LEVEL FLIGHT PERFORMANCE DETERMINATION USING COLLECTIVE PITCH

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ABSTRACT

Using "Non-Dimensional" parameters for measuring and presenting the level-flight performance of Turbine-Engined Helicopters is very efficient when conducting a flight test performance program. In this study, the level-flight performance of a helicopter-example (AS 550 Fennec) is determined using the collective pitch position as main parameter and the methodology described by the Engineering Sciences Data Unit ESDU No. 74042. The purpose of this study is threefold. The first is to present graphics of level-flight performance for a helicopter-example (AS 550 Fennec) using collective pitch position. The second is to present the relationship between the torque curve and collective pitch. The last is to exemplify some cases where this methodology can be applied to produce level flight performance graphics for operating data manual of a helicopter.

NOTATION

Symbols

Ddc,Dδc	*Collective Pitch Position*
g	*Gravity*
Hp	*Pressure-altitude*
m	*Helicopter mass*
P	*Power*
P´	*Referred power* – $P/[(\rho/\rho_0)(\Omega/\Omega_n)^3]$
Ta	*Outside air temperature*
Tq	*Torque*
Tq´	*Referred torque* – $Tq/[(\rho/\rho_0)(\Omega/\Omega_n)^3]$
V	*Forward speed*
V´	*Referred forward speed* – $V/(\Omega/\Omega_n)$
W	*Weight*
W´	*Referred weight*- $W/[(\rho/\rho_0)(\Omega/\Omega_n)^2]$
ρ	*Density of the air*
Ω	*Main rotor speed*
Ω_n	*Nominal main rotor speed*
ΔVi	*Instrument error*
ΔVp	*Position error*
Θ	*Collective pitch angle*

Subscription

$_0$	*Standard conditions (ISA) at sea level*
$_c$	*Calibrated condition*

1. INTRODUCTION

During the mission planning, graphics about the level flight give the possibility to predict information about range, fuel consumption, maximum speed for all combinations of pressure-altitude and outside air temperature where the helicopter is certified to fly.

Using instruments from pilots cabin the pilot can fix some parameters and perform a level flight in an engine power condition which gives the desired forward speed.

Theory about level flight performance for helicopters is generally well understood and a complete theoretical discussion can be found in the reference section used in this paper[1][2][3][4].

The purposes of this study are:

- General: provide and understand practical problems that can arise when conducting performance flight tests in level flight at various types of gas turbine powered helicopters.

- Specific: (1) Get graphics of level flight performance based on collective pitch using the helicopter-example AS 550 Fennec, which is a conventional single-engine light helicopter (01 main rotor and 01 tail rotor), (2) obtain the relationship between collective pitch and power, using the same example helicopter mentioned before, and (3) exemplify cases where this method can be used.

The paper presents some considerations regarding the theory, testing techniques, instrumentation and data reduction when using the collective pitch as a primary parameter for determining the level flight performance of a helicopter. In addition, the paper details the description of the data acquisition system used in this helicopter.

2. **THEORY AND METHODOLOGY**

The helicopter level flight performance in forward flight is measured in terms of required power (or in some cases in terms of the collective pitch angle) to maintain stable flight for different atmospheric conditions, helicopter weight and external configurations.

For the level flight condition, factors affecting the performance consist of engine power, weight (or mass), rotor radius, forward speed, rotor speed and ambient conditions. By dimensional analysis, it can be shown how these parameters relate. Considering the methodology presented in ESDU 73026[2], the pratical "non-dimensional" relationships based only on atmospheric density to describe the flight condition, are described as follows.

In terms of power, it´s possible to obtain the so-called "referred power" parameter as the following relationship:

(1) $$P'=\frac{P}{(\rho/\rho_0)(\Omega/\Omega_n)^3}=f\left[\left(\frac{W}{(\rho/\rho_0)(\Omega/\Omega_n)^2}\right),\left(\frac{V}{(\Omega/\Omega_n)}\right)\right]=f(W',V').$$

The same relationship using the collective pitch angle is:

(2) $$\Theta=h\left[\left(\frac{W}{(\rho/\rho_0)(\Omega/\Omega_n)^2}\right),\left(\frac{V}{(\Omega/\Omega_n)}\right)\right]=h(W',V').$$

Note that the collective pitch angle parameter measured at the rotor hub do not need be corrected by relations of density or main rotor speed, and therefore, it consist of a direct measure reading.

Once you set the density parameter as a measure of atmospheric conditions, it is possible to vary altitude, forward flight speed for sufficient weight values to cover the desired range of "referred power". The parameters of the right side of equations 1 and 2 must be maintained constant during the test points so that relations are obtained satisfactorily. That is, when investigating the dependence of the required power (*P*) as a function of forward flight speed (*V*), as the aircraft's weight (*W*) varies, it is needed to change the flight altitude to keep constant the ratio $W/[(\rho/\rho_0)(\Omega/\Omega_n)^2]$. It should be remembered that the method described in this paper, which uses only the density as a measure of atmospheric conditions, does not account for the effects of compressibility in a systematic way and hence these effects are not discussed here.

3. **FLIGHT TEST INSTRUMENTATION**

The relevance of some key parameters measured when seeking to obtain data for level flight performance testing is presented as follows:

- Outside Air Temperature (*Ta*): relevant parameter for the density calculation (ρ) at flight level studied. Errors in temperature sensor may influence the results and necessary calibration of this instrument shall be performed before flight testing performance;

- Forward Speed (*V*): the level flight information is usually presented using a corrected speed. The observed forward speed, or indicated airspeed, contains instrument errors (ΔVi) and position errors (ΔVp), which shall first be found in calibration tests, to get the calibrated airspeed (*Vc*), which is be used in this paper for presenting the results.

- Pressure-altitude (*HP*) as well as the outside air temperature, the altitude information allows the computation of the density at flight level studied. Required calibration of this instrument must be performed before level flight testing;

- Torque (*Tq*): here lies one of the main points of discussion. Most often, due to the numerous existing projects, this parameter is taken as essential for determining the helicopter performance. As presented in ESDU 73026[2], the torque value measured when combined with the appropriate rotor speed, provides the simplest power measurement source. It should be noted that in some cases the torque sensor is part of engine system and its calibration must be performed during calibration of the engine (ROOTS[5]) and in other cases the torque sensor is part of the main transmission system . In level flight, this parameter is a "mirror" of the power required for the complete helicopter and its variation with the forward flight speed is indicative of the power required variation by the helicopter.

- Collective pitch angle (Θ): When this parameter is available in a cockpit instrument, the measure generally consists of values obtained "above the minimum collective pitch" and this information is very relevant for some types of helicopters. The reference point is particular in each helicopter design because, in general, is related to the tilt blade angle needed for a complete autorotation. The measurement can be made by recording the linear position of the "swashplate" on the main rotor hub (collective plateau). Collective pitch measurements are particularly useful in cases where torquemeters, or other means of the engine power measuring, are not available (ESDU[2]), or where the series representative helicopters contain collective pitch angle meter and torquemeter are available only in the prototype helicopter used during the testing phase. Importantly, the data representative of collective pitch obtained in flight tests and used for preparation of this paper take into consideration these details and all flights were conducted with the same setting of minimum collective rotor pitch.

- Main rotor speed (Ω): as can observed from equations (1) and (2), this parameter is present both squared and cubed, which means that even small changes can have a significant effect. Hence, it is needed to obtain this parameter precisely. In addition, the information displaying torque and main rotor speed shown in the cockpit often correspond to different systems in the helicopter (engine/rotor), which means that an equivalence factor is necessary to relate the main rotor speed with the engine shaft speed where is taken the torque measurement.

The methodology discussed in this paper is applied to obtain test data in level flight using a AS 550 Fennec helicopter (Figure 1) - series representative helicopter, except for the automatic acquisition data system installed. The data were obtained during the implementation of the Test Program for Flight Data Acquisition for Fennec Helicopter Simulator and the section responsible for the execution of the test campaign was Testing and Evaluation Group from Brazilian Army Aviation in partnership with the Institute for Research and Flight Test (São José dos Campos, SP).

Figure 1 –AS 550 Helicopter with Flight Test Instrumentation installed.

A diagram of the data acquisition system used in aircraft is shown in Figure 1 (Appendix A). This system consists of pressure sensors, anemometric transducers, anemometric boom, inertial unit, laptop, screen and central acquisition unit.

Among the various parameters recorded by Acquisition Data System, the relevant data sources for this study are:

- from aircraft instruments: the air data obtained through derivation – using hoses – of the static and dynamic pressures (left side panel). These hoses are connected to pressure transducers installed in the instrument console, providing sufficient data for calculation of altitude and airspeed. Additionally, by derivation of aircraft instruments, information about engine limits (temperature, gas generator turbine speed), torque (Tq), main rotor speed (Ω) and fuel quantity are obtained;

- from anemometric "Boom": the outside air temperature and airspeed for comparison with the helicopter airspeed measurements;

- from potentiometric transducers installed in the flight control: information about the collective pitch position (Dδc).

The data acquisition frequency is 100 Hz for all parameters.

The main rotor has no dedicated instrumentation; thus, in this study, instead of the collective pitch angle taken from main rotor hub, the collective control pitch position (Dδc) expressed in % and graded above the minimum collective pitch until stop is used. As mentioned previously, all flights were conducted with the same setting of minimum collective pitch, and thus, for purposes of this study, Dδc parameter was considered representative of the rotor collective pitch.

4. **DATA REDUCTION**

Data reduction is performed using the relationship presented in equations 1 and 2 of this paper.

5. **RESULTS AND DISCUSSION**

The following paragraphs present some results obtained in this study:

5.1 **Collective Pitch vs Calibrated Airspeed**

The results presented in Figure 2 (Appendix A) shows a curve relating the collective pitch as a parameter of level flight performance. Curves show speed above 40 KCAS and in each curve, the maximum value of collective pitch indicates that some parameter of maximum continuous engine power was achieved. The main information that the pilot can get from this type of chart is the collective pitch position needed to obtain maximum speed in level flight, for a given density-altitude (pressure-altitude and temperature) and helicopter weight.

It is possible to relate the collective pitch with information of fuel consumption per hour or fuel consumption per distance and present them with this chart, enabling calculations of range and endurance in various conditions of pressure altitude and temperature.

5.2 **Torque vs Collective Pitch**

Figure 3 (Appendix A) presents the relationship between collective pitch and torque corrected for ambient conditions and main rotor speed ratio (parameter also called referred torque). In the tested conditions, a percentage increase in collective pitch indicates an increase in the supplied torque, and hence an increase in required power. In practice, the plot shows that the value of collective position (collective pitch or angle) can be used directly, without correcting it for density and main rotor speed ratio.

The usefulness of this plot is to give the possibility of relating the position information of the collective (or collective pitch angle) with the characteristics of engine fuel consumption and torque limits.

It's possible to suppose that, in any case, there is a need to get the torque parameter to produce this curve. This is not entirely true, because in some projects the main limitation is the gas generator speed or engine fuel flow, and this could be directly related to the collective pitch, as in Figure 3 (Appendix A), whereas the measurement of torque on the engine output shaft or the transmission shaft is not an essential parameter.

6. APPLICABILITY

As an example of applicability, the methodology can be applied in Russian-made helicopters Mi-24 (Hind) and Mi-17. In the cockpit of the Russian-made helicopters type Mi-24 (export version Mi-35) and Mi-17, the torque information from rotor or engine output shaft is not available. This happens because while in American and European helicopters there is a general policy providing the minimum transmission power to perform the task with acceptable margins, saving weight and cost, allowing the pilot to do the power limitation, the Russians' typically have over-engineered transmissions, so that it can handle the maximum power available from the engine, and thus the power limiter is the top edge of the collective (COOKE[4]). In other words, in any environment condition within the flight envelope of such helicopters the limit parameter is not the transmission torque; therefore the absence of this indicator in this type of aircraft.

Figure 2 – Mi-35 helicopter used by Brazilian Air Force

Mi-24 and Mi-17 helicopters have a sensor/indicator of collective pitch angle; however, they do not present any performance information in the Aircraft Operations Manual that relate this indicator with the forward flight speed during the level flight. Applying the techniques presented in this paper can fill easily such gap of information.

7. CONCLUSION

This paper highlights the method limitations of obtaining data from level flight that uses indicators of power required parameters as collective pitch and torque. These limitations are discussed the relevance of the calibration of the aircraft instrumentation sensors in the results. Also, it was mentioned about the importance of setting the reference point of the minimum pitch when using measures of collective pitch angle, and the equivalence between the main rotor speed with the rotating shaft speed at the point of torque measurement.

Applying the methodology which uses as a primary power measurement parameter the collective pitch, it is possible to obtain curves whose main information to the pilot consists of the collective pitch to be applied in order to obtain a desired speed, for example, the maximum forward speed in level flight.

Another curve obtained by this method is the relationship collective pitch vs power or collective pitch vs consumption, which gives predictions to the pilot about consumption, range and endurance, during a mission planning, for example.

As can be noticed, the method described within this paper is of great importance for obtaining plots of level flight for helicopters which do not present torquemeter, such as the Russian-made helicopters Mi-24 family (Mi-35) and Mi-17.

The main contribution of the paper in the area of flight test is leaving useful practical information for those working in the determination of level flight performance on different powered gas turbine helicopters existing today.

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APPENDIX A

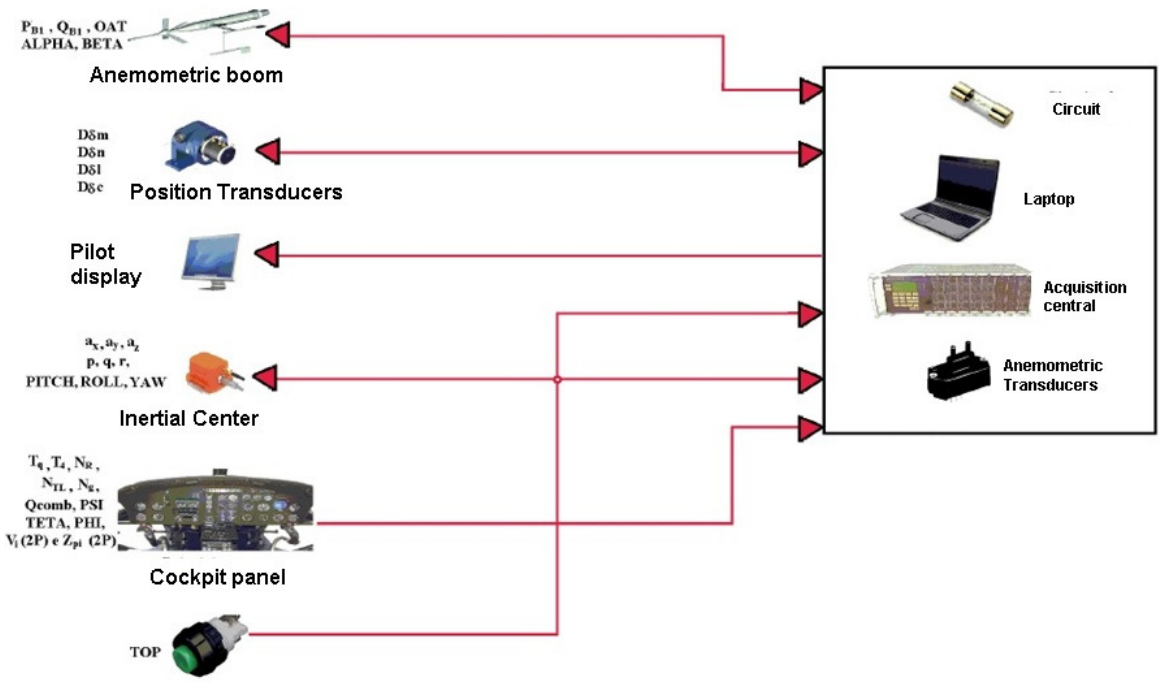

Figure 1 – Data Acquisition System installed in AS 550 Helicopter.

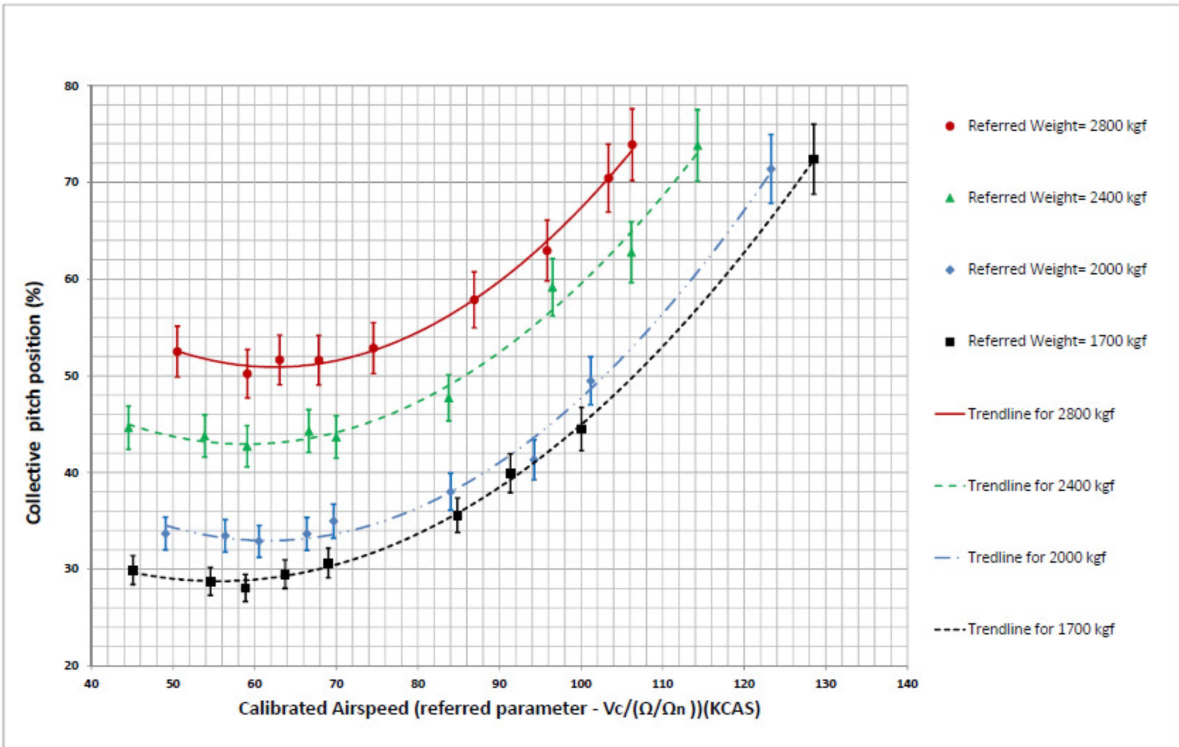

Figure 2 – Level flight performance using collective pitch.

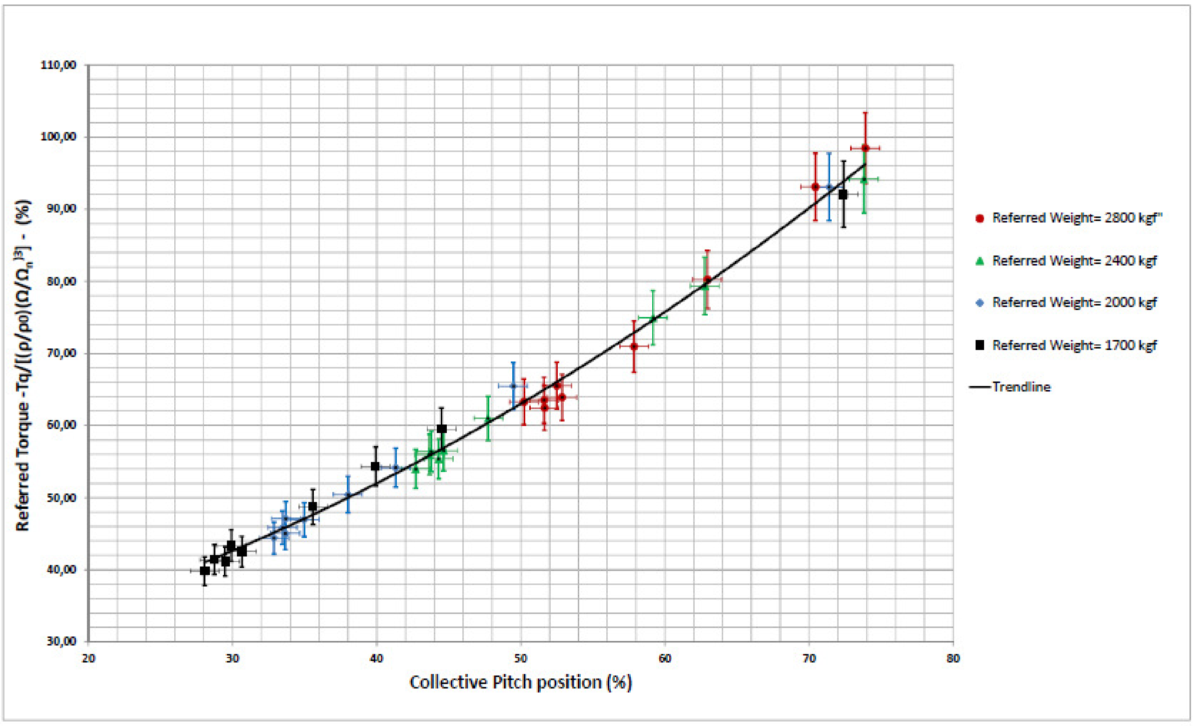

Figure 3 – Relationship between Torque (“referred Torque”) and Collective Pitch.