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HELICOPTER HOVER PERFORMANCE ESTIMATION
COMPARISON WITH UH-1H IROQUOIS FLIGHT DATA

by

M.J. WILLIAMS and A.M. AIRNEY

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SUMMARY 

The hover performance of the UH-1H Iroquois has been estimated under a variety of operational conditions using POLAR2, a program based on blade element theory. This program is an improved version of POLAR, a program previously developed at ARL, which did not allow for compressibility effects. The occurrence of these effects in a hovering situation is discussed, and a relationship allowing for such effects has been derived and included in POLAR2. Other improvements, designed to make the program more convenient to use include the calculation of tail rotor performance together with variables such as tip loss, air density and Lock number which were previously input. The role of the induced velocity factor is also discussed. Finally, comparisons of estimates using POLAR2 and ARDU flight trials data for the UH-1H are presented.
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NOTATION

B  tip loss factor
C_p power coefficient, \( P/\rho \pi R^2 (\varpi R)^3 \)
C_T thrust coefficient, \( T/\rho \pi R^2 (\varpi R)^2 \)
F_blk fin blockage factor
I  blade mass moment of inertia about flapping hinge
M_0 blade tip Mach number at compressibility onset
M_{tip} blade tip Mach number
\( \Delta M \) \( M_{tip} - M_0 \)
N_2 gas generator angular velocity (rpm)
P  power
Q  torque absorbed by main rotor, \( P/\Omega \)
R  main rotor radius
T  rotor thrust
\( (T_{TR})_{NET} \) net tail rotor anti-torque thrust required to balance main rotor torque
Z  main rotor height above ground
a  blade section lift curve slope
b  number of main rotor blades
c  blade section chord
k_h  induced velocity factor at hover
k_{ind}  induced velocity factor, \( (P_i)_{actual}/(P_i)_{momentum} \)
l_{TR} distance of tail rotor from main rotor shaft
\( \Omega \) angular velocity of main rotor
\( \alpha(1,270) \) angle of attack of main rotor retreating blade at tip
Y  Lock number, \( \rho \alpha c R^4 / I \)
\( \mu \) advance ratio
\( \nu \) induced velocity at rotor
\( \rho \) density of air
\( \sigma \) blade solidity; ratio of blade area to rotor disk area,\( \sigma = bc/\pi R \)
NOTATION (cont.)

Subscripts

acc  accessories and transmission  
c  compressibility  
i  induced  
o  profile  
SL,ISA  sea level, ISA conditions  
stall  stall  
MR  main rotor  
TR  tail rotor  
\(\infty\)  out of ground effect
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>ABS-RW</td>
<td>Aircraft Behaviour Studies - Rotary Wing</td>
</tr>
<tr>
<td>ARDU</td>
<td>Aircraft Research and Development Unit</td>
</tr>
<tr>
<td>ARL</td>
<td>Aeronautical Research Laboratories</td>
</tr>
<tr>
<td>AUW</td>
<td>All Up Weight</td>
</tr>
<tr>
<td>DPTV</td>
<td>Data Plate Torque Value</td>
</tr>
<tr>
<td>IGE</td>
<td>In Ground Effect</td>
</tr>
<tr>
<td>ISA</td>
<td>International Standard Atmosphere</td>
</tr>
<tr>
<td>OAT</td>
<td>Outside Air Temperature</td>
</tr>
<tr>
<td>OGE</td>
<td>Out of Ground Effect</td>
</tr>
<tr>
<td>PNG</td>
<td>Papua New Guinea</td>
</tr>
<tr>
<td>RAAF</td>
<td>Royal Australian Air Force</td>
</tr>
<tr>
<td>RAN</td>
<td>Royal Australian Navy</td>
</tr>
<tr>
<td>rpm</td>
<td>Revolutions Per Minute</td>
</tr>
<tr>
<td>RSRA</td>
<td>Rotor Systems Research Aircraft</td>
</tr>
</tbody>
</table>
1. INTRODUCTION

The hovering performance of the UH-1H Iroquois helicopter has been described in References 1, 2. Flight testing was carried out by ARDU for a wide range of operating conditions in Australia, PNG and Irian Jaya at density altitudes up to 12000 ft. Power consumption was derived from torque meter readings which were converted for presentation in nondimensional form, $C_p$ vs $C_T$. Data were obtained OGE and IGE at a skid height of 3 ft with a view to formulating procedures for estimating power margins required over and above IGE values.

Following these tests a simple calculator was developed by ARDU for Service use, from which torque requirements for flight under varying conditions could be obtained rapidly. Later tests by Mackerras$^{(3)}$ under similar conditions confirmed the accuracy of the ARDU Performance Computer.

More recently the ABS-RW Group at ARL has been involved in performance estimation as part of tender evaluations of prospective helicopter acquisition by the RAN and RAAF. A simple program 'POLAR' has been described by Arney$^{(4)}$ which is based on blade element theory but makes no allowance for compressibility or stall effects. However, an indication of the likelihood of stall is output so that a manually applied correction may be made to the calculated profile power.

Comparison of 'POLAR' with flight results has shown good agreement at low thrust coefficients but underestimates at high thrust coefficients. For this reason the program prediction of torque margins compared with those given in Reference 3 is in error at the higher altitudes and AUW (high $C_T$).

The purpose of this Memo is to show results produced by an improved program 'POLAR2' which corrects these deficiencies. In the next section evidence of compressibility effects is noted in the flight data and the derivation of a simple expression to account for this
additional power loss is discussed. Other improvements incorporated in POLAR2 are discussed in the next section. Finally, predictions of POLAR2 are compared with flight data for hovering both OGE and IGE for a wide range of loadings and atmospheric conditions.

2. COMPRESSIBILITY EFFECTS AT HOVER

Examples of flight data from the ARDU reports (1,2) are reproduced in Figures 1a, b for the OGE, IGE cases respectively. Due to the difficulty of performing hover tests there is a fair degree of experimental scatter. The 'pessimism' curves represent the upper limit of the data i.e. maximum power likely for a given thrust. On the other hand, the mean curves were fitted and used by ARDU to form the basis of the ARDU Performance Calculators, especially prepared for engines of DPTV from 58 through 64.

Figure 2 shows a comparison of POLAR with the mean curve fitted to the flight data of Figure 1a. Like many performance programs POLAR requires an empirically based value of the induced velocity factor, $k_{ind}$, which is used to modify the induced velocity as given by momentum theory. In this manner, the induced power losses arising from 'non-ideal' inflow conditions are approximated. As described in Reference 4, POLAR set $k_{ind}$ equal to 1.30 for any hovering helicopter. Figure 2 shows that by adjusting POLAR to use a value of $k_{ind} = 1.22$, good agreement can be obtained at conditions of low thrust and power coefficients, where stall and compressibility effects would be expected to be negligible. Further comment on the use of $k_{ind}$ is given in the next section. As can be seen in Figure 2, with $k_{ind} = 1.22$, the estimate of power coefficient becomes progressively worse as thrust coefficient is increased. The additional power increment evidenced by flight data suggests the presence of compressibility effects, as blade angles of attack are well below stall.

Keys(5) presents data for the hover situation (reproduced here in Figure 3a) which gives the power increment arising from compressibility
as a function of $C_{T}/C$ (average angle of attack) and tip Mach number. Figure 3a shows a comparison between results given by vortex theory and CH-47 test data. The latter show a delayed $M_{tip}$ effect which is ascribed to the relief afforded by three-dimensional flow at the blade tips. Reference 5 suggests that the experimental data should be applicable to other blades of thickness ratio in the 10-12% range, therefore an approximation to these compressibility power increments has been derived for use with POLAR2 as is shown in Figure 3b.

In the case of the two-bladed UH-1H main rotor, the tip speed is higher than most multi-bladed helicopters. An indication of the range of tip Mach number experienced during the ARDU flight tests is given in Table 1 below.

### TABLE 1

**Effect of atmospheric conditions on tip Mach number for rotor speeds used in UH-1H tests (References 1, 2)**

<table>
<thead>
<tr>
<th>Atmospheric Conditions</th>
<th>Tip Mach Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude</td>
<td></td>
</tr>
<tr>
<td>O.A.T</td>
<td>Speed of Sound</td>
</tr>
<tr>
<td>(-°C)</td>
<td>(ft/s)</td>
</tr>
<tr>
<td>N₂ = 6400 rpm</td>
<td>RRPM = 315</td>
</tr>
<tr>
<td>N₂ = 6600 rpm</td>
<td>RRPM = 325</td>
</tr>
<tr>
<td>Altitude</td>
<td></td>
</tr>
<tr>
<td>ISA</td>
<td></td>
</tr>
<tr>
<td>Sea Level</td>
<td>15</td>
</tr>
<tr>
<td>5,000 ft</td>
<td>5</td>
</tr>
<tr>
<td>10,000 ft</td>
<td>-5</td>
</tr>
<tr>
<td>ARDU tropical atmosphere</td>
<td></td>
</tr>
<tr>
<td>Sea Level</td>
<td>28</td>
</tr>
<tr>
<td>5,000 ft</td>
<td>18</td>
</tr>
<tr>
<td>10,000 ft</td>
<td>9</td>
</tr>
</tbody>
</table>
From Table 1 it may be seen that under many flight conditions the tip Mach number exceeds $M_0$, the onset Mach number, as given by Figure 3b (top curve). For the flight data of Figure 1a, $C_{T/o}$ varies between 0.05 and 0.08 corresponding to an $M_0$ variation from 0.72-0.68.

The effect of OAT, inasmuch as it influences $M_{tip}$ is summarised in Figure 4. The solid lines are power vs thrust curves for the UH-1H obtained for different but constant OATs. Compressibility effects alone account for the divergence of the curves. Also indicated is the locus taken for constant AUW and varying altitude for an ISA+5°C atmosphere. A rapidly increasing power increment is shown as $M_{tip}$ rises with decreasing temperature at higher altitudes.

3. PERFORMANCE PREDICTION PROGRAM - POLAR2

The main deficiency of the earlier program POLAR has been rectified in POLAR2 by the addition of a profile power compressibility factor based on the data of Reference 5. This was fully discussed in Section 2. Before demonstrating its effect on predicted performance, several other improvements which have been included in POLAR2 are discussed below.

3.1 Blade Tip Loss Factor

The blade tip loss factor ($B$) is no longer input, but is now calculated from the expression below:

$$B = 1 - \sqrt{\frac{2C_{T/o}}{b}}$$

3.2 Lock Number

The Lock number at sea-level, ISA conditions ($S'_{ISA}$) is now input and the program calculates the Lock number for the given atmospheric condition ($r$) from the expression below:
\[ i = \text{SL, ISA} \left( \frac{- \rho}{p_{\text{SL, ISA}}} \right) \]

3.3 Atmospheric Conditions

As described in Reference 4, atmospheric conditions were found from the program 'ATMOS', the relevant density being then input to POLAR. The program POLAR2 now includes 'ATMOS' as a subroutine to calculate density and the speed of sound for the given conditions and for a variety of Standard Atmospheres.

3.4 Stall Power

Previously, when using POLAR, the stall power was calculated by hand as described in Reference 4. Program POLAR2 now calculates stall power using the following expression

\[ P_{\text{stall}} = P_o \left( \frac{\alpha(1,270)}{4^\circ} \right)^{12^\circ} \]

for \(12^\circ < \alpha(1,270) < 16^\circ\)

3.5 Induced Velocity Factor

The effect of non-uniform inflow is to increase the induced power above the value given by momentum theory for uniform inflow. This effect is usually accounted for by applying an induced velocity factor, \(k_{\text{ind}}\), to the momentum value of induced velocity.

The program POLAR2 has provision to input an appropriate value pertaining to hover conditions, \(k_h\). For the range of forward flight \(k_{\text{ind}}\) is calculated by POLAR2 from the relation
\[ k_{\text{ind}} = 1 - \frac{k_h - 1}{0.14} (\mu - 0.14) \]

and

\[ k_{\text{ind}} = 1.0 \text{ for } \mu \geq 0.14 \]

Reference 5 (p31) presents curves derived from vortex theory which show the dependence of \( k_{\text{ind}} \) on thrust coefficient, number of blades and blade twist. For the UH-1H case a value of 1.10 would be applicable which is considerably lower than the value of 1.22 found to be necessary to give agreement with flight results. However this \( k_{\text{ind}} \) value of 1.22 also includes the influence of downwash impinging on the aircraft fuselage. Flemming and Erikson (6) have shown for the RSRA, where direct measurement of thrust is possible, that the downwash is approximately \( \frac{3}{4} \) of the AUW when OGE. They also showed that, for the IGE case as the aircraft approaches the ground, the downwash decreases and eventually becomes an upload. In the absence of any data on the down loads for the UH-1H these effects will be absorbed in the induced velocity factor. If, on the other hand, downloads were separately accounted for by increasing the effective AUW, a value of about 1.16 for \( k_{\text{ind}} \) would be appropriate.

Whilst POLAR2 has no facility for inputting the download as a percentage of AUW, if required the AUW can be suitably adjusted and input in the normal manner, provided \( k_{\text{ind}} \) is adjusted.

3.6 Tail Rotor, Transmission and Accessories

An estimate of the percentage power absorbed by the combination tail rotor, transmission and accessories is now input to POLAR2 so that the helicopter total power is now output. Alternatively for the special case of a hovering helicopter the tail rotor may be treated also as a separate rotor of sufficient thrust (AUW) to provide the necessary anti-torque moment. This assumes that there is no main rotor - tail rotor - fuselage interactions which in certain cases may give rise to large side-forces on the tail boom (Reference 8). Program POLAR2 first calculates the power required by the main rotor, \( P_{\text{MR}} \). The main rotor torque is given by
\[ Q_{MR} = p_{MR}/\alpha \]

The distance between the main rotor and tail rotor hubs, \( l_{TR} \), is input so that the anti-torque thrust can be calculated from

\[ (T_{TR}')_{NET} = Q_{MR}/l_{TR} \]

The tail rotor thrust will be greater than the anti-torque thrust because of the deleterious influence of the tail fin. Reference 5 gives a fin blockage factor \( (F_{blk}) \), dependent on tail assembly geometry and configuration, which is input to POLAR2 to calculate tail rotor thrust

\[ T_{TR} = F_{blk}(T_{TR}')_{NET} \]

The tail rotor power is then calculated by POLAR2, treating it as a separate rotor supporting an all-up weight of \( T_{TR} \).

Finally in the hover case, additional factors must be allowed for auxiliary power losses arising from transmissions and accessories. Reference 5 suggests values of 2% for each, giving a combined 4% for auxiliary power losses.

An example of running POLAR2 on the new ELXSI 6400 computer at ARL is given in the Appendix.

4. RESULTS

4.1 Comparison of POLAR2 with ARDU flight data in hover

4.1.1 OGE Case

Using POLAR2, the agreement between flight data and predicted values shown in Figure 5 is seen to be very good. Points on this curve represent calculations for the wide range of conditions experienced during flight trials, as shown in Table 2.
### TABLE 2
Atmospheric conditions at various flight test locations (Ref. 1)

<table>
<thead>
<tr>
<th>Location</th>
<th>Start Date</th>
<th>Average Pressure Altitude</th>
<th>Average Ambient Temperature</th>
<th>Average Density Altitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laverton</td>
<td>3 SEP 73</td>
<td>Sea Level</td>
<td>7°C</td>
<td>-1,000 ft</td>
</tr>
<tr>
<td>Lae</td>
<td>4 OCT 73</td>
<td>Sea Level</td>
<td>24°C</td>
<td>1,000 ft</td>
</tr>
<tr>
<td>Mt Hagen</td>
<td>23 OCT 73</td>
<td>5350 ft</td>
<td>16°C</td>
<td>6,800 ft</td>
</tr>
<tr>
<td>Tambul</td>
<td>28 OCT 73</td>
<td>7300 ft</td>
<td>13°C</td>
<td>9,000 ft</td>
</tr>
<tr>
<td>Mt Giluwe</td>
<td>30 OCT 73</td>
<td>10,000 ft</td>
<td>12°C</td>
<td>12,000 ft</td>
</tr>
</tbody>
</table>

The calculated values are also given in Table 3 where the individual contributions to the overall power coefficients are listed. For the worst case compressibility losses represent about 5% of the total power.

### TABLE 3
Estimated power components for various atmospheric conditions

<table>
<thead>
<tr>
<th>All Up Weight (lb)</th>
<th>Atmospheric Conditions</th>
<th>Thrust Coefficient $C_T \times 10^4$</th>
<th>Tip Mach Number $M_T$</th>
<th>$C_P$</th>
<th>$C_P^0$</th>
<th>$C_P^T$</th>
<th>$C_P^{Tr}$</th>
<th>Power Coefficients ($x10^5$)</th>
<th>Total Power HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>7500</td>
<td>Sea Level OAT 24°C</td>
<td>25.7</td>
<td>0.693</td>
<td>0.0</td>
<td>5.9</td>
<td>13.3</td>
<td>1.7</td>
<td>0.3</td>
<td>21.7</td>
</tr>
<tr>
<td>8500</td>
<td>Sea Level OAT 24°C</td>
<td>32.5</td>
<td>0.693</td>
<td>0.0</td>
<td>6.2</td>
<td>16.0</td>
<td>2.0</td>
<td>1.0</td>
<td>25.2</td>
</tr>
<tr>
<td>7500</td>
<td>5350 ft OAT 16°C</td>
<td>34.0</td>
<td>0.708</td>
<td>0.0</td>
<td>6.1</td>
<td>17.1</td>
<td>2.2</td>
<td>1.1</td>
<td>26.7</td>
</tr>
<tr>
<td>9500</td>
<td>Sea Level OAT 24°C</td>
<td>36.3</td>
<td>0.698</td>
<td>0.2</td>
<td>6.5</td>
<td>18.9</td>
<td>2.6</td>
<td>1.2</td>
<td>29.4</td>
</tr>
<tr>
<td>8500</td>
<td>5350 ft OAT 16°C</td>
<td>38.5</td>
<td>0.708</td>
<td>1.0</td>
<td>6.7</td>
<td>20.6</td>
<td>2.9</td>
<td>1.4</td>
<td>32.6</td>
</tr>
<tr>
<td>7500</td>
<td>10000 ft OAT 12°C</td>
<td>40.0</td>
<td>0.713</td>
<td>1.7</td>
<td>6.9</td>
<td>21.8</td>
<td>3.2</td>
<td>1.9</td>
<td>35.0</td>
</tr>
</tbody>
</table>
For a given $C_{t}/u$ the compressibility increment depends only on $M_{tip}$ which, for a constant rotor speed, depends on OAT. It follows then that the plotting of $C_{p}$ vs $C_{T}$ should not be expected to correlate all data. This was illustrated earlier in Figure 4 where it is shown that at low temperatures there is some compressibility loss even at low $C_{T}$, typically at sea level. Thus it would appear that some of the experimental scatter observed in the flight results could arise from a varying presence of compressibility caused by OAT variation.

Increases in the tip Mach number also result directly from operating with a higher rotor speed, as shown in Figure 6. Here the flight data for $N_{2} = 6600$ rpm (rotor rpm = 325) show increasing divergence from corresponding data for $N_{2} = 6400$ as the thrust coefficient is raised. At the same time estimates given by POLAR2 at typical flight conditions suggest that the compressibility increments are slightly higher in this case when compared with the flight data fairing curve for $6600N_{2}$ rpm.

4.1.2. IGE Case

Ground effect is usually explained in terms of the reduction in rotor inflow, $\nu$, caused by the presence of the ground. Hence for a given induced power, $T_{\nu}$, a greater thrust is achieved in ground effect i.e. $(T_{\nu})_{IGE}=(T_{\nu})_{OGE}$. It follows conversely that for a given AUW (thrust) the IGE power is less than the OGE value. In the present calculations, it is assumed that the IGE power, for a given AUW and $Z/R$ (rotor height/rotor radius) may be deduced by calculating the OGE power for a reduced equivalent AUW such that

$$\frac{(AUW)_{IGE}}{(AUW)_{OGE}} = \frac{T_{\nu}}{T_{\nu}} = f(Z/R)$$

where $f(Z/R)$ is a ground effect function.
Taking a value of \( Z/R \) corresponding to hovering at 3\,\text{ft skid height}, comparison of OGE and IGE flight data at the lower thrust coefficients gives a value for \( f(Z/R) = 1.17 \), which agrees with Figures 5-14 of Reference 9. POLAR2 has been run for various atmospheric conditions using the equivalent all up weights for OGE conditions given by

\[(\text{AUW})_{\text{OGE}} = (\text{AUW})_{\text{IGE}}/1.17\]

Using the value of 1.22 for \( k_{\text{in}} \), the results are compared with flight data in Figure 7.

Generally, agreement is good, but at higher values of \( C_T \) when compressibility is present the calculated power tends to be slightly high. This suggests that the calculated compressibility power increment even at the reduced equivalent AUW as described above, is greater than that occurring in the IGE flight condition. This may be explained by referring to Figure 5-10 of Reference 9, where the presence of the ground is shown to reduce the average induced velocity but simultaneously brings about a readjustment of its radial distribution. The inflow is reduced below the mean value towards the centre of the rotor disk but increases above the mean towards the blade tips. Thus in this tip region, the higher-than-otherwise inflow results in smaller angles of attack and hence reduced compressibility (Mach number) effects.

4.2 Out of Ground Effect Hover Margins

To give a further example of the improved capability of POLAR2 we take the case of OGE hover margin prediction. In the practical case the pilot notes the power, i.e. torquemeter* reading in psi, to maintain IGE hover. Reference to a torque margin chart or table gives the extra torque needed for OGE hover, from which the pilot can assess the ability

* Maximum allowable torquemeter reading is transmission limited to a value of 50 psi.
of the aircraft to perform safely such a manoeuvre. One form of presentation has been used in Reference 3 from which a curve applicable to an AUW of 8000 lb has been drawn in Figure 8.

The basis of this curve may be traced via the ARDU flight calculator back to the flight data of References 1 and 2. Thus the torque margins are directly related to the difference in OGE and IGE power coefficients as given by the mean curves of Figures 1a,b. It so happens that the flight data for the higher thrusts were obtained at higher altitude where the OAT averaged ISA+17°C in some cases. In view of the dependence of $C_p$ on temperature (effectively $M_{tip}$) shown earlier in Figure 4, the mean curve of Figure 1a will indicate a lower power at the higher $C_p$ than might be expected under ISA conditions. On the other hand IGE values are comparatively uninfluenced by compressibility effects. Thus OGE hover margins presented in Reference 3 may be unduly optimistic from the pilot's viewpoint.

Therefore in Figure 8 we note that the thrust margins calculated by POLAR2 for ISA conditions are about 1 psi greater at the higher altitudes. Also shown for comparison is the result given by POLAR(4) where the effect of neglecting compressibility is to seriously underestimate the OGE hover margins at high altitude.

5. CONCLUDING REMARKS

1. The effects of compressibility should be recognised as having a significant influence on the hover performance of the UH-1H Iroquois.

2. The inclusion of a compressibility power expression into the program POLAR2, results in good agreement with UH-1H hover flight data over a wide range of operating conditions.

3. In Service use, the OGE hover margins for the UH-1H, are found using the ARDU calculator, which is based on mean curves fitted to data over a wide range of atmospheric conditions. Since the tip Mach number,
and hence compressibility effects are temperature dependent, these margins may not be sufficient when operating at low temperatures, particularly at high altitudes and all up weights.

4. POLAR2 includes the following features which make it more convenient to use:

a. Variables such as tip loss, atmospheric density and Lock number are calculated within the program rather than being separately input. Likewise the stall power correction is now made by the program.

b. For the hover case, tail rotor performance is calculated along with the main rotor rather than being the subject of a repeat run of the program.

5. An empirical value of induced velocity factor has to be chosen to match flight measurements, as current calculation techniques are not sufficiently well developed. Various influences on the appropriate choice have been discussed.
REFERENCES


APPENDIX

An example is given below of running 'POLAR2' on the new ELXSI 6400 computer at ARL, for the case of the UH-1H Iroquois at hover.

The data required are essentially the same as for 'POLAR', but with additional inputs relating to atmospheric conditions, tail-rotor geometry and various loss factors. These include induced velocity factors for both rotors, tail-fin blockage and auxiliaries.

The auxiliary power loss, i.e. transmission and accessories, is assumed to be 4% of the total power required, which is usual practice.

As stated in Section 2, Ref. 5 gives induced velocity factors which are derived from vortex theory, but as far as is known, have not been validated. Since no other information is available, the value of 1.40 suggested by Ref. 5 for the tail-rotor has been taken. Aerofoil profile drag data for a NACA 0015 (Iroquois tail-rotor) have been analyzed and fitted by a quadratic expression whose coefficients are:

\[
\delta_0 = 0.0093, \quad \delta_1 = -0.009, \quad \delta_2 = 0.294.
\]

Because of Reynolds Number effects on the tail-rotor, it is suggested in Ref. 5 that \( \delta_0 \) should be increased by 0.0027. Thus the tail rotor profile drag data are taken to be

\[
\delta_0 = 0.012, \\
\delta_1 = -0.009, \\
\delta_2 = 0.294.
\]
A. INPUT DATA (see Ref. 4 for 'ATMOS' details)

:POLAR2
TITLE (TWO LINES OF UP TO 60 CHARACTERS)
: POLAR2 - Iroquois Hover OGE
: 7500lb at 10000ft, OAT 12C
SET ATMOSPHERIC FLAG, KEYAIR (1,2,3,4,5 OR 6): 3
STATE PRESSURE ALTITUDE (IN FEET): 10000
AIRFIELD REFERENCE TEMPERATURE, TODAY (IN DEG. C): 12
QNH OF THE DAY (IN MILLIBARS): 1013.25
HEIGHT OF THE AIRFIELD REFERENCE POINT, HAHR: 10000
ARE UNITS IN IMPERIAL OR METRIC (I OR M)? I
ALL UP WEIGHT (N OR LB) = 7500
EQUIVALENT FLAT PLATE AREA (M**2 OR FT**2) = 22.5

main rotor data:
ROTOR TIP SPEED (M/S OR FT/S) = 791.7
ROTOR RADIUS (M OR FT) = 24
ROTOR BLADE CHORD (M OR FT) = 1.75
NUMBER OF ROTOR BLADES = 2
2D LIFT CURVE SLOPE (/RAD) = 5.73
INDUCED VELOCITY FACTOR (in hover) = 1.22
BLADE TWIST (DEG) = -10
LOCK NUMBER (ISA, sea level) = 7
DRAG POLAR CO-EFFICIENT (DEL0) = 0.0084
DELTA1 (/RAD) = -0.0102
DELTA2 (/RAD**2) = 0.384
AUXILIARY POWER LOSS (as % of total power) = 4.0
IS RANGE/ENDURANCE REQUIRED? (Y OR N)? N
IS A SPEED-POWER POLAR REQUIRED? (Y OR N)? N
IS HELICOPTER HOVERING (Y OR N)? Y

tail rotor data:
ROTOR TIP SPEED (M/S OR FT/S) = 715.7
ROTOR RADIUS (M OR FT) = 4.25
ROTOR BLADE CHORD (M OR FT) = 0.7
NUMBER OF ROTOR BLADES = 2
2D LIFT CURVE SLOPE (/RAD) = 5.73
INDUCED VELOCITY FACTOR (in hover) = 1.40
BLADE TWIST (DEG) = 0
LOCK NUMBER (ISA, sea level) = 2
DRAG POLAR CO-EFFICIENT (DEL0) = 0.012
DELTA1 (/RAD) = -0.009
DELTA2 (/RAD**2) = 0.294
TAIL ROTOR MOMENT ARM (M OR FT) = 28.79
FIN BLOCKAGE FACTOR = 1.11
B. 'POLAR2' Output

LIST POLAR2.OUT
POLAR2 - Iroquois Hover QGE
7500 lb at 10000 ft, OAT 12C

atmospheric conditions:
ATMOSPHERIC FLAG = 3
AIRFIELD REFERENCE ALTITUDE = 10000.0 ft
PRESSURE ALTITUDE = 10000.0 ft
AIRFIELD REFERENCE TEMPERATURE = 12.0 Celsius
AMBIENT TEMPERATURE = 295.15 Kelvin
QNH = 1013.25 mb
AMBIENT PRESSURE = 1455.33 lbs/ft**2
AIR DENSITY = 0.016519 slug/ft**3
SPEED OF SOUND = 1110.0 ft/s

aircraft data:
ALL UP WEIGHT = 7500.0 lbs
EQUIVALENT FLAT PLATE AREA = 22.5 ft**2
Airspeed = 0.00 knots
AUXILIARY POWER LOSS (as % of total power) = 4.0%

main rotor data:
NUMBER OF ROTOR BLADES = 2.0
ROTOR TIP SPEED = 791.7 ft/s
ROTOR RADIUS = 24.0 ft
ROTOR BLADE CHORD = 1.8 ft
ROTOR BLADE TWIST = -10.0 deg
2D LIFT CURVE SLOPE = 5.73
DRAG POLAR COEFFICIENT (DELTA 0) = .0084
DELTA 1 = .0102 /rad
DELTA 2 = .3840 /rad**2
LOCK NUMBER (ISA, sea level) = 7.0

LOCK NUMBER = 4.86
INDUCED VELOCITY FACTOR (in hover) = 1.22
INDUCED VELOCITY FACTOR = 1.22
ADVancing Tip Loss Factor = .96
ADVANCE RATIO (MU) = .000
INDUCED VELOCITY (NU) = 43.21 ft/s
INFLOW RATIO (LAMBDA) = .0546
FLAT PLATE DRAG = .0 lbs
THRUST = 7500.0 lbs
THRUST COEFFICIENT = .00400
ROTOR SOLIDITY = .0464
COLLECTIVE (THETA 0) = 18.0 Deg
CONING ANGLE (AO) = 3.0 Deg
LATERAL FLAPPING ANGLE (Al) = 0.0 Deg
DISC ANGLE OF ATTACK = 0.0 Deg
RETREATING BLADE TIP ANGLE OF ATTACK = 4.9 Deg
INDUCED POWER = 889.3 Hp
PARASITE POWER = 92.0 Hp
PROFILE POWER = 31.7 Hp
COMPRESSIBILITY POWER = 81.7 Hp
STALL POWER = 0.0 Hp
TOTAL POWER = 823.0 Hp
REQUIRED AVAILABLE SHAFT POWER = 823.0 Hp
CLIMB POWER = 0.0 Hp
RATE OF CLimb = 0.0 ft/min
CLimb ANGLE = 0 Deg

tail rotor data:
TAIL ROTOR MOMENT ARM = 28.79 ft
FIN BLOCKAGE FACTOR = 1.11
NUMBER OF ROTOR BLADES = 2.0
ROTOR TIP SPEED = 215.7 ft/s
ROTOR RADIUS = 4.3 ft
ROTOR BLADE CHORD = .7 ft
ROTOR BLADE TWIST = 0.0 deg
2D LIFT CURVE SLOPE = 5.73 deg
DRAG POLAR COEFFICIENT (DELTA 0) = .0120
DELTA 1 = -.0090 /rad
DELTA 2 = .2940 /rad**2
LOCK NUMBER (ISA, sea level) = 2.0

LOCK NUMBER = 1.39
INDUCED VELOCITY FACTOR (in hover) = 1.40
INDUCED VELOCITY FACTOR = 1.40
TIP LOSS FACTOR = .93
ADVANCING TIP MACH NUMBER = .64
ADVANCE RATIO (MU) = .000
INDUCED VELOCITY (NU) = 74.41 ft/s
INFLOW RATIO (LAMBDA) = -.1040
FLAT PLATE DRAG = .0 lbs
THRUST = 529.5 lbs
THRUST COEFFICIENT = .01103
ROTOR SOLIDITY = 1.049
COLLECTIVE (THETA 0) = 17.4 Deg
CONING ANGLE (a0) = 1.1 Deg
LONGITUDINAL FLAPPING ANGLE (a1) = 0.0 Deg
LATERAL FLAPPING ANGLE (b1) = 0.0 Deg
DISC ANGLE OF ATTACK = 0.0 Deg
RETESTING BLADE TIP ANGLE OF ATTACK = 11.5 Deg
INDUCED POWER = 71.6 Hp
PARASITE POWER = 16.0 Hp
PROFILE POWER = 16.0 Hp
COMPRESSIBILITY POWER = .0 Hp
STALL POWER = .0 Hp
TOTAL POWER = 87.7 Hp
REQUIRED/AVAILABLE SHAFT POWER = 87.7 Hp
CLIMB POWER = .0 Hp
RATE OF CLIMB = 0.0 ft/min
CLIMB ANGLE = 0.0 Deg

TOTAL ROTOR POWER = 910.7 Hp
TOTAL HELICOPTER POWER = 948.6 Hp
TOTAL HELICOPTER POWER COEFFICIENT = 35.27E-05

CPURTIME = .196 seconds
FIG. 13 POWER REQUIRED TO HOVER OUT, K2 = 0.8
(Andes Flight Data Reproduced from Fig. 11)
FIG. 1: POWER REQUIRED TO RISE 100 ft,
AVERAGES OF 14,000 ft.
(After flight data are recorded from Sec. 1)
FIG. 2 - COMPARISON OF FAIRING CURVE FOR THE HULL,
M2 = 0.54, 12° WITH PREDICTIONS OF POLAR WITH
VARYING K12
FIG. 31 COMPRESSIONIBILITY POWER INCREMENT AS A FUNCTION OF THE TIP MACH NUMBER AND \( C_{\infty} \)

(Ref. 2, Ref. 5)
$M_0 = 0.78 - 1.25C_n/\sigma$

$\frac{C_\tau}{\sigma} = 0.25(X)^2$

$\sqrt{\frac{C_\tau}{\sigma} \times 10^2}$

$M(n_{\text{max}} - M_0)$

FIG. 31: EXPRESSIONS USED TO PLOT THE COMPRESSIONABILITY EXPONENTS OF FIG. 30.
FIG. 4 VARIATION OF PREDICTED POWER WITH AIR TEMPERATURE FOR CONSTANT RPM SPEED (N2 = 6400 rpm, 0°C)

\[ \text{Coefficient of thrust} = C_T \times 10^4 \]

\[ \text{Coefficient of power} = C_P \times 10^5 \]

- OAT = 0°C
- 20°C
- 40°C

\[ \text{AUW} = 7500 \text{lb} \]

\[ \text{ISA} + 5°C \text{ atmosphere} \]
FIG. 5 COMPARISON OF FAIRING CURVE (FIG. 1a) WITH POLAR 2 PREDICTIONS, OGE, N2 = 6400 rpm
FIG. 6 EFFECT OF HIGHER TIP SPEED ON GGE POWER LOSS
COMPARISON WITH POLAR 2
FIG. 7 COMPARISON OF FAIRING CURVE (FIG. 11.) WITH POLAR 2 PREDICTIONS, ICE, N₂ = 0.47
FIG. 9 COMPARISON OF OUR BOUND TOORE MARGINS FOUND USING ARDU CALCULATOR (REF. 3) WITH THOSE FOUND USING POLAR AND POLAR2 FOR ISA CONDITIONS. AUN = 3000L.
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HELCIPTER HOVER PERFORMANCE ESTIMATION - COMPARISON WITH UH-1H IROQUOIS FLIGHT DATA

Abstract

The hover performance of the UH-1H Iroquois has been estimated under a variety of operational conditions using POLAR2, a program based on blade element theory. This program is an improved version of POLAR, a program previously developed at ARL, which did not allow for compressibility effects. The occurrence of these effects in a hovering situation is discussed, and a relationship allowing for such effects has been derived and included in POLAR2. Other improvements, designed to make the program more convenient to use include the calculation of tail rotor performance together with variables such as tip loss, air density and Lock number which were previously input. The role of the induced velocity factor is also discussed. Finally, comparisons of estimates using POLAR2 and ARDU flight trials data for the UH-1H are presented.
This paper is to be used to record information which is required by the Establishment for its own use but which will not be added to the DISIS database unless specifically requested.

### Abstract (cont'd)

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<tr>
<td>Aerodynamics Technical Memorandum 377</td>
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### Computer Programs Used

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### Establishment File Ref(s)

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