Assessment of the Conversion of a Helicopter Engine for Electrical Power Production

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Abstract. The paper considers the conversion of the T53-L-13B turboshaft engine for electrical power generation. Small gas turbines generators are compact, have low emissions and exhibit potential for low day to day operating and maintenance cost. Their quick start-up capability allows them to power up very quickly; their compact size provides easy foundation and compact footprint, while they are ideal for cogeneration applications. These features suggest that small gas turbines may be suitable for distributed power production. At the same time legacy military vehicles utilizing gas turbines as prime movers, such as helicopters and aircrafts, are retiring creating an inventory of gas turbine engines and their spare parts. The conversion of these gas turbines for civilian use such as generators for electricity and/or heat production and pressure pumps is a path worth examining. The scope of this work is to investigate the conversion of the T53-L-13B engine, available to the Hellenic Army, for electrical generation. The investigation is conducted by developing an adapted engine performance model capable to reproduce the available engine performance data at design and off-design operation. The simple cycle engine model is extended for simulating (design and off-design) a recuperated version of the engine. Using the engine performance models the conversion of the engine to electrical generator is assessed in terms of operability and performance. For the technoeconomic evaluation of the conversion several cases of interest are examined by applying the NPV method using a whole year ambient conditions data for calculating the annual electrical power production and fuel consumption. The results indicate that the conversion is feasible in terms of operability, given that the engine does not operate synchronized at low power settings. The addition of a recuperator significantly reduces the engine fuel consumption at the expense of surge margin and engine net power. In terms of investment assessment the recuperated cycle is the best candidate for base load operation giving an electricity price reduction of 19% compared to the simple cycle for ten years payback period. For standby generator an available converted T53 engine is a rather promising candidate even compared to Diesel engines.

Keywords: Gas turbines, Performance assessment, Performance Modeling, Small-scale aeroderivatives, Technoeconomic assessment,

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INTRODUCTION

Small gas turbines (up to 5MW) offer an attractive alternative for electrical power generation within distribution grids and for consumers wanting to generate their own power. Their main disadvantage, especially for the power range up to 3MW is the noticeably higher price per kilowatt than competing reciprocating engines, due principally to low production volumes. As distributed generation applications increase, manufacturing economies of scale could make small gas turbines a source of power or combined heat and power to commercial and small industrial customers with high intermediate power prices [1].

Several small gas turbines are derivatives from turboshaft and turboprop engines converted by the engine OEMs [1]. In this context the conversion of existing retired helicopter engines for commercial use is a path worth examining. At this time a great number of military vehicles that utilize gas turbines as prime movers are retiring, thus an inventory of low priced gas turbines and their spare parts is available. Several attempts to utilize these gas turbines for civilian application, such as their use to pressure pump systems for hydraulic fracturing are undergoing [2], thus it is of interest to the owners of these gas turbines to assess their conversion for electrical or mechanical power production, rather than selling or retiring them. The conversion of an existing gas turbine is expected to significantly reduce the investment and maintenance cost for the owners of the engine.

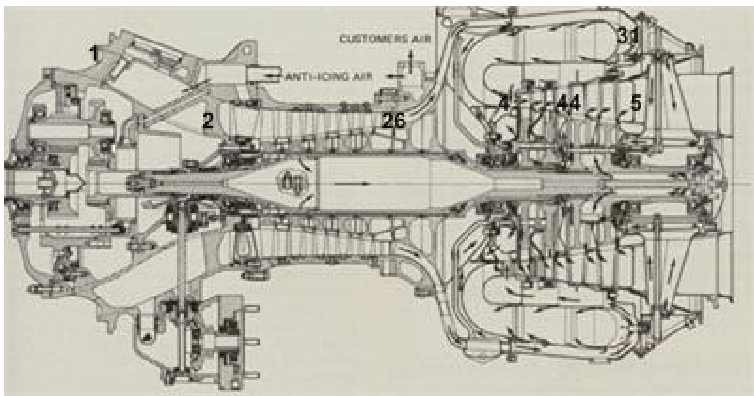
For assessing the conversion of an existing helicopter engine available to the Hellenic Army the operability and performance of the converted engine should be examined. The main modifications and equipment needed for this conversion should be recognized and their feasibility and cost should be determined. Also the economic benefit of converting an existing engine should be evaluated and be compared to available technical solutions. In order to achieve these objectives the first step is to obtain a reliable engine performance model of the turboshaft engine and examine its operation as a genset namely with constant power turbine rotating speed. Following the creation of a reliable engine model the power production and fuel consumption for suitable operating profiles can be calculated and used for the economic assessment of the conversion.

In this paper the conversion of a helicopter turboshaft engine to an aero-derivative industrial gas turbine for electrical power production is considered. An engine model adapted to available test-bed data is created and used for assessing the engine operability and performance when used for electrical power production (operation with constant power turbine rotating speed). The changes on performance and components operability are recognized and discussed. Since the performance enhancement of these engines by applying recuperation and/or intercooling are of interest, as discussed by Nkoi et al. [3] the addition of a heat exchanger to the existing engine for recuperation is also examined and assessed in terms of performance and operability. The engine models are used for calculating the produced electrical power and fuel consumption throughout a typical year taking into consideration the variation of ambient condition. The cost of engine conversion and other investment costs for utilizing the engine as genset are defined and the investment is evaluated for operation as base load and standby unit.

ENGINE PERFORMANCE MODEL

ENGINE DESCRIPTION

The engine considered for conversion is the turboshaft engine T53-L-13B, which entered service in 1966 and is powering the UH-1 helicopters of the Hellenic Army and its civilian versions the Bell 204 and 205 helicopters. In Greece the engine maintenance, overhaul and testing is done by the Hellenic Aerospace Industry (HAI) which is an approved and certified maintenance center by the engine OEM (Honeywell). T53 is a twin shaft engine with a mixed flow compressor consisting of 5 axial flow stages and one centrifugal stage, a two stage gas generator turbine and a two stage power turbine. The combustor is annular of reverse-flow with 22 fuel nozzles. The engine has a reduction gearbox with a ratio of 3.2105/1. The secondary air system provides cooling air to the turbines stages and air for sealing and pressurization. For part load operation an interstage air bleed valve (Bleed Off Valve) located at the exit of the fourth compressor stage is used for ensuring stable operation over the whole operating envelope. The engine schematic is depicted in Fig. 1. The engine reference performance data is given in TABLE 1.



1: Engine Inlet **2:** Compressor Inlet **26:** Centrifugal Stage Inlet **31:** Combustor Inlet **4** Core Turbine Inlet **44** Power Turbine Inlet **5** Turbine Exit

FIGURE 1: Engine Schematic

TABLE 1: Engine Datum Performance [**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**]

Ratings	**Power SHP (min)**	**Gas Producer N1[RPM] (max)**	**Power Turbine N [RPM] (optimum)**	**Output shaft N2[RPM] (optimum)**	**SFC[lb/SHP/hr] (max)**
			Reduction gear ratio: 3.2105/1		*Exhaust area: 203 sqin*
Take off	1400	25400	21190 (max 21300)	6600 (max 6635)	0.580
Max continuous	1250	24650	19390	6040	0.600
90% max.Cont.	1125	24250	18655	5810	0.620
75% max.Cont.	938	23475	17465	5440	0.663

AUTOMATED ADAPTIVE METHOD

An engine model can be based on production engine data, fleet-average overhauled engine data or engine specific data. In this context, it is important to have an adaptive procedure as automated as possible for quick and accurate generation of engine specific models. The PROOSIS gas turbine simulation platform is used to build the required engine performance model [5]. PROOSIS is a tool capable of modelling any gas turbine engine configuration using the default and/or any user-defined library of gas turbine engine components. Components are described using a high-level object-oriented language while an advanced graphical user

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interface allows an engine model to be constructed graphically by ‘dragging-and-dropping’ the required component icons from one or more library palettes to a schematic window, connecting the components through the appropriate ports (Fluid, Mechanical, Fuel, Control, Secondary Air System, Sensor, etc.) and editing their attributes [6]. The associated mathematical model (Partition) can then be defined through the specification of appropriate boundary and iteration (algebraic) variables. The final step is to describe one or more simulation cases (Experiments) such as single or multi-point design, parametric, sensitivity, optimization, test analysis, diagnosis, transient, etc. The tool also has the capability to perform multi-system, mixed-fidelity, multi-disciplinary and distributed simulations ([7]-[9]). Last but not least, different types of customer decks can be automatically generated for a variety of platforms while a standard interface is available for some applications (e.g. MS Excel and Matlab/Simulink). The tool’s flexibility and configuration control capabilities along with its clear distinction between modelling and simulation tasks makes it ideal for automating the work of the performance engineer. In order to generalize and automate the model creation process, the authors have developed in PROOSIS a library of various gas turbine engine configurations. For each configuration, a single robust mathematical model is created. Various experiments are then defined for this partition in order to create the final engine model as shown schematically in Fig. 2. For the design point calculation, the model uses known data and best engineering judgment in order to fix the model unknown details and calculate parameters that are needed for the off-design calculations such as nozzle areas and turbomachinery component map scaling factors. The first step in the design point procedure is to select the operating point at which the calculation will be carried out. In practice, a multi-point method is employed utilizing the available discrete operating point data.

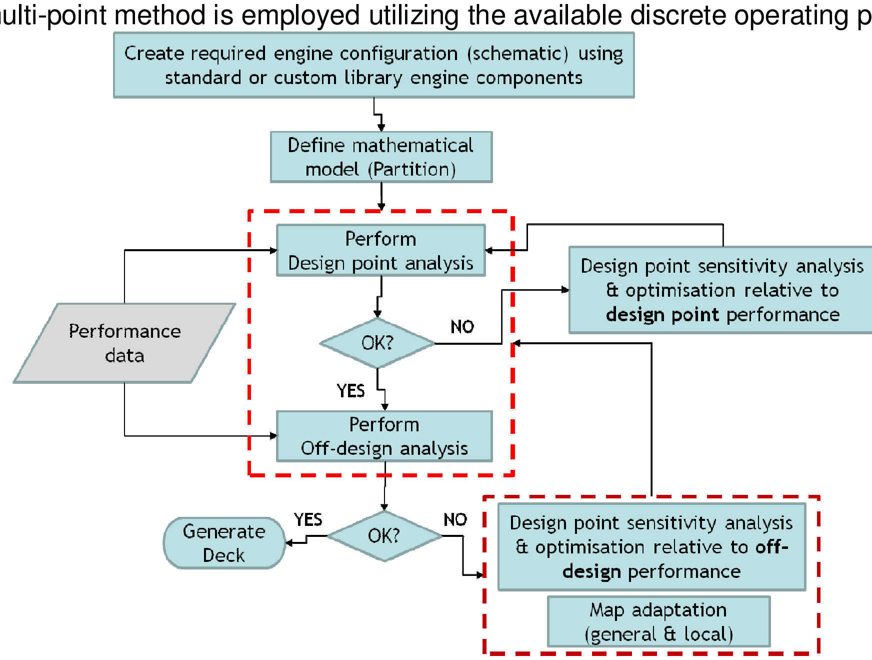

FIGURE 2: Model Creation Process

A typical approach is to carry out the design calculation at one representative point e.g. “take off” and then check whether the requirements and constraints at other operating points are met. The procedure is repeated until the best compromise is achieved. The differences between model predictions and available specifications can be minimized through a two-step procedure. Initially, an optimization algorithm (Simplex [10]) is employed that adjusts selected design point performance parameters and component data (e.g. location of design point on turbomachinery component maps, secondary air system flows, duct and burner pressure losses, etc.) within a user-specified range in order to match the known performance at selected off-design operating conditions. Next, for the calculated design point, the turbomachinery component characteristics are modified according to the required off-design performance through scalars of isentropic efficiency and corrected mass flow (global map adaptation scalars). The scalars selected are typically the ones producing the lowest possible cost function with minimum variation. The design point is included as an off-design point in the formulation of the relevant cost function since the objective is to reduce all the differences between model predictions and specifications. Finally, a third step maybe necessary in order to perform map adaptation locally at discrete operating points that they were either not included in the previous analysis and/or cannot be matched adequately with the last step global map adaptation scalars.

All the experiments are generic using globally defined variables for all the required inputs (e.g. component maps, fluid model tables, design-point and off-design performance data, etc.) and their values are set externally by the user through input files. Hence, the model of a specific engine can be generated simply by modifying the input files of the corresponding generic configuration and running the experiments. Using the tool's intrinsic deck generation capability, the entire model creation process can also be exported (e.g. as an executable with a graphical user interface) using switches to select the required calculation. In addition, the final engine deck can also perform fault simulation and diagnosis using gas path analysis.

T53 ENGINE MODEL

For the work reported here, the TURBO library of engine components available as standard in PROOSIS is used to create the free turbine turboshaft engine model shown in Fig. 3. The engine model has a gas generator consisting of an axial compressor (LPC) and a single centrifugal stage (HPC) driven by the core axial turbine (CT). The free power turbine (PT) is delivering shaft power through a gearbox component (GBX). The model uses appropriate maps to define off-design performance for the turbomachinery components [11]. The combustor pressure losses vary with the combustor inlet corrected mass flow rate while combustion efficiency is a function of combustor loading [12]. Ducts pressure losses are a function of mass flow rate. Cooling/sealing flows for the CT and PT components are extracted from the LPC and HPC exit as required. Shaft and gearbox transmission losses are also accounted for. Stability and customer bleed as well as customer power extraction can be specified. JP-4 is used as fuel in this study. The TURBO library in PROOSIS uses three-dimensional linearly interpolated tables for calculating the caloric properties of the working fluid in the engine model. These are generated with the NASA CEA software [13]. For a given set of ambient conditions, the model only needs the power required or the fuel flow and rotational speed at the gearbox outlet shaft in order to calculate the complete cycle.

Data from the HAI engine test bed are used for building a model that closely represents a tested engine performance. The available measured data set is given in TABLE 2. The take-off operating point is selected as the design point (DP). Basic parameters at the design point such as nozzle area, pressure loss coefficients, cooling air flows and pressure ratios of axial and centrifugal compressor are specified by using measured data combined with literature data such as overall pressure ratio, utilizing basic aerothermodynamic analysis principles. Then the adaptive method described is used for evaluating component map scaling factors and design points locus. Having built an adapted model the complete cycle data are calculated for given fuel mass flow (WF) and gearbox outlet shaft rotational speed (NII). Depending on the analysis different engine control variable can be used (e.g. Shaft Power PWSD, Turbine Entry Temperature -TET etc). As seen in TABLE 3 the adapted performance model built closely

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represents the engine operation, with a difference of less than 1% from the available measured data.

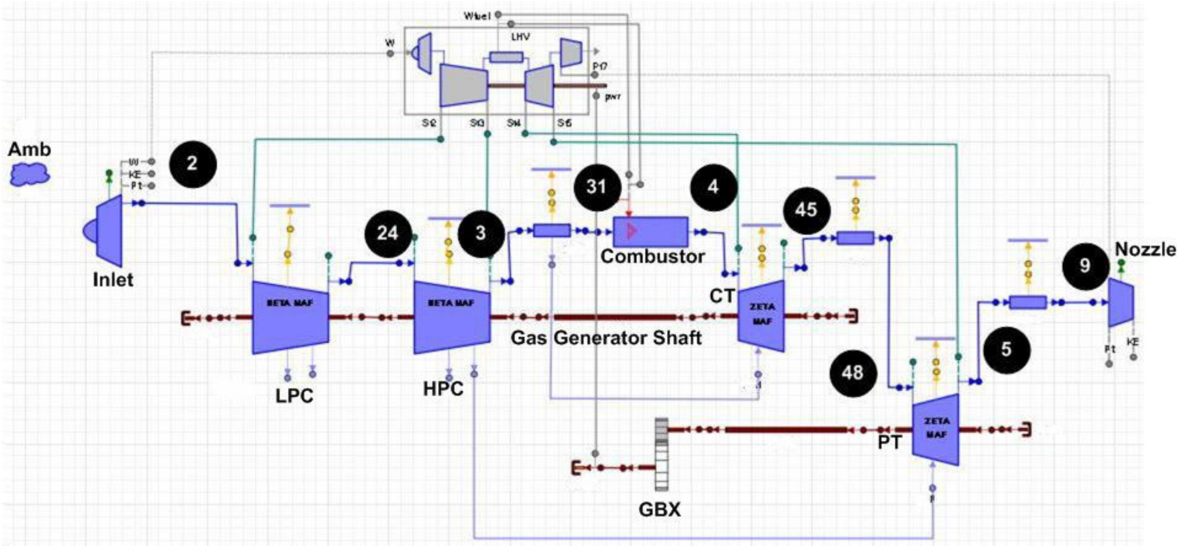

FIGURE 3: Turboshaft engine PROOSIS schematic diagram & station numbering

TABLE 2: Engine Measured Data

Ratings	GG speed [RPM]	GBX shaft speed [RPM]	Power [kW]	Fuel Flow [kg/s]	EGT [K]	Pt1 [bar]	Pt2 [bar]	Tamb [K]
75%	24130	5502.9	735.77	0.07686	789.15	1.00914	1.00576	285.15
max cont	25146	6033.3	967.31	0.09261	827.15	1.00914	1.00406	285.15
take off	25400	6265.35	1071.23	0.10029	843.15	1.00914	1.00237	285.15

TABLE 3: Model Deviations (Deltas) from Measured Data

	take off[DP]	max cont	75%
Δpower[%]	0.000	-0.556	0.091
ΔNI[%]	0.000	-0.783	-0.642
ΔNII[%]	0.000	0.000	0.000
ΔEGT[%]	0.000	-0.057	-0.440
ΔWF[%]	0.000	0.000	0.000

ENGINE OFF-DESIGN OPERATION

Having built a reliable model that closely represents the engine performance and operation the next step is to analyze the engine operation as electrical power generator. The turboshaft engine is designed so that the speed of the power turbine varies with load demand. For its application as electrical power generator the power turbine roational speed should remain relatively constant after synchronization to ensure frequency stability. The gear box rotational speed for the electrical generation version of the engine is selected equal to 6040 rpm, which is the max. continious rating GBX rotational speed. The full power for the genset is defined according to the TET calculated for the max. continious rating. The stability bleed flow schedule is selected to ensure stable operation throughout the whole engine operating envelope. The engine operating line from 20% up to 100% of power can be seen in the following figures.

As seen in Fig. 4 and 5, operating the engine with constant power turbine rotational speed results to operation with reduced surge margin at part load for the LPC, while the HPC operates at acceptable surge margin. At high power the surge margin of the LPC and HPC is acceptable and close to its original value. The operating line (power increase) of the power turbine for constant and varying speed operation is depicted in Fig. 7. As seen power turbine operation is limited when the engine operates as genset. The engine can operate synchronized only if the power is greater than 20% of the nominal one. The limitations enforced by the power turbine should be taken into consideration when the transfer switches (in the case of grid-isolated standby units) or the grid interconnection equipment is considered. In any case the genset can operate for a significant load range after synchronization. The Specific Fuel Consumption (SFC) variation with shaft power PWSD for ISO conditions and for electrical power generation is illustrated in Fig. 8. At high power conditions SFC remains almost constant but increases sharply at lower power setting, as expected. The engine's SFC at max. power is comparable to the avaialable commercial non-recuperated engines of the same power rating [14, 15].

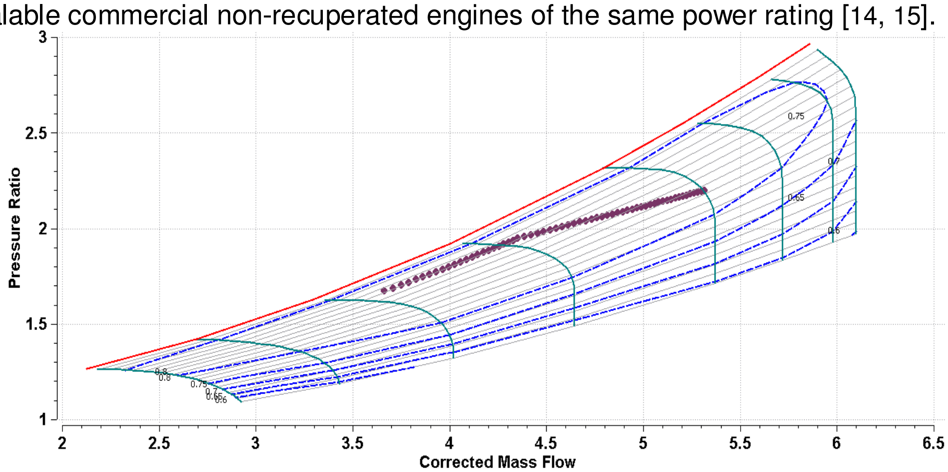

FIGURE 4: LP Compressor Map and Operating line

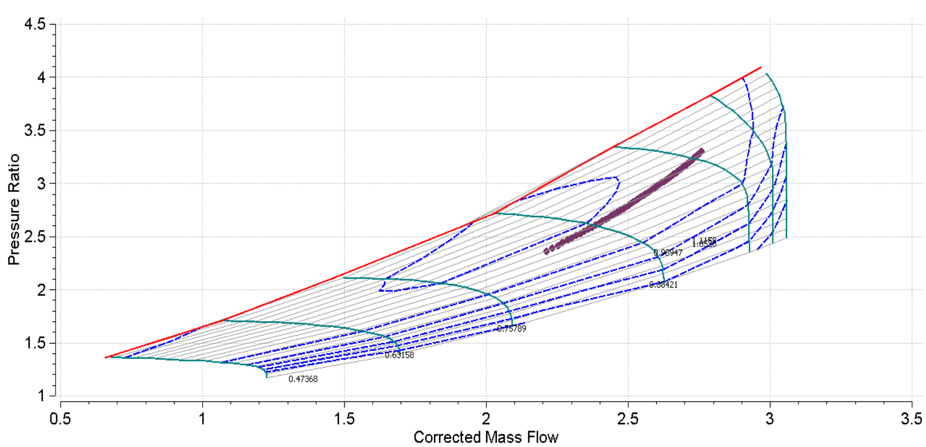

FIGURE 5: HP Compressor (Centrifugal Stage) Map and Operating line

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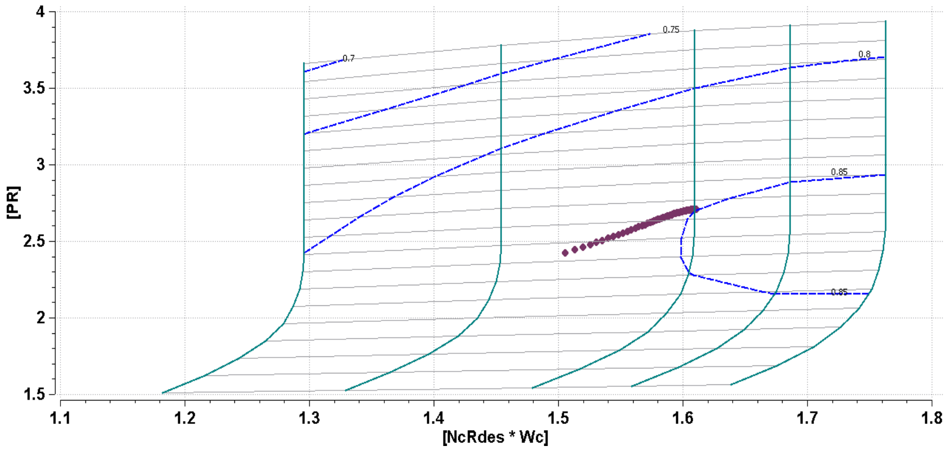

FIGURE 6: Core Turbine Map and Operating line

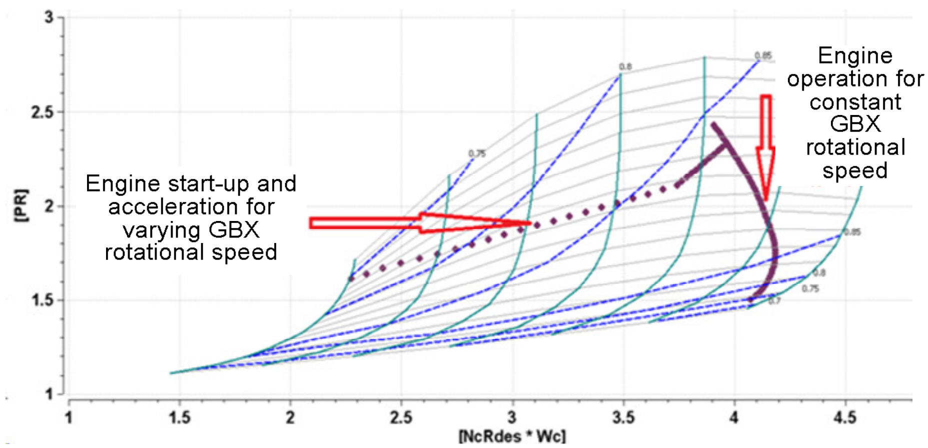

FIGURE 7: Power Turbine Operating line for constant and free GBX rotational speed

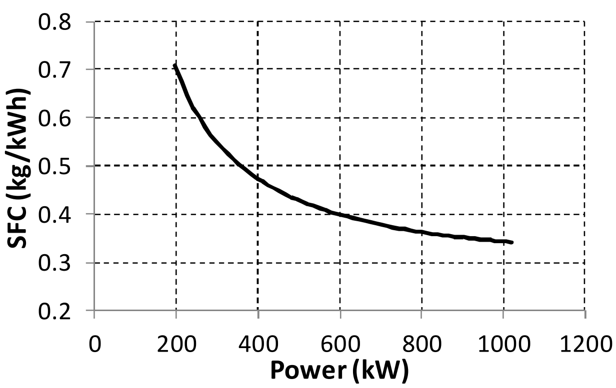

FIGURE 8: Engine sfc-power performance curve

RECUPERATED ENGINE OFF-DESIGN OPERATION

For engines of relatively low pressure ratio, recuperation is a mean to significantly enhance the overal performance (decrease of full and part load SFC). This betterment is not free, since a recuperator significantly decreases the shaft power due to pressure losses and increase the cost and the complexity of the cycle. The recuperator is a heat exchanger connected between the turbine exhaust and the compressor exit. During the process of recuperation, hot gases from the engine exhaust are passed through the heat exchanger and increase the temperature of the compressed air at the compressor exit. The compresed heated air is then fed to the combustion chamber. The increase of the air temperature and, therefore, the use of less fuel to achieve the desired turbine inlet temperature may increase the cycle overall efficiency, depending on heat saved and power decrease due to pressure losses.

For caclulating the combustor inlet temperature, the heat exhanger effectiveness is used, while the pressure losses are modelled via appropriate (hot and cold) pressure loss coefficients. For predicting off-design recuperator performance the equations proposed by Walsh and Fletcher [12] are used. The design point heat exhanger effectiveness is ε_{DP}=75%, and the cold and hot stream pressure loss coefficients are $PL_{DP,c}$=3% and $PL_{DP,h}$=4% respectively. The engine model built in PROOSIS is depicted in Fig. 9.

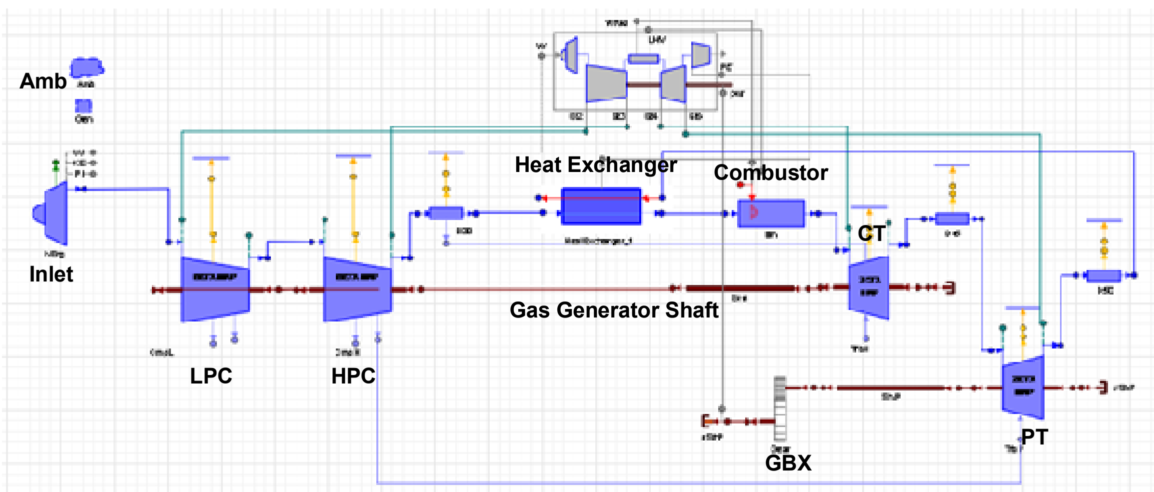

FIGURE 9: Recuperated Turboshaft engine PROOSIS schematic diagram

For the recuperated engine the increased pressure losses move the LPC and HPC operating lines towards the surge line decreasing the surge margin, as seen in Fig. 10 and 11. The decrease of the LPC surge margin at part load is signifcant thus if the engine is to be used as recuperated the BOV schedule should be changed to ensure stable operation during power increase (acceleration). Concerning the engine performance, as seen in Fig. 12 the engine SFC is signifcantly decreased, while the engine power for the limit TET defined at the max. continious rating is decreasing. Specifically the power at 100% is decreased by 16.3% relative to the simple cycle and the efficiency is ehnanced by 24.4% to a value of SFC=0.259kg/kWh.

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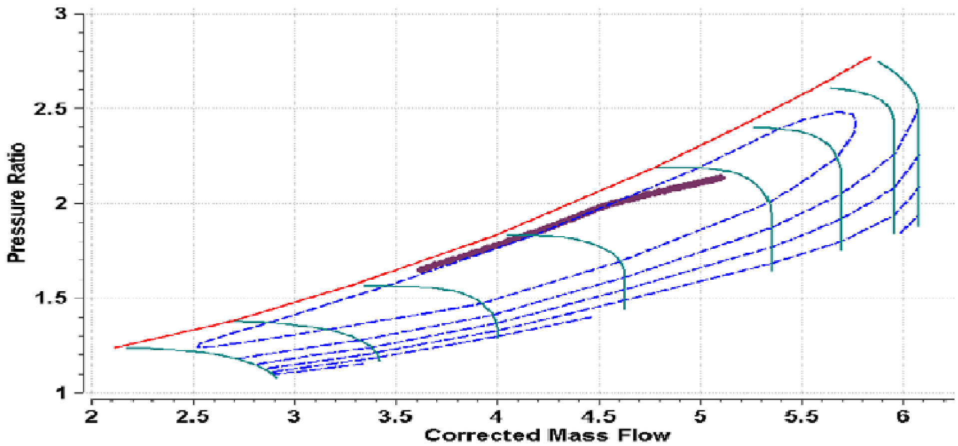

FIGURE 10: LP Compressor Map and Operating line for recuperated engine

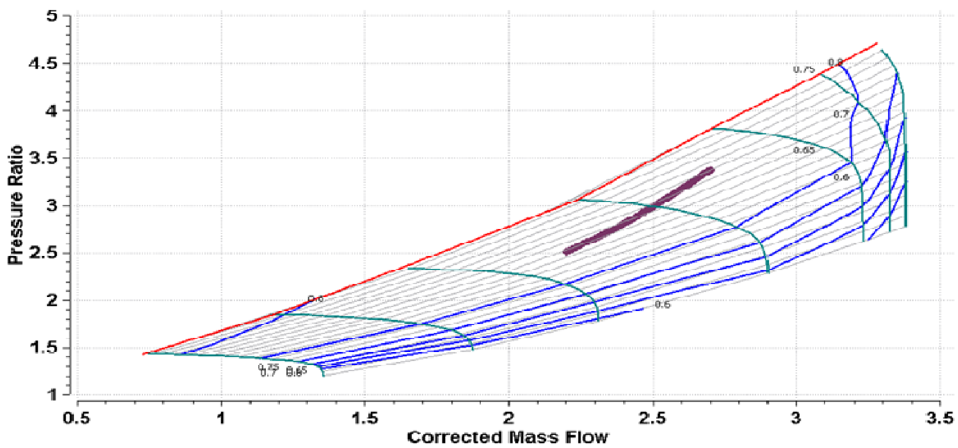

FIGURE 11: HP Compressor Map and Operating line for recuperated engine

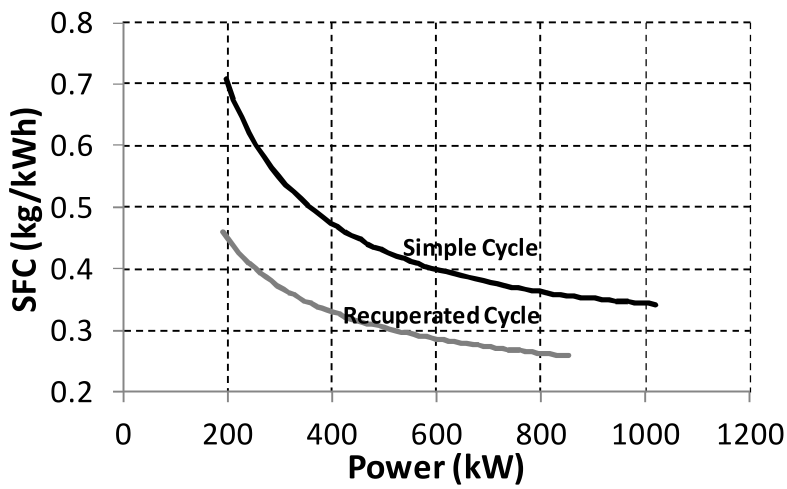

FIGURE 12: Engine sfc-power performance curve for the recuperated engine

ECONOMICAL ASSESSMENT of T53 GENSETS

For assessing the feasibility of the T53 genset for the Hellenic Army a preliminary economic analysis of electrical generation is undertaken. For this purpose the Net Present Value of investment (NPV) can be used as a measure of economic performance. It is the present worth of the total profit of an investment, which results as the difference between the present worth of all expenses and the present worth of all revenues. The NPV is calculated via eq. (1).

$$NPV = \sum_{t=0}^{n} C_t \cdot \left(1 + d_t\right)^{-t} \quad (1)$$

Where C_t is the profit or net cash flow (revenue + savings - expenses) in period t, d_t is the market interest rate during period t and n is the selected payback period. If NPV is greater than zero then the investment is economically viable under the specified conditions (n, d_t), if it is zero the investment is economically viable and it has a return of the investment equal to d_t for the selected period (n) and if it is negative then the investment is not economically viable under the specified conditions (n, d_t).

For evaluating the economic performance of selected cases the investment cost, the operation cost and the operating profile of the plant (availability, stand-by or baseline unit etc.) should be calculated. The investment or capital cost breaks down to equipment cost, installation cost and “soft” or project cost. The site development, installation and project management cost are assumed negligible, since the means and trained personnel are available to the organization. The equipment cost for the case of power generation includes the electrical generator cost, the switchgear and interconnection cost and the cost of an additional gearbox for connecting the engine to the generator. The generator and gearbox costs are estimated to 37k€ and 53k€ accordingly using off the shelf solutions [16]. The switchgear and interconnection costs are estimated to 45k€ according to [17]. If the engine is not readily available it can be purchased used/refurbished at the price of 155k€ and new at an estimated price of 360k€ [16]. For the recuperated engine the additional cost is estimated to the 68% of the simple cycle cost, namely 245k€, according to [18]. The gas turbine operation cost is dominated by the fuel cost which is assumed equal to 0.8€/kg_f. The maintenance cost is assumed equal to 5.4€/MWh [19]. In the case of Hellenic Army the maintenance cost may be significantly lower, given that spare parts and trained personnel are available.

For the evaluation of the annual electricity production and fuel consumption the engine models (simple and recuperated cycle) are utilized for a typical annual ambient conditions profile, assuming that the engine operates as base load at the maximum continuous rating TET and rotating speed. It should be noted that the gearbox and generator efficiency are modeled via appropriate efficiency curves. The generated electrical power for a whole year is depicted in Fig. 13 for the case of simple and recuperated cycle.

Having calculated the engine performance throughout the year the economic evaluation of the cases of interest is performed by calculating the electricity price for zero NPV and 10 years payback period. The data used for this preliminary economic analysis is presented in TABLE 4. The electricity price to achieve 10 years payback period (NPV=0) for the examined cases is presented in Fig. 14. It can be easily concluded that the engine acquisition cost has small effect on the investment payback, since the fuel cost is the dominant parameter. The utilization of recuperation results to a decrease of the electricity price by 18.5%, thus making it a worth examining solution if the engine is to be used as base load generator. It should be considered that a recuperated engine may have additional maintenance costs.

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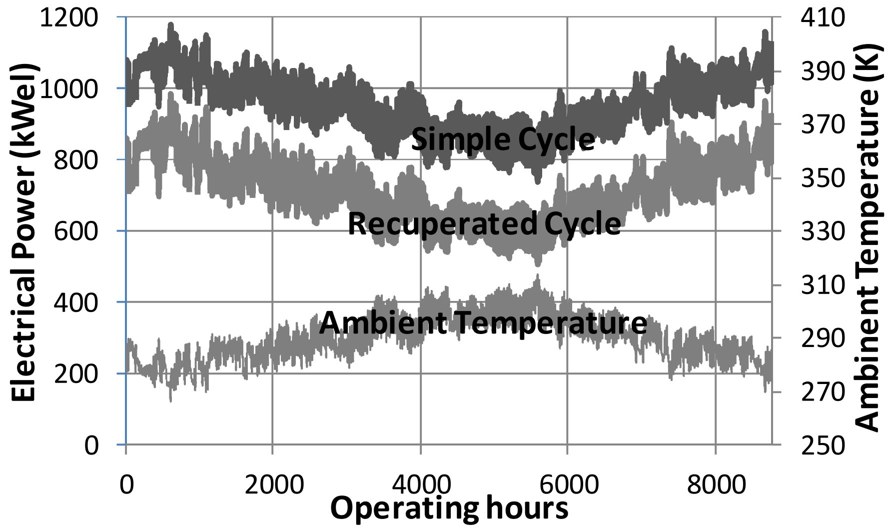

FIGURE 13: Annual Electrical Power production

TABLE 4: Technoeconomic Data

	Simple Cycle			Recuperation Cycle	
	Available Engine	Used Engine	New Engine	Available Engine	New Engine
Investment Cost [k€]	135	290	495	380	740
Electrical Power Production [MWh/year]	8023.29			6015.96	
Fuel Consumption [tn/year]	2920.4			1726.58	
Fuel Cost [€/kg_f]	0.8				
Maintenance Cost [€/MWh]	5.4				
Market Interest Rate[%]	6				
Payback Period [years]	10				

Another use of the engine is as standby generator. In this case the engine acquisition cost becomes dominant, thus the investment should be re-evaluated. Gas turbines are ideal for emergency generators especially in remote sites due to their infrequent maintenance and compactness.

The standby engines may operate less than 150 to 200 hours per year, so setting the operating hours as 200 per year the electricity price for the cases discussed above changes dramatically, as depicted in Fig. 15. It is apparent that for infrequent operation the use of an existing engine is expected to significantly reduce the cost of electricity for the operator, while the Recuperated cycle presents no advantage when periodic operation is considered. The low electricity price for the case that the engine is available indicates that the utilization of the converted turboshaft engine as standby generator may be economically viable compared to the acquisition of a new Diesel genset. The cost of a Diesel genset of 1MW excluding the enclosure cost is approximately 400k€ according to [17]. The maintenance cost of a Diesel genset can be assumed equal to 9.2€/MWh [19] or if outsourced in the range of 2k€ to 5k€ [17] for 200 hours operation per year. The main advantage of the Diesel engine is its low SFC, which for a High Speed Diesel engine is in the range of 0.2 to 0.22kgf/kWh [18]. Assuming a fixed SFC of 0.21

kgf/kWh, since the detailed modeling of the Diesel engine is not in the scope of the present paper, the electricity price for the case of Diesel standby generator for 200 hours of operation is calculated equal to 0.463€/kWh, exceeding the converted turboshaft engine electricity price by approximately 16.7%. This preliminary evaluation indicates that the conversion of the existing turboshaft engine for use as standby generator in remote sites can be a viable solution for the Hellenic Army and should be examined in greater detail.

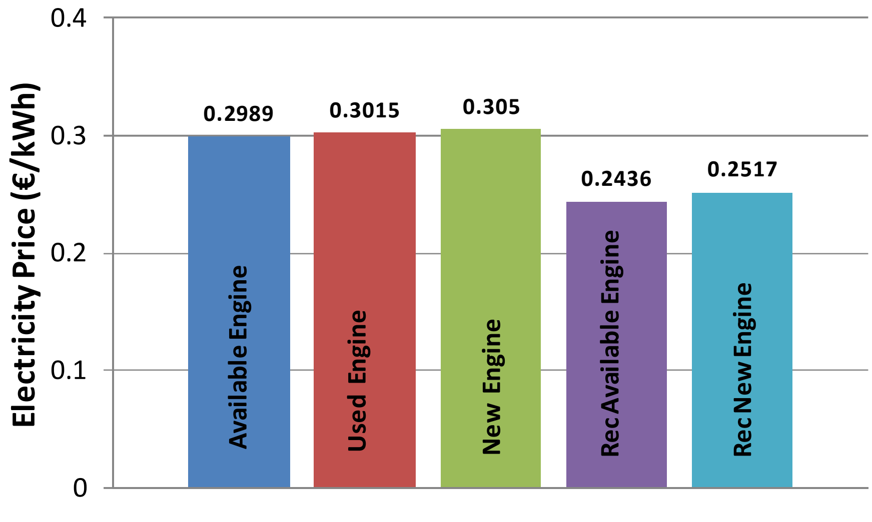

FIGURE 14: Electricity price for 10 years payback period

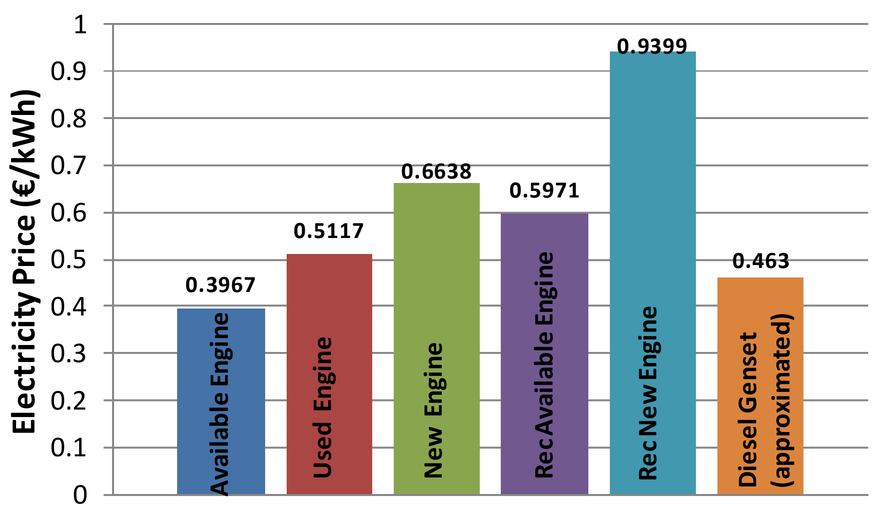

FIGURE 15: Electricity price for 10 years payback period – standby generator

SUMMARY

The conversion of an available helicopter engine (T-53) to genset has been discussed and assessed in terms of performance, operability and economic viability. An appropriate design and off-design model of the turboshaft engine has been built and adapted to available test-bed data.

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The analysis of engine operation for power generation indicated that the engine will operate at reduced surge margin at part load. At the same time the power turbine introduce limitations to part load operation. Specifically the engine can not operate synchronized for power less than 20% of the nominal one. The performance of the converted engine is in the range of the commercially available small gas turbines and close to the turboshaft engine performance. Since modified engine cycles are of interest for the case of small gas turbines, the simple cycle engine model has been modified for modeling gas turbine recuperation. The off-design model has been used for evaluating the performance and operability of the recuperated engine. The results indicate that the recuperated engine will have operability issues with respect to surge margin if the BOV schedule remains unchanged. Recuperation of the specific engine results to the decrease of nominal power by 16.3% and to the decrease of specific fuel consumption by 24.4%. The recuperated engine nominal SFC is 0.259kg/kWh, which is rather good compared with commercially available small gas turbines.

The engine performance models have been used for calculating the annual produced power and fuel consumed for the ambient conditions of a specific site. This data has been used in conjunction with suitable economic data for calculating the levelized cost of electricity (LCOE) for a payback period of ten years and several cases for assessing the benefit of converting the engine versus buying it. The results indicate that for base load application the acquisition cost is a small parameter of the total cost and the converted engine offers a 2% benefit when compared to a new engine. On the other hand a recuperated engine has a 17.5% benefit in terms of LCOE compared to the simple cycle engine. In this context the investment for a recuperated engine may be economically feasible for the case of high utilization of the engine.

Small gas turbines are also used as emergency / standby generators. For low engine utilization the acquisition cost becomes dominant, thus the converted engine LCOE is half of the new engine's LCOE. The investment for the case of the recuperated engine is not justifiable, since the additional heat exchanger cost results to a LCOE higher than the one of the simple cycle engine. Finally a preliminary comparison between the converted turboshaft engine and a new Diesel genset for annual operation of 200 hours indicates that the user can have a cost reduction of 16.7% if the converted engine is used instead of buying a new Diesel genset.

REFERENCES

1. Small Gas Turbines for Distributed Generation Markets: Technology, Products, and Business Issues", EPRIsolutions, Palo Alto, CA, and GTI: 2000. 1000768. GTI-00/0219.
2. Shauk Z., "Redeployment: Battlefield engines take on oil field mission", Fuel Fix, May 2013
3. Nkoi B., Pilidis P., Nikolaidis T., 2013, "Performance of small-scale aero-derivative industrial gas turbines derived from helicopter engines", Propulsion and Power Research 2013;2(4):243–253
4. T53-L-13B Student's Workbook
5. http://www.proosis.com/
6. Alexiou, A., 2014, "Introduction to Gas Turbine Modelling with PROOSIS", 2nd Edition, Empresarios Agrupados Internacional (EAI) S.A., Madrid Spain.
7. Alexiou, A., Baalbergen, E.H., Kogenhop, O., Mathioudakis K. and Arendsen, P., 2007, "Advanced Capabilities for Gas Turbine Engine Performance Simulations", ASME Paper No. GT-2007-27086.
8. Pilet, J., Lecordix, J-L., Garcia-Rosa, N., Barènes. R. and Lavergne, G., 2011, "Towards a Fully Coupled Component Zooming Approach in Engine Performance Simulation", ASME paper No. GT2011-46320.
9. Roumeliotis, I., Aretakis, N., Alexiou, A., Sieros, G. and Mathioudakis, K., 2014, "Integration and Simulation of Rain Ingestion Effects in Engine Performance Simulations", ASME Paper No. GT2014-26556.
10. Nelder, J.A. and Mead R, 1965, "A simplex method for function minimization", Computer Journal 7, 308–313.
11. Kurzke J., "Compressor and Turbine Maps for Gas Turbine Performance Computer Programs", 2004

12. Walsh P., Fletcher P., 2004, “Gas Turbine Performance”, Blackwell Science
13. Gordon, S. and McBride, B.J., 1994, "Computer Program for Calculation of Complex Chemical Equilibrium Composition and Applications", NASA RP1311, National Aeronautics and Space Administration, Washington DC.
14. Diesel & Gas Turbine Publications Global Sourcing Guide: http://www.gsgnet.net/
15. Giampaolo T., 2003, “Gas Turbine Handbook: Principles and Practice, 3rd Ed.”, Taylor & Francis Ltd, USA
16. Tsiokas S., 2014, “Study on conversion of helicopter engine to gas turbine for electricity production.”, Diploma Thesis, National Technical Univ. of Athens.
17. “Costs of Utility Distributed Generators, 1-10 MW: Twenty-Four Case Studies”, EPRI, Palo Alto, CA, and Cooperative Research Network, Arlington, VA: 2003. 1007760.
18. Woud H.K., Stapersma D, 2002, Design of Propulsion and Electric Power Generation Systems, IMarEST publications
19. Boyce MP. Gas turbine engineering handbook. Gulf Professional Publishing, Linacre House, Jordan Hill, 4 Oxford, UK.

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