

NON-DIMENSIONAL METHODS FOR THE MEASUREMENT OF HOVER PERFORMANCE OF TURBINE-ENGINED HELICOPTERS

1. NOTATION AND UNITS[†]

		SI	British
C_P	power coefficient, $\frac{P \times 550}{\rho \left(2\pi \frac{\Omega}{60} R \right)^3 \pi R^2}$ in British units, $\frac{P \times 10^3}{\rho \left(2\pi \frac{\Omega}{60} R \right)^3 \pi R^2}$ in SI units		
C_T	thrust coefficient, $\frac{F}{\rho \left(2\pi \frac{\Omega}{60} R \right)^2 \pi R^2}, \text{ or } \frac{W}{\rho \left(2\pi \frac{\Omega}{60} R \right)^2 \pi R^2}$ in hover		
F	rotor thrust	N	lbf
f_3, f_6, f_8, f_{10}	functions used in equations in Table 5.1		
G	fuel flow $\left\{ \begin{array}{l} \text{volume flow basis} \\ \text{weight flow basis} \\ \text{mass flow basis} \end{array} \right.$	l/h N/h kg/h	gal/h lbf/h slug/h
g	acceleration due to gravity	m/s ²	ft/s ²
H_p	pressure height	m	ft
m	helicopter mass	kg	slug
P	shaft power output from engine	kW	hp
p	atmospheric pressure	N/m ²	lbf/ft ²
R	rotor radius	m	ft
T	ambient temperature	K	°C
W	helicopter weight, mg	N	lbf
Z	geometric height of wheel or skid above ground	m	ft

[†] The units quoted here are those most commonly used in practice; they do not constitute coherent sets (hence, for normal analytical purposes, the use of conversion factors would be necessary). Such units are permissible here since the object of the Item is the presentation, in parametric form, of flight-measured data and it is only necessary that the same units be applied throughout any given piece of work.

Issued November, 1973

With Amendment A, March 1977

δ	relative pressure, p/p_0		
Θ	collective pitch angle	deg	deg
θ	relative temperature, T/T_0		
ρ	density of air	kg/m ³	slug/ft ³
σ	relative air density, ρ/ρ_0		
Ω	rotor speed*	rev/min	rev/min
Ω_s	standard rotor speed*	rev/min	rev/min
ω	relative rotor speed, Ω/Ω_s		

Suffixes

<i>max</i>	maximum
<i>min</i>	minimum
0	denotes value at sea level in International Standard Atmosphere (Item No. 68046 gives numerical values)

* Units other than those quoted may also be in use.

Standard (sea level) values

	<i>SI</i>	<i>British</i>
p_0	$101.325 \times 10^3 \text{ N/m}^2$	$2.116\ 22 \times 10^3 \text{ lbf/ft}^2$
T_0	288.15 K	15°C
ρ_0	1.225 0 kg/m ³	$2.376\ 88 \times 10^{-3} \text{ slug/ft}^3$

2. INTRODUCTION

This Item describes the application of “non-dimensional” methods to the measurement of hover performance of turbine-engined helicopters. Item No. 73026 gives a general introduction to “non-dimensional” methods, as applied to helicopters, and presents the equations that provide the necessary theoretical bases of the methods. The “non-dimensional” equations relevant to the measurement of hover performance are obtained from Equations (3.2) to (3.11) of Item No. 73026 by setting the forward speed and rate of climb, V and V_c , equal to zero and by including the additional parameter[†] Z when the variation with height of hover performance in ground effect is to be measured. References for the present Item are included in Section 7 of Item No. 73026.

[†] In strictly non-dimensional form the hover height would be expressed as, for example, Z/R ; however, following the convention established in Section 3.2 of Item No. 73026, linear dimensions are often omitted since they remain constant for the helicopter under test.

3. TEST METHODS

Table 5.1 gives details of several “non-dimensional” test methods for hovering flight based on the measurement of engine shaft power output. (The Equations in Table 5.1 also apply if measurements of power are made at other locations, see Item No. 73026, Section 5.1.) Reference to the footnotes to Table 5.1 and to Item No. 73026 shows how these methods may be adapted

- (i) to cases where helicopter mass is used instead of weight,
- (ii) to cases where collective pitch is measured instead of power,
- (iii) to the presentation of helicopter fuel flow data.

The main practical difficulty in carrying out hover trials is to establish and hold a steady zero-airspeed flight condition in which accurate measurements can be made. Flight techniques used to overcome this problem may be divided into two categories:

- (i) methods suitable for free-flight testing,
- (ii) the tethered method of testing.

3.1 Free-Flight Hover Tests

Free-flight testing is used for most hover trials and particularly for tests conducted well above ground level. Since it is impossible to establish a hover by reference to current airspeed indicators, it is necessary either to use some other means of indicating zero-airspeed conditions or to rely on a fixed, ground reference. The ground reference method is the simplest way of establishing hovering flight but does require that tests be conducted relatively close to the ground and in as near zero-wind as possible. The latter factor is important since helicopter performance at and near the hover is particularly sensitive to airspeed. For those cases where it is not possible to use a ground reference, various techniques have been developed to permit the helicopter to hover relative to the local wind and two examples of these techniques are as follows.

The “hover meter”: this consists of two vertical vanes mounted on a boom extended from the nose of the helicopter and indicates the direction of the local airflow. The device may be used either visually or to provide an input to a suitable cockpit display which, after calibration in still-air conditions, can be used in-flight to obtain true hovering relative to the local wind.

Balloons and smoke puffs: these may be ejected or fired respectively from the test helicopter to provide a fixed reference point relative to the local wind.

3.2 Tethered Hovering

The use of a tether enables hover height to be kept constant without difficulty and allows a wide range of W to be simulated, without the use of ballast, by using a range of values of rotor thrust and hence of tension in the tether. During tethered tests it is usual to carry an on-board read-out of the tension measuring device so that the simulated value of W is known in flight and to ensure that neither tether nor attachment point maximum load is exceeded.

Tethered flight is particularly suited to hover tests close to the ground, where performance is sensitive to hover height. The variation of ground effect with hover height can thus be accurately measured by using tethers of different length. However, in common with all hover test methods that rely on a ground reference, tethered hovering must be carried out in *as near zero-wind conditions as possible* if the results are to be of practical use.

In tethered tests, the helicopter is usually flown at the lowest practicable take-off weight. Test results are obtained by increasing engine power (or rotor collective pitch) progressively from the point at which the tether is just taut until either the maximum permitted engine power or maximum cable tension is reached. Since this test technique is practical only when relatively close to the ground, the ranges of values of W/δ or $W/\sigma\omega^2$ obtainable are restricted by the extremes of p and ρ at the test site. To deal with this situation it may sometimes be necessary to use data measured in free flight as a guide to extrapolate the results obtained close to the ground.

3.3 Presentation of Results[†]

The final form in which results are plotted depends on the particular test method used, see Table 5.1. For tests performed out of ground effect and where rotor Mach number effects are disregarded, the results reduce to a single curve of, for example, $P/\sigma\omega^3$ against $W/\sigma\omega^2$, see Sketch 4.1. When rotor Mach number effects are to be considered, a separate curve is obtained for each value of $\omega/\theta^{1/2}$. When the variation of ground effect with height is to be considered, separate curves can be obtained for each of a range of values of Z , see Sketch 4.2. In practice, unless such detailed results are particularly necessary, it is usually sufficient to quote results

- (i) “in ground effect” – for, say, $Z = 5$ ft,
- (ii) “out of ground effect” – for $Z > 3R$.

4. EXAMPLE

(a) A single-engined helicopter is to be flight tested to determine the power required to hover in and out of ground effect for heights in the range 0 to 7 000 ft and in atmospheric conditions between ISA and ISA + 25. The helicopter is equipped with a torquemeter suitable for measuring engine output shaft power and has the following physical characteristics:

minimum operating weight	7 100 lbf,
maximum operating weight	10 900 lbf,
standard rotor speed	294 rev/min,
permitted range of rotor speed	274 to 304 rev/min,
rotor radius	25 ft.

It may be assumed that the tests can be carried out without regard to rotor Mach number effects and that the practical weight range for test purposes is 7 450 to 10 900 lbf.

Determine the extent to which the power required can be measured for the stated ranges of weight, height and atmospheric conditions, given that three test sites are available whose heights above sea level and mean ambient temperatures for the periods of the tests are as follows

[†] Values of δ , θ and σ necessary for the evaluation of the “non-dimensional” parameters, may be obtained from Item No. 68046.