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# Linear approximations of relations between preliminary design parameters for utility helicopters

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ABSTRACT

Utility helicopters represent an important category of helicopters with evolving design requirements which include the level of emitted noise. The scope of the present work is to contribute towards simplification of both the preliminary design process, and the evaluation of existing helicopters. Noise is included as a design criterion from this early stage of the process. A large number of pairs of design parameters were examined leading to selection of *linear* approximations between them. The correlations are derived from a created database of current and representative designs which includes noise levels. The relations presented offer simpler and direct estimations of key parameters compared to more elaborate calculation procedures currently employed in the preliminary design.

## 1. Introduction

Utility helicopters represent a significant class of helicopters. The design of new vehicles and the evaluation of existing ones evolves according to new demands for increased performance, fuel efficiency and stricter environmental regulations on their noise. The phase of *preliminary* design is important to the introduction of a new helicopter which satisfies the evolving requirements. It is typically based on data from existing helicopters and makes use of correlations between the key design parameters. The correlations can also be employed in order to yield an initial evaluation of an existing design. Usually, noise data are not used in the *preliminary* design.

Data on utility helicopters have been published in several books including [7,8,10] as well as at internet sites, such as [1,5]. More complete data on an exhaustive list of helicopters appears in the volume "Jane's All the World's Aircraft: Years 2004–2005" [6]. It is one of the most reliable sources of data on almost all existing helicopters. The present work chose this list to extract a new database for utility helicopters that is current and includes the key design parameters. The range of the maximum helicopter weight is from 1400 to 6000 kg.

Noise data have been taken from Federal Aviation Administration (FAA) [3]. A key feature of the present work is the inclusion of noise data correlations in the *preliminary* design. Noise amplitude is correlated with typical *preliminary* design parameters, such as weights, and geometry features of the helicopter, thus forming an integral part of the process.

Correlations of certain design parameters appear in previous works including [7–10]. The scope of the present work is on finding (i) strong correlations between the design parameters, as well as (ii) simple mathematical approximations connecting them. Specifically, linear approximations are sought after.

The helicopters included in the database formed in the present work, cover the range of number of passengers and total weights typically encountered in this category. Conventional designs are considered excluding the *Fenestron* tail rotors which size differently from the tail sections of the rest of the helicopters.

The types of design parameters forming the database are: (i) weights and loads, (ii) characteristics of the geometry, (iii) performance and engine parameters, as well as (iv) noise amplitudes. Specifically, the weights included are: empty weight ($W_E$), maximum payload weight ($W_{PL}$), maximum fuel capacity ($V_F$), maximum take-off weight ($W_{TO}$), and the number of passengers (Pax). The loads are the maximum *disc loading* ($W_{TO}/S_{MR}$), and the transmission *loading* ($W_{TO}/P$). Characteristics of the geometry category include the following parameters: main rotor diameter ($D_{MR}$) main rotor blade chord ($C_{MR}$), tail rotor diameter ($D_{TR}$), and tail rotor blade chord ($C_{TR}$), as well as the overall length rotors turning ($L$), and the overall height up to the rotor head ($H$) of the helicopter. The tailplane span ($b_{TAIL}$) is included. The areas of the main rotor disc ($S_{MR}$), and the tail rotor disc ($S_{TR}$), are also part of the database. The third category of design parameters (performance and engines) includes the following: maximum cruising speed ($V_C$), service ceiling ($S_C$), maximum rate of climb at sea level, range ($R$), and the engine power for take-off ($P$). The range is specified in [6] for maximum fuel and without reserves for a standard mission.

Federal Aviation Administration data [3] on the noise generated by helicopter operations is employed to augment the new

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## Nomenclature

| | | |
|---|---|---|
| $b_{\mathrm{TAIL}}$ | tailplane span | m |
| $C_{\mathrm{MR}}$ | main rotor blade chord | m |
| $C_{\mathrm{TR}}$ | tail rotor blade chord | m |
| $D_{\mathrm{MR}}$ | main rotor diameter | m |
| $D_{\mathrm{TR}}$ | tail rotor diameter | m |
| EPNL | effective perceived noise level | EPNdB |
| $H$ | helicopter height (to top of rotor head) | m |
| $L$ | helicopter length (overall, rotors turning) | m |
| $P$ | engine power for take-off | kW |
| Pax | number of passengers | |
| $R$ | range (with maximum fuel, no reserves) | $n$ miles |
| $R^2$ | coefficient of determination | % |
| $S_{\mathrm{C}}$ | service ceiling | m |
| $S_{\mathrm{MR}}$ | main rotor disc area | $\mathrm{m}^2$ |
| $S_{\mathrm{TR}}$ | tail rotor disc area | $\mathrm{m}^2$ |
| $V$ | "volume" of helicopter ($V \equiv \mathrm{LHD_{MR}}$) | $\mathrm{m}^3$ |
| $V_{\mathrm{C}}$ | maximum cruising speed at $S/L$ | kt |
| $V_{\mathrm{F}}$ | maximum fuel capacity | liters |
| $W_{\mathrm{E}}$ | empty weight | kg |
| $W_{\mathrm{PL}}$ | maximum payload weight | kg |
| $W_{\mathrm{TO}}$ | maximum take-off weight (internal load) | kg |
| $W_{\mathrm{TO}}/P$ | transmission loading at maximum take-off weight and power | kg/kW |
| $W_{\mathrm{TO}}/S_{\mathrm{MR}}$ | maximum disc loading | $\mathrm{kg/m^2}$ |

database. Specifically, the data extracted concern the *Effective Perceived Noise Level* (EPNL) for three flight conditions referred to as "flyover", "take-off", and "approach", which are described in this section.

The *Effective Perceived Noise Level*, measured in EPNdB, is chosen as the design parameter regarding emitted noise. The employed database contains EPNL values as recorded during standardized noise measurements for the issuance of a type certificate for a helicopter model or airworthiness certificate for an individual helicopter. The EPNL is an *annoyance*-based metric, as opposed to the most commonly known SPL (Sound Pressure Level), which is a *loudness*-based metric [4,2]. For the computation of EPNL, information is used on the level, the frequency distribution and the time variation of sound. During a pre-determined flight path the SPL, is recorded for specified flight conditions for time intervals of 0.5 sec. For each such time interval, these values are transformed into perceived noisiness, a noise metric that characterizes the annoyance produced by a sound of a certain amplitude and frequency. The resulting quantity is PNL (the total Perceived Noise Level), which is subsequently corrected for tonal characteristics, and duration, thus yielding the EPNL.

The EPNL values for the three flight conditions are correlated with the maximum take-off weight (Fig. 1). The *flyover* EPNL correlates the best (correlation coefficient $R^2 = 84.7\%$). The same observation was made on all correlations studied in the present work, and thus, the *flyover* EPNL will be employed here. It should be noted that the noise data of each helicopter are obtained with different reference airspeeds as prescribed by the rules.

The following sections investigate the existence of *linear* relationships between the *preliminary* design parameters including noise amplitudes. The emphasis is placed on strong correlations with values of the *coefficient of determination* $R^2$ higher than 80% for most of them. The correlation results are grouped according to the four types of *preliminary* design parameters.

It should be noted that the present work does not give an exhaustive list of all possible good correlations between the design parameters. Nevertheless, the presented correlations form a complete set for the initial calculation of the key design parameters.

## 2. Weights correlations

The maximum helicopter weight is at take-off ($W_{\mathrm{TO}}$). It can be analyzed into the weights of the structure ($W_{\mathrm{E}}$), the fuel ($W_{\mathrm{F}}$), the crew ($W_{\mathrm{CR}}$), and the payload ($W_{\mathrm{PL}}$).

$$W_{\mathrm{TO}} = W_{\mathrm{E}} + W_{\mathrm{F}} + W_{\mathrm{CR}} + W_{\mathrm{PL}} \tag{1}$$

The take-off weight ($W_{\mathrm{TO}}$) is highly correlated with the rest of the weights as evidenced in Figs. 2 through 4. The fuel weight is typically calculated from the power of the engine and its specific fuel consumption. The engine data however, are not known at this stage of the design. An estimate has to be employed and corrected later. The direct correlation between $W_{\mathrm{F}}$ and $W_{\mathrm{TO}}$ presented in Fig. 4 simplifies this calculation.

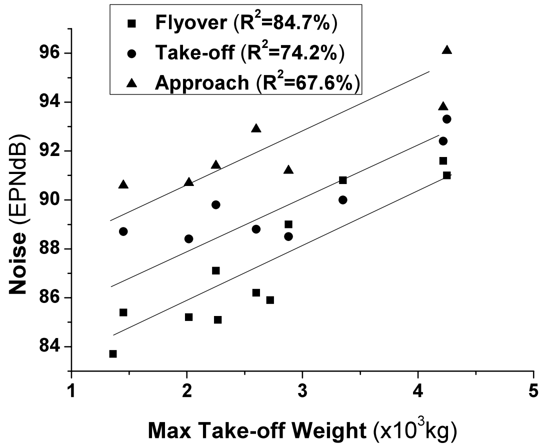

**Fig. 1.** Example correlations of the maximum take-off weight ($W_{\mathrm{TO}}$) with the three noise level (EPNL) values.

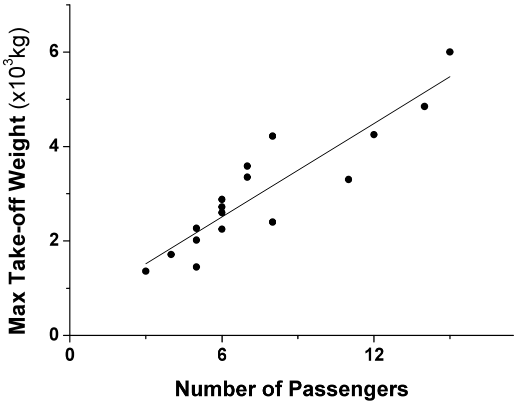

**Fig. 2.** Maximum take-off weight ($W_{\mathrm{TO}}$) *vs* number of passengers (Pax).

Table 1 lists the related linear approximations between the weights along with the degrees of correlation.

## 3. Characteristics of the geometry

This section presents the linear approximations found that involve geometry parameters related to (i) the main rotor, (ii) the fuselage, and (iii) the tail section of the helicopter.