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PARAMETRIC STUDY OF THE INFLUENCE OF THE ENGINE UPON THE OPERATING COST OF A CIVIL HELICOPTER

Gilbert BEZIAC
Jean-Pierre DEDIEU
Philippe CABRIT

Société Nationale Industrielle Aérospatiale

Helicopter Division

Marignane, France

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Garmisch-Partenkirchen
Federal Republic of Germany

DEUTSCHE GESELLSCHAFT FUER LUFT- UND RAUMFAHRT e.V.
GOETHESTR, 10, D-5000 KOELN 51, F.R.G.

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ABSTRACT

This study states the influence of engine characteristics (weight, fuel consumption, price, power range) upon the helicopter operating cost.

After having defined the parametric relationship between the various factors, we compare several engine alternatives for a medium weight helicopter.

A sufficient power reserve is necessary but too high a value is not profitable. The fuel consumption should be the result of a compromise : interest of a low value, engine complexity, reliability. A substantial increase in helicopter cost effectiveness is obtained thanks to a simultaneous evolution of aircraft and engine.

1– INTRODUCTION

The purpose of this presentation is to determine the effects of engine characteristics (weight, fuel consumption, power range, price, complexity, evolution capability) on the operating cost of a civil helicopter.

After a theoretical approach aiming at determining the parametric relationship between the different factors we make a practical application on a civil helicopter like the Dauphin 2 - 365 N using different engines.

2– THEORETICAL APPROACH

2.1 – Engine selection parameters (Fig. 1)

The most important parameter is generally the power range which is necessary for obtaining the desired helicopter performance level. Subsequently it is necessary to determine the optimum fuel consumption. In most cases the reduction in fuel consumption results in an increasingly complex design (multiplication of the number of compressor or turbine stages, variable geometry) with the following penalties as regards weight, price, maintenance cost and reliability.

– POWER LEVELS AT VARIOUS RATINGS	
– SPECIFIC FUEL CONSUMPTION	EFFECT ON THE
– WEIGHT	HELICOPTER PROJECT
– PRICE	
– RELIABILITY – MAINTAINABILITY	
– INSTALLATION PROBLEMS	
– PROGRAM COMPATIBILITY (LEAD TIMES - PRODUCTION RATES)	

Fig. 1 : ENGINE SELECTION PARAMETERS.

The specific fuel consumption and the engine weight can have a direct effect on the helicopter project (size, gross weight).

2.2 – Helicopter operating cost (Fig. 2)

The helicopter operating cost, or Total Operating Cost (T.O.C.), includes the following factors.

- Airframe and engine depreciation
- Fixed assets (airframe, engines)
- Insurance (airframe, engines)
- Crew expenses
- Maintenance (airframe, engines)
- Fuel.

$$T.O.C. = A_0 . P_a + A_1 + B . P_m + \frac{C . P_m}{T.B.O.} + W . P_C . C_S$$

T.O.C.	TOTAL OPERATING COST
$A_0 P_a$	AIRFRAME COST : DEPRECIATION, FIXED ASSETS, INSURANCE, MAINTENANCE
P_a	AIRFRAME PRICE
A_1	CREW EXPENSES
$B . P_m$	ENGINE COST : DEPRECIATION, FIXED ASSETS, INSURANCE
P_m	ENGINE PRICE
$\frac{C . P_m}{T.B.O.}$	ENGINE MAINTENANCE
T.B.O.	TIME BETWEEN OVERHAUL
$W . P_C . C_S$	FUEL COST
W	CRUISE POWER
P_C	FUEL PRICE
C_S	SPECIFIC FUEL CONSUMPTION AT CRUISE POWER

Fig. 2 : OPERATING COST PER FLYING HOUR

In order to have a precise idea of the helicopter cost effectiveness, it is necessary to take into account the payload which depends on the fuel quantity necessary for the flight.

The various factors which determine the payload are :

- the helicopter gross weight at take-off
- the weight of airframe with crew (without engines)
- the weight of engines
- the weight of fuel.

We will calculate the payload cost per distance unit :

P_K = kg . km cost (Fig. 3)

We will use those values to compare several engines on a given mission.

For an easier comparison between the different engines, we take one engine as a reference. The T.O.C. and payload cost are expressed relatively to that reference engine. For a same gross weight, no allowance is made for the effect of different end-of-mission weights on the cruising speed with a given power : *on the Dauphin 2, a 100 kg weight increase only* reduces the cruise speed by . 3 %.

PAYLOAD

$$Cp = M - m - m_1 - W . C_S . t$$

M HELICOPTER GROSS WEIGHT

m AIRFRAME EMPTY WEIGHT (WITHOUT ENGINES)

m_1 ENGINE WEIGHT

$W . C_S . t$ FUEL WEIGHT

t MISSION TIME

COST OF PAYLOAD

$$P_K = \frac{T.O.C.}{C_p . V}$$

V *HELICOPTER AVERAGE SPEED*

Fig. 3 : PAYLOAD – COST OF PAYLOAD

3– APPLICATION TO A MEDIUM WEIGHT HELICOPTER (4 tons)

3.1 – Helicopter

This analysis is based on Dauphin 2 - SA 365 N data. The empty weight includes provisions for IFR equipment, equipment necessary for flight over water (off-shore missions) or comfortable seats and improved cabin sound proofing (corporate mission).

3.2 – Mission

The helicopter is most efficient on flights over a distance between 50 and 400 km (speed, interest of vertical take-off possibility). At the Dauphin Cruise speed * this corresponds to a flight time between 30 min. and 1 hour 45 min. with a 20 minute reserve.

3.3 – Data for estimating T.O.C. per flying hour

Annual flying time	1,000 hours
Helicopter utilization time	10 years
Residual value (after 10 years)	20 % of new value
Financial cost	10 %/year
Insurance	5 % of new value
Crew	1 pilot

* 280 km/h

3.4 – Influence factors (Fig. 4)

With a same helicopter gross weight, we can observe the effect of a *10 % variation of the following engine parameters* : price, weight, fuel consumption. The engine weight has a significant effect on the payload cost (P_K). The fuel consumption exerts the largest influence because it has an effect on the total operating cost and on the payload ; its influence on the payload cost increases with the flight time. These influence factors make it possible to evaluate quickly the interest of having an engine evolution.

The effect on the T.B.O. is also considered. In this case the T.O.C. does decrease if the T.B.O. actually increases and corresponds to an increased engine reliability. It would then be wise to use the M.T.B.R. (Mean Time Between Removal) instead of the T.B.O. This influence factor shows that a 50 % increase of the T.B.O. is equivalent to a 10 % reduction of the engine price : this confirms the interest of a T.B.O. and reliability increase for a given engine.

FLYING TIME		1 HOUR		2 HOURS
ENGINE PRICE	+ 10 %	T.O.C.	+ 1.8 %	+ 1.8 %
ENGINE WEIGHT	– 10 %	T.O.C. Cp P_K	0 % + 2.3 % – 2.3 %	0 % + 3 % – 3 %
FUEL CONSUMPTION	– 10 %	T.O.C. Cp P_K	– 1.7 % + 2.5 % – 4.1 %	– 1.7 % + 6.7 % – 7.9 %
T.B.O.	+ 100 %	T.O.C.	– 3.9 %	– 3.9 %

Fig. 4 : INFLUENCE FACTORS

3.5 – Engine alternatives (Fig. 5)

The basic engine has a simple design that gives it a satisfactory specific fuel consumption for a 850 hp-class engine of the 80ies. Basic engine A has a large potential thermodynamic evolution. The main steps in the evolution of engine A are engines B and C.

- B features an increase in the turbine inlet temperature through the cooling of the high pressure turbine.
- C has a new axial compressor design which gives a higher pressure ratio and also a new power turbine with two stages.

This evolution leads to an increase in engine power. Engine A_1 has the same take-off power as engine A but the thermodynamic characteristics and its technology are the same as for engine C (higher pressure ratio, 2-stage power turbine). It is a new engine which cannot be derived from engine A.

For the purpose of this comparison all engines are considered to have the same T.B.O.

CALCULATION OF MEAN PAYLOAD COST
FOR VARIOUS UTILIZATIONS

FLIGHT DISTANCE (km)	OPERATOR ①	OPERATOR ②
50	25 %	10 %
100	30 %	10 %
200	25 %	25 %
300	10 %	30 %
400	10 %	25 %

% OF TOTAL FLIGHTS PERFORMED

MEAN PAYLOAD COST :

ENGINE A_1 VERSUS ENGINE A	①	②
BASIC FUEL COST	+ 0.8 %	+ 0.4 %
DOUBLED FUEL COST	− 0.2 %	− 0.6 %

Fig. 8 : COMPARISON OF ENGINES A AND A_1

3.6.2 — Gross weight evolution

The availability of an increased power will authorize a higher helicopter gross weight. Now we adapt the gross weight to the power of the various engines. Let us make the following assumptions :

- The power reserve * is constant for all engine-aircraft combinations
- The difference in empty weight is 50 % of the gross weight increase
- The airframe price (Pa) is proportional to the empty weight
- The cruise power is calculated at the same speed but with the new gross weight ; this requires a small increase in the power necessary, to allow for the gross weight increase.

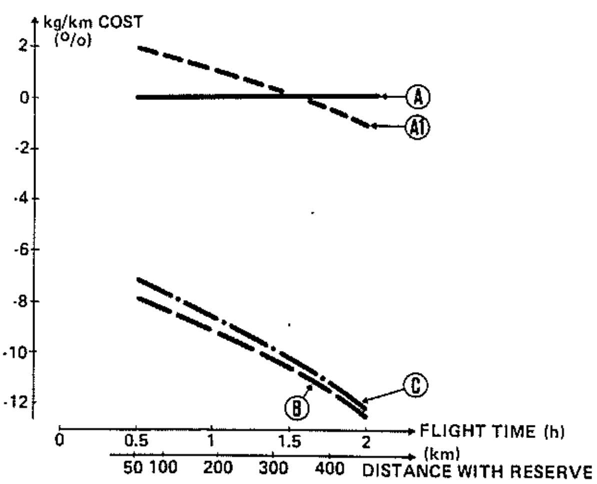

*Fig. 9 : PAYLOAD COST
GROSS WEIGHT EVOLUTION WITH
CONSTANT POWER RESERVE*

Now the kg / km cost results are very interesting for engines B and C (Fig. 9).The helicopter cost effectiveness increases substantially : 8 to 12 % according to the flight time.

This result shows the interest of developing the aircraft together with the engine : the engine must have a certain evolution potential.

4– CONCLUSION

The influence factors derived from the parametric study allow to evaluate the effects of engine parameters on the helicopter operating cost. On the basis of their application on the Dauphin 2 we can conclude as follows :

- a sufficient power reserve is necessary but too high a value penalizes the civil helicopter operating cost. This confirms the interest of having available a super emergency rating on civil helicopter engines.
- a low fuel consumption is of obvious interest but should be the result of a compromise with the level of complexity since a high complexity increases the engine cost and can reduce reliability.
- a substantial increase in helicopter cost effectiveness is obtained thanks to a simultaneous evolution of aircraft and engine. This shows the interest of designing an engine with a certain evolution potential that enables it to follow the normal evolution of the aircraft.

$$\text{* Power reserve} = \frac{\text{Power necessary for OGE hover}}{\text{2-Engine take-off power}}$$

(for twin-engine helicopters)

ENGINE	CONFIGURATION	Δ - PRICE	Δ - TAKE-OFF POWER	Δ - FUEL CONSUMPTION (420 kW)	Δ - WEIGHT	REMARKS
A	2A + 1C 1 H.P.T. + 1 P.T.	REF.	REF. (625 kW)	REF.	REF.	REFERENCE ENGINE
B	2A + 1C 1 H.P.T. (C) + 1 P.T.	+ 5 %	+ 22 %	+ 1.5 %	0 %	TURBINE INLET TEMPERATURE INCREASE (H.P. TURBINE COOLING)
C	2A + 1C 1 H.P.T. (C) + 2 P.T.	+ 17 %	+ 34 %	+ 3.6 %	+ 12.5 %	- NEW AXIAL COMPRESSOR DESIGN - 2-STAGE POWER TURBINE
A_1	2A + 1C 1 H.P.T. (C) + 2 P.T.	+ 15 %	0 %	− 6.5 %	+ 5 %	- REFERENCE ENGINE POWER - TECHNOLOGY OF ENGINE C

A AXIAL COMPRESSOR
C CENTRIFUGAL COMPRESSOR
H.P.T. HIGH-PRESSURE TURBINE
P.T. POWER TURBINE
C COOLING (HIGH PRESSURE TURBINE)

Fig. 5 : ALTERNATIVES

3.6 — Comparison of engines

3.6.1 — Constant gross weight

We first compare the various engines from the Total Operating Cost point of view. (Fig. 6). The fuel cost has no significant effect on the relative position of each engine.

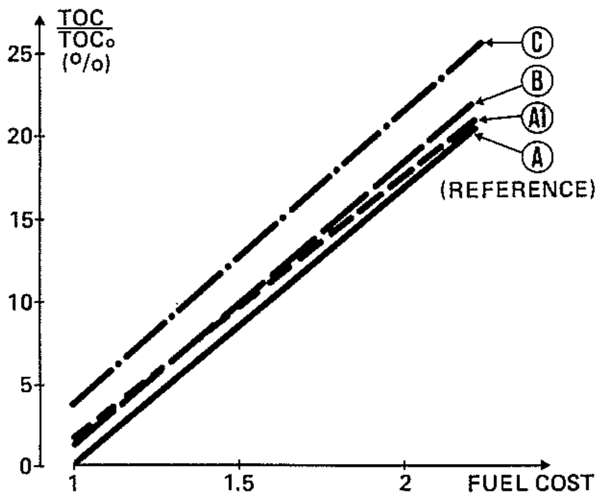

Fig. 6 : TOTAL OPERATING COST VERSUS FUEL COST

The comparison of the payload costs shows that too high a power reserve is penalizing as regards the operating cost (Fig. 7). For a civil application, the power level must be sufficient to give good category A take-off performance to the helicopter but an excessive power increases the cost and is superfluous. This example shows the interest of having available a super-emergency power rating on a civil helicopter : the use of this rating requires the engine overhaul.

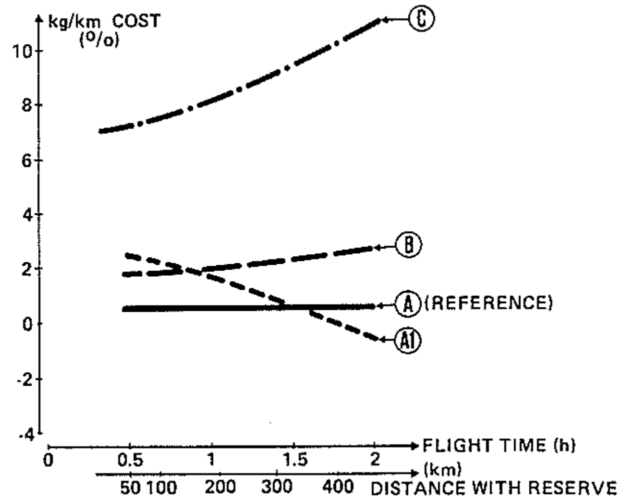

Fig. 7 : PAYLOAD COST CONSTANT GROSS WEIGHT

This possibility allows to design a smaller engine for a same helicopter performance. Now the engine design would not be contingent anymore on a low-occurrency flight configuration : engine failure during take-off.

Obviously a low specific fuel consumption allows to increase the payload but the payload cost data shows that it is not always the best solution (see engines Aand A_1). In order to complete the comparison between the two engines, we consider two operators : one needs his helicopter essentially for short distances, the other for longer distances and we calculate the mean payload cost for each operator (Fig. 8). The payload cost difference rests with the fuel cost but it is not significant — less than 1 % — and the two engines can be considered equivalent.