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# Metaheuristic approach for an artificial neural network: Exergetic sustainability and environmental effect of a business aircraft

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ABSTRACT

In the current study, exergetic metaheuristic design for a business jet aircraft are presented for the prediction of exergetic sustainability index (ESI) and environmental effect factor (EEF) with the aid of artificial neural network (ANN) models at various flight phases. In this respect, real databases of ESI and EEF with regards to several engine parameters achieved by multiple number of runs of a business aircraft engine at various settings have been utilized to develop hybrid GA (genetic algorithm)-ANN models. Adoption of a metaheuristics based optimization on the developed MLP (Multilayer perceptron) ANN models has yielded optimum initial network weights, biases, step-size, and momentum rate for the BP (back-propagation) training algorithm as well as the optimum number of neurons in the hidden layer(s) in terms of network topology design. An error analysis has revealed that linear correlation coefficient values between the reference real data and predicted ESI and EEF values have been attained as 0.999862 and 0.999986, respectively. For both models, more accurate testing results have been achieved for one-hidden-layer networks compared to two-hidden-layer ones. Consequently, optimization of ANN models by GAs has enhanced the time effectiveness and accuracy of the derived models ensuring a drop-off in the testing phase errors.

## 1. Introduction

Air traffic between 2011 and 2031 is estimated to grow by an annual rate of nearly 5; whereas, the increase in number of passengers for air transportation is predicted as 4% yearly around the world (Enviro, 2016; Boeing, 2016). According to recent fuel price fluctuations and increasing concerns about reliable performance and cost effective aircraft, airlines must choose aircraft that minimize risk and are adaptable to the market environment.

New transportation aeroplanes currently in research and development suggest extensive options for intercity transportation. These new aircraft are classified by their power systems: aircraft with jet and turboprop engines (Leea et al., 2007). Aeroplanes with updated turboprops offer low operating costs.

Comparative aircraft costs depend on fuel price. Main advantage of gas turbine propeller aircraft is due to their low specific fuel consumption. By using these engines, airplane can fly under efficient and economic conditions. Moreover, due to increasing importance on environmental concerns and emissions along with fuel cost fluctuations, turboprop aircraft promise better performance efficiency for air vehicles in terms of environmental pollution released (Sahin and Turan, 2016; Meric, 2015a, 2015b; Aydin et al., 2013). In this regard, aircraft fuel, performance, energetic and exergetic efficiencies are deduced to be the prominence parameters to

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achieve social, environmental, and economic sustainability in air transportation sector (Midilli and Dincer, 2009; Norberg et al., 2009; Ji et al., 2009). In the last decades, performance and thermodynamics analyses have been applied to aircraft gas turbine engines (Aydin et al., 2013; Balli and Hepbasli, 2013, 2014; Turan and Aydin, 2014; Atilgan et al., 2013; Baklacioglu et al.,2015; Turan, 2012a, 2012b, 2015; Baklacioglu, 2016; Turan and Aydin, 2016). In this study, prediction of exergo-sustainability index (ESI) and environmental effect factor (EEF) of a business aircraft is presented via a metaheuristic design for initial parameters and architectures of two artificial neural network (ANN) models at various flight phases. In this respect, real databases of ESI and EEF are utilized to derive hybrid GA (genetic algorithm)-ANN models. Although there are several studies held in other research areas in the literature that combines GA and ANN approaches (Cook et al., 2000; Wang, 2005; Cheng and Shu, 2010; Mellit et al., 2010; Togun and Baysec, 2010; Wang et al., 2010; Ashena and Moghadasi, 2011; Ding et al., 2011; Mohamed, 2011; Amin, 2013; Sanaye and Asgari, 2013; Asadi et al., 2014; Malleswaran et al., 2014; Yu and Xu, 2014; Taghavifar et al., 2014a, 2015a, Sun and Xu, 2016), it should be noted that there exists no reported study on the exergo-metaheuristic approach for ESI and EEF with the aid of metaheuristics-optimized ANN models. Due to this fact, this article has a novelty and this constitutes the main motivation in developing models for business aircraft and their propulsion systems during a typical flight.

## 2. Methods of thermodynamic analysis

### 2.1. Exergy: terminology and definitions

Exergy describes the maximum theoretical work obtained from a working fluid considering its temperature, pressure, and velocity to a state equilibrium with its surrounding environment.

Total exergy of any control volume ($\dot{E}x$) can be written including specific exergy ($ex$) (Balli and Hepbasli, 2013; Hepbasli, 2008).

$$\dot{E}x = \dot{m}(ex_{pt} + ex_{kn} + ex_{ph} + ex_{ch}) \tag{1}$$

Exergetic statement of a system can be written mathematically as follows (Hepbasli, 2008):

$$\sum\left(1-\frac{T_0}{T_k}\right)\dot{Q}_k-\dot{W} + \sum_{in}\dot{E}x_{in}-\sum_{out}\dot{E}x_{out}-\dot{E}x_{dest} = 0 \tag{2}$$

$$\sum\dot{E}x_{in}-\sum\dot{E}x_{out} = \sum\dot{E}x_{dest} \tag{3}$$

$$\dot{E}x_{heat} = \sum\left(1-\frac{T_0}{T_k}\right)\dot{Q}_k, \tag{4a}$$

$$\dot{E}x_{work} = \dot{W}, \tag{4b}$$

$$\dot{E}x_{mass,in} = \sum\dot{m}_{in}\psi_{in}, \tag{4c}$$

$$\dot{E}x_{mass,out} = \sum\dot{m}_{out}\psi_{out}. \tag{4d}$$

The chemical exergy can be written as (Bejan et al., 1996):

$$\overline{ex_{ch,i}} = \sum x_i\overline{ex_i}^{ch} + \bar{R}T_0\sum x_i\ln x_i \tag{5}$$

Liquid fuels ($C_xH_yO_zS_r$) chemical exergy (i.e. specific exergy) can be formulated on a unit mass as in the following (Kotas, 1995):

$$\frac{ex_{ch,f}}{h_{PR}} = \gamma_f \cong 1.0401 + 0.01728\frac{H}{C} + 0.0432\frac{O}{C} + 0.2196\frac{S}{C}\left(1-2.0628\frac{H}{C}\right) \tag{6}$$

Here, $\gamma_f$ is calculated as 1.067893 for the kerosene type of Jet-A1 gas turbine fuel.

## 3. Exergy, sustainability and environmental definitions

### 3.1. Exergetic efficiency ($\eta_{ex}$)

Exergetic efficiency ($\eta_{ex}$) can be written as follows (Dincer, 2007):

$$\eta_{ex} = 1-\frac{\dot{E}x_{dest} + \dot{E}x_{loss}}{\dot{E}x_i} \tag{7}$$

For simplicity, exergy flows of business aircraft and gas flow path stations of the turboprop engine are shown in Figs. 1 and 2, respectively. Saab 340 business aircraft selected the twin turboprop engine to power the aircraft. Fig. 2 shows the main components of the propeller aero engine with compressor (C), combustor (CC), high pressure turbine (GT), and free turbine (PT) (Baklacioglu et al., 2015).

Considering Fig. 1, the exergy flows of the business aircraft (BA) can be given as: