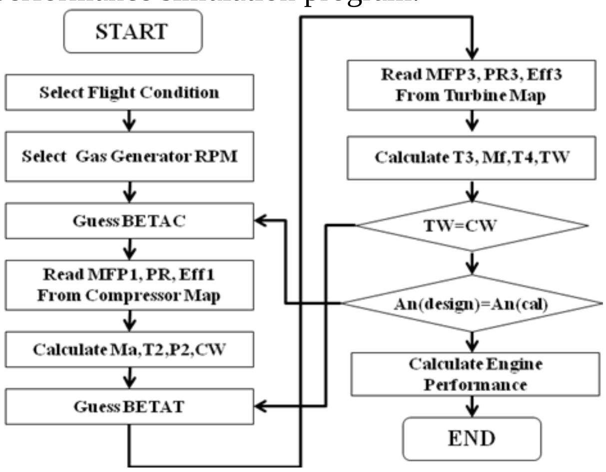


Fig. 9 Flow chart of performance simulation program using C^{++}

BETAC: Compressor work point, BETAT: Turbine work point, TW: Turbine work, CW: Compressor work, An: Nozzle area

Figure 10 shows comparison results of temperature and pressure at turbine exit, thrust and error between the performance analysis results using the component maps generated by the proposed method, the validation experimental test data at 70000~100000 gas generator rpm.

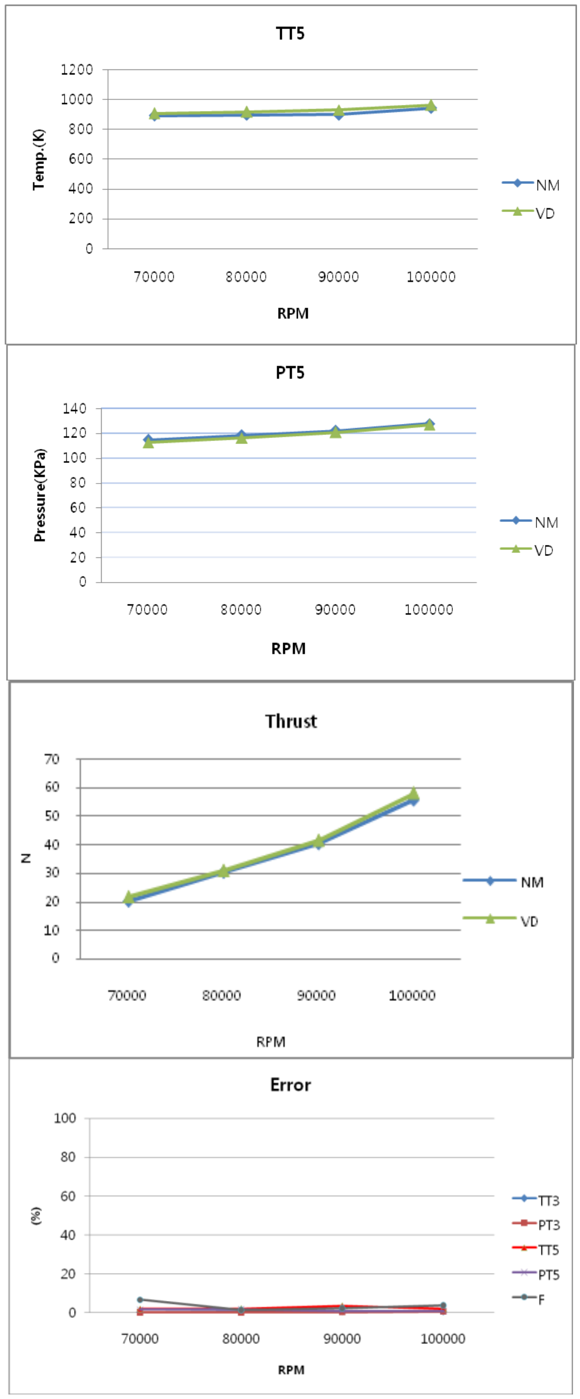


Fig. 10 Comparison of temperature and pressure at turbine exit, thrust and error between NM and VD

As comparison shown in Fig 10, the performance analysis results using the component maps generated by the proposed method are well agreed with the validation experimental test data. Through this comparison, it is confirmed that the proposed map generation method using experimental test data is more effective than the traditional scaling method.

6 Conclusion

In this work, a component map generation method is proposed to improve the drawback of the traditional scaling method which has large amount of error at off-design points. The proposed method uses inverse approach from more realistic experimental performance test data of the component.

In order to demonstrate the proposed method, the NI data acquisition device with the proposed LabVIEW on-condition monitoring program is used to obtain real-time performance data such as temperatures, pressures, thrust and fuel flow using a micro turbojet engine for the test setup. The acquired experimental test data are processed by a numerical technique as representative values of different gas generator speeds. With these numerically processed data, several sets of scaled component performance parameter values at various gas generator speeds are obtained using the scaling equations. These scaled component performance parameter values are then extended to other gas generator speed conditions and the component maps are finally generated.

Verification of the proposed method is performed through comparison of error of performance parameter values between the performance analysis results using the component maps generated by the newly proposed method, the validation experimental test data. Through this comparison, it is verified that the proposed map generation method is well agreed with the validation experimental test data.

Acknowledgments

This study has been supported by the NRF(National Research Foundation of Korea) under Development of Foundation Technology Research Program

References

[1] Sellers J.F. and Daniele C.J. “DYNGEN-A Program for Calculating Steady State and Transient Performance of Turbojet and Turbofan Engines”, Technical Report TN-D-7901, NASA Lewis Research Center, 1975.

[2] Kong, C.D., Ki, J.Y. and Kang, M.C.. “A New Scaling Method for Component Maps Gas Turbine using System Identification”, Journal of Engineering for Gas Turbines and Power Vol. 125, Copyright 2003 by ASME.

[3] Kong, C.D., Kho, S.H. and Ki, J.Y. “Component Map Generation of a Gas Turbine Using Genetic Algorithms”, Journal of Engineering for Gas Turbines and Power Vol. 128, Copyright 2006 by ASME.

[4] Kong, C.D., and Ki, J.Y. “Study on Component Map Identification from Gas Turbine Performance Deck Data Using Hybrid Method”, International Journal of Turbo and Jet Engines, 24, 2007.

[5] I-Jet 130 Manual Version 1.4, i-Complete Sdn Bhd, 2008.

[6] Kho, S.H., Ki, J.Y. and Kong, C.D., “Development of Condition Monitoring Test cell using Micro gas turbine engine”, ASME Turbo Expo, GT-2009-59931,2009.

[7] Philip P. Walsh and Paul Fletcher. “Gas Turbine Performance”, Blackwell Science, 1998.

Copyright Statement