# NEW METHOD FOR THE PRESIZING OF HEAVY LIFT CIVIL TRANSPORT HELICOPTERS.

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## Abstract

In this work, a new method based on an iterative and multi-level process is used for presizing of heavy lift helicopters having a capacity of 90 passengers over a range of at least 1000Km. This method is based on an iterative and multi-level process. It allows to define in broad outlines several dimensioning characterized by a series of parameters, starting from mission specification and helicopter characteristics in the form of modeling. The models used in this study, are based on a combination of statistical and physical laws. Some components of the heavy lift helicopter configuration are similar to those of an airplane. Thus, for this reason, the statistical laws of weight relative to a transport plane are applied to these organs.

The results obtained were compared with the values obtained by the NASA NDARC tool for the same helicopter configuration. The difference of the parameters does not exceed 8%, giving an average relative difference of 4%.

## Notation

| | |
|---|---|
| $A$ | Main rotor disk area (m$^2$) |
| $b$ | Number of blades of the main rotor |
| $CI$ | Construction index |
| $C_{xp0}$ | Mean airfoil drag coefficient |
| $C_{zm}$ | Blade mean lift coefficient |
| $DL$ | Disk loading (Kg/m$^2$) |
| $D$ | Main rotor diameter (m) |
| $k$ | Downforce factor |
| $K_{pns}$ | Overpower coefficient |
| $C$ | Main rotor blade chord (m) |
| $L_{fus}$ | Fuselage length (m) |
| $N_{equi}$ | Number of crew members |
| $N_{eng}$ | Number of engines |
| $N_{pas}$ | Number of passengers |
| $P_{avail}$ | Available power (kW) |
| $Pins$ | Installed engines power (kW) |
| $R$ | Main rotor radius (m) |
| $Sfc$ | Specific fuel consumption (Kg.kW$^{-1}$.hr$^{-1}$) |
| $T_{miss}$ | Mission time (h) |
| $U$ | Main rotor tip speed (m/s) |
| $W$ | Helicopter gross weight (Kg) |
| $W_{blade}$ | Blades weight (Kg) |
| $W_{empty}$ | Helicopter empty weight (Kg) |
| $W_{eng}$ | Engines weight (Kg) |
| $W_{equi}$ | Equipment weight (Kg) |
| $W_{fc}$ | Flight controls weight (Kg) |
| $W_{fs}$ | Fuel system weight (Kg) |
| $W_{fuel}$ | Fuel weight (Kg) |
| $W_{fus}$ | Fuselage weight (Kg) |
| $W_{habi}$ | Habitability's weight (Kg) |
| $W_{hub}$ | Rotor hub weight (Kg) |
| $W_{lg}$ | Landing gear weight (Kg) |
| $W_{pay}$ | Payload (Kg) |
| $W_{tran}$ | Transmission weight (Kg) |
| $Z$ | Altitude (m) |
| $\rho$ | Air density (kg/m3) |
| $\Omega$ | Main rotor rotational speed (rad/s) |
| $\sigma$ | Solidity |

## 1. INTRODUCTION

Conceptual and presizing studies on rotorcraft are problems that attract significant interest from academic and governmental researchers. Indeed, the development of civil aircraft and the increase of market needs are factors that incite the production of tools intended for presizing. However, rotorcraft design is a more difficult task than aircraft design. The more complex the tools are, the more demanding they are in terms of the costs of computation time. Moreover, the complexity of these tools is not a real guarantee of the validity of the results.

Currently, the United States and Europe are very active in this field. Studies on the conventional design of the heavy lift helicopter have been developed by the American and French aerospace agencies, NASA and ONERA, which have their own rotorcraft design software tools NDARC [1] and C.R.E.A.T.I.O.N. [2] [3] respectively. NDARC for "NASA Design and Analysis of Rotorcraft" is the most advanced computer tool in the world for the sizing, design and evaluation of rotorcraft. C.R.E.A.T.I.O.N. for "Concepts of Rotorcraft Enhanced Assessment Through Integrated Optimization Network" is a digital platform designed for the presizing as well as for the rotorcraft performance evaluation.

The study conducted by NDARC on a helicopter with the capacity to carry 90 passengers over 1000Km is designated as H90. The one of C.R.E.A.T.I.O.N. study is designated HO90. It is a heavy lift helicopter with a fuselage similar to that of an airplane, equipped with a both horizontal and vertical stabilizer and a landing gear. Propulsion and lift are controlled by a 7- blade rotor. The dimensioning of the H90 is achieved through an iterative and multi-level process leading to the various characteristics of the aircraft.

A collaboration in the framework of the French-American project agreement on rotorcraft studies has been started since 2011 on rotorcraft design methodologies. In this framework, the pre-dimensioning concerned the transport mission defined for the H90 helicopter [3]. The NDARC model underwent some modifications in particular on the propulsion and on the weight groups (application of the technology factor of 0.79) [3]. The results obtained by the NDARC and CREATION tools following these modifications are in very good agreement.

In the current work, we are interested in the presizing of heavy lift helicopters by a method based on an iterative and multi-level process. This method allows to define in broad outlines several dimensioning characterized by a series of parameters, starting from mission specification (mission time, altitude, capacity) and characteristics of the helicopter in the form of modeling: mass modeling, aerodynamic modeling (rotor and fuselage) and engine modeling (power and consumption). The proposed method will be validated, first, by presizing tests on various existing aircraft.

We then compare the results of the present model with those obtained by NDARC applied to a conventional heavy lift helicopter without taking into account the technology factor 0.79 presented in [3].

## 2. DESCRIPTION OF THE SUPPORT TOOL FOR HELICOPTERS PRESIZING

### 2.1. The Approach

The method of the preliminary design that we are going to use allows outlining several dimensions of the preliminary design, characterized by a series of parameters, starting from mission specification (time of the mission, altitude, capacity) and characteristics of the helicopter in the form of modeling (modeling of the weights, of the rotor, of the engine power). The parameters characterizing the various dimensions of the preliminary design are the parameters of definition related to the characteristics of the rotor, installed power, and weight estimation of the helicopter. To begin with, it is necessary to fix certain parameters in order to be able to calculate the other parameters by checking the design specifications. In addition to that, we need to input the parameters that characterize the design mission specifications such as number of crew members, number of passengers, mission time, and flight altitude.

The inputs to the presizing stage of the preliminary design are considered as follows : five parameters have been set: (1) DL, (2) $\sigma$, (3) b, (4) U, (5) Kpns. Moreover, the parameters that characterize the design mission specifications have been filled in: (1) Neng, (2) Nequi, (3) Npas, (4) Tmiss, (5) Z.

The outputs to the presizing stage of the preliminary design are as follows : (1) W, (2)

$W_{empty}$, (3) $W_{pay}$, (4) $W_{fuel}$, (5) D, (6) C, (7) $C_{zm}$, (8) $P_{ins}$.

The problem is solved through iteration on the total weight $W$, by performing the following steps:

0) The inputs listed above are fixed,
1) Initialize the total weight $W$ to a reasonable value of $2 \times W_{pay}$,
2) Find the outputs that are listed below using the equations that relate the different parameters,
3) Check whether the determined value of $W$ is equal to its initial value. If they are different: start again at step 2 with the new value of $W$ until convergence.

At the convergence, we, therefore, obtain the set of definition parameters representing a preliminary design of the helicopter.

We have drawn in figure 1 the flowchart that summarizes the steps that lead to obtaining the parameters we are seeking in the presizing phase using our method.

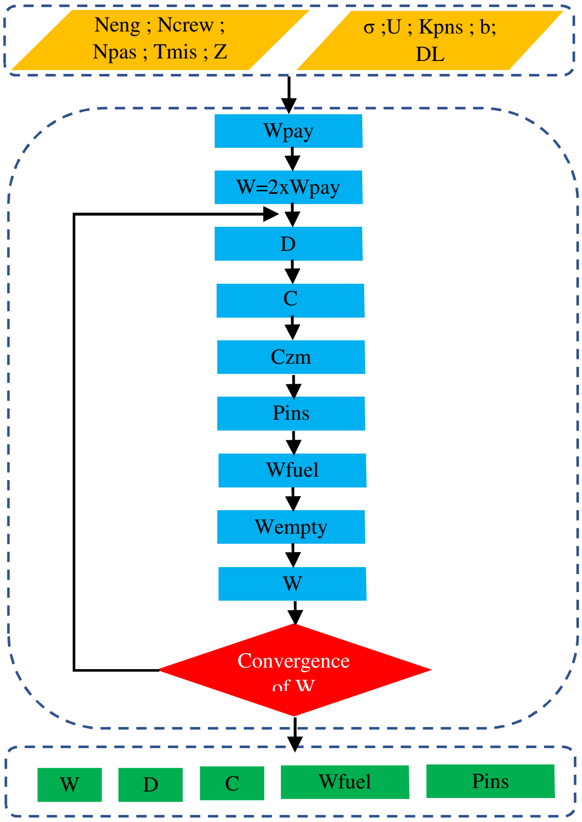

**Figure 1:** Iterative design process

## 2.2. Modeling

### 2.2.1. Empty Weight

The empty weight is evaluated by means of statistical relations established on the basis of existing devices for which the gross weight and its main parameters are known [4][5]. The empty weight is divided into ten main items (see Figure 2) whose formulations are established on the basis of the ten parameters mentioned above.

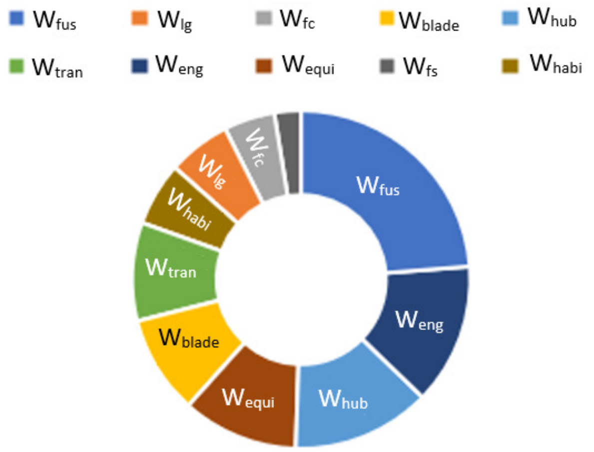

**Figure 2:** Empty weight breakdown

The empty mass can be written as :

$$(1) \quad W_{empty} = \sum_{i=1}^{10} Weight\ of\ Item\ i$$

With :

**Item 1** : Fuselage, Tail boom, Stabilizers
$W_{fus}$ estimated at 13% of the total weight

**Item 2** : Landing gear
$W_{lg}$ 1,4% of the gross weight for landing gear with skids;
2,2% of the gross weight for fixed wheels landing gear;
2,9% of the gross weight for retractable wheels landing gear

**Item 3** : Flight controls, Swashplate

$$(2) \quad W_{fc} = 0{,}044.M^{0{,}94}$$

**Item 4** : Main rotor blades, Tail rotor blades

$$(3) \quad W_{blade} = 1{,}05 \times 20 \times \sigma \pi R^2$$

20 represents the mass per unit area of the blade

**Item 5** : Rotor hub

$$(4)\quad W_{hub} = 22{,}47\left(W_{blade}U^2k_{pns}Pins.R^{0{,}82}b^{1{,}5}.2{,}58.10^{-12}\right)^{0.36}$$

**Item 6** : Main gearbox (MGB), Tail rotor gearbox (TGB) and intermediate gearbox (IGB), Transmission system, Oil
It depends on the output torque:

$$(5)\quad W_{tran} = 0.04\left(k_{MGB}Pins\frac{R}{U}\right)^{0.84}$$

$k_{MGB}$ : MGB limitation factor ≈ $0{,}8$

**Item 7** : Engines

Depends on its power:

$$(6)\quad W_{eng} = \left(\frac{Pins}{N_{eng}} \times \frac{1}{736}\right)^{0.75} \times N_{eng}$$

**Item 8** : equipment : Hydraulic, Electrical, Standard

$$(7)\quad W_{equi} = 0{,}0276.W + 139{,}89$$

**Item 9** : Fuel system, Fuel tanks
$W_{fs}$ It is estimated at 5% of total fuel weight

**Item 10** : Crew seats, Passenger seats, Habitability, Others: toilets, fire extinguishers.

$$(8)\quad W_{habi} = 12 \times \left(N_{pas} + N_{equi}\right) + 0{,}3.D^{1{,}86}$$

### 2.2.2. Total Weight

The total weight of the aircraft is designed as the sum of the empty weight $W_{empty}$, payload $W_{pay}$, fuel weight $W_{fuel}$ and the weight of mission equipment $W_{mis}$.

$$(9)\quad W = W_{empty} + W_{mis} + W_{pay} + W_{fuel}$$

The payload $W_{pay}$ includes crew, cargo and passengers for a civil aircraft, and ammunition for a military aircraft.

For a civil transport helicopter, we give the following $W_{pay}$ formula:

$$(10)\quad W_{pay} = N_{equi} \times 85 + N_{pas} \times 80$$

To evaluate the technology used for the preliminary design, the construction index is calculated:

$$(11)\quad CI = W_{empty}/M$$

This index is supposed to be around 50% in the preliminary design.[5]

### 2.2.3. Main Rotor Diameter

The disk loading is a function of gross weight and rotor disk area:

$$(12)\quad DL = \frac{W.g}{A}$$

Hence, the rotor diameter will be determined based on the fixed disk loading at the start of the design and the total weight which will change with each iteration of the weight loop until the total weight converges. The diameter equation is as follows:

$$(13)\quad D = 2\sqrt{\frac{W}{\pi.DL}}$$

### 2.2.4. Chord of the Main Rotor Blade

The mean chord is determined based on the selection of the solidity $\sigma$, the number of blades $b$ and the calculated diameter. We obtain the following equation:

$$(14)\quad C = \frac{\pi D\sigma}{2b}$$

### 2.2.5. Required power

The required power from the main rotor is determined based on the blade element theory for blades with an ideal twist, a constant chord and a mean airfoil drag coefficient $C_{xp0}$:

$$(15)\quad P = \frac{{F_N}^{3/2}}{\sqrt{2\rho A}} + \frac{\rho}{8}A\sigma C_{xp0}U^3$$

While hovering, the lift force $F_N$ is expressed as the product of the total weight of the helicopter and the downforce factor $k = 1.05$ (downforce = 5%):

$$(16)\quad F_N = k.M.g$$

To take into account the blade tip losses and the induced quality of the rotor, the induced power is divided by $\eta_i$. It is set to 0,85.

Therefore, the power from the main rotor while hovering is expressed as:

$$(17)\quad P = \frac{1}{\eta_i}\frac{{F_N}^{3/2}}{\sqrt{2\rho A}} + \frac{\rho}{8}A\sigma C_{xp0}U^3$$

We calculate the total required power by adding the required power from the anti-torque rotor supposed equal to 15% of the required power from the main rotor. Therefore, the required power in hovering flight is expressed:

$$(18)\quad P_{nec_{stat}} = 1{,}15\left(\frac{1}{\eta_i}\frac{{F_N}^{3/2}}{\sqrt{2\rho A}} + \frac{\rho}{8}A\sigma C_{xp0}U^3\right)$$

$C_{xp0}$ is determined from the mean lift coefficient $C_{zm}$ using the relation:

$$(19)\quad C_{xp0} = 0{,}008 + 0{,}009.{C_{zm}}^2$$

This expression remains valid as long as $C_{zm}$ does not exceed 0.9 and the Mach number at the blade tip is lower than the critical Mach number of the profile.

The mean lift coefficient is determined by integrating the elementary lift along the blade:

$$(20)\quad F_N = \frac{b}{2}\rho C_{zm}C\int_0^R(\Omega y)^2dy = \frac{b}{2}\rho C_{zm}C\frac{RU^2}{3}$$

We find $C_{zm}$ equal to:

$$(21)\quad C_{zm} = \frac{6.F_N}{\rho bCRU^2}$$

Hence the result:[2]

$$(22)\quad C_{zm} = \frac{6.F_N}{\rho A\sigma U^2}$$

### 2.2.6. Available power

To take into account the decrease in the power from the engines as a function of temperature $T$ and altitude $Z$, we calculate the power available in hover as follows:[5]

$$(23)\quad P_{avail_{stat}} = Pins \times k_p$$

$$(24)\quad k_p = \left(\frac{p}{p_0}\right)[1 - 0{,}007(T - T_0)]$$

With $p_0$ and $T_0$ are successively the atmospheric pressure and temperature.

And the relations that connect the temperature and the pressure with the altitude $Z$ are:

$$(25)\quad \frac{p}{p_0} = (1 - 22{,}557\ 10^{-6}Z)^{5{,}256}$$

$$(26)\quad T - T_0 = -6{,}5\ 10^{-3}Z$$

By replacing, we obtain:

$$(27)\quad k_p = (1 - 22{,}557.10^{-6}.Z)^{5{,}256}(1 + 0{,}007.6{,}5.10^{-3}.Z)$$

### 2.2.7. Installed power

For our pre-sizing, we will determine the installed power by equalizing powers $P_{nec_{stat}}$ et $P_{avail_{stat}}$ at altitude $Z$ and with overpower coefficient $K_{pns}$:[5]

$$(28)\quad P_{avail_{stat}} = K_{pns}.P_{nec_{stat}}$$

### 2.2.8. Fuel Weight

To estimate the fuel weight, we will follow the recommendation from the book of Prouty [6] and assume a mean specific fuel consumption $Sfc$ equal to $0{,}24\ kg.kW^{-1}hr^{-1}$ for turboshaft engines and therefore the fuel weight is calculated as follows:

$$(29)\quad W_{fuel} = Sfc.P_{avail}.T_{miss}$$

## 3. VALIDATION

After establishing the above design method estimating the definition parameters of a helicopter based on specifications, the method must be validated on existing aircrafts. For this purpose, it is first necessary to know the specifications to be inserted as inputs for each helicopter. The radar diagram values are calculated by dividing the calculated value by the actual value of the parameters. In this way, this value can be compared to the unit to find out the error of the estimation.

Three helicopters were selected to compare the calculated results with the actual specifications. The aircrafts were chosen from different aircraft weight categories.

The first one is the Dauphin AS365N (see **Figure 3**). It is a twin-engine, medium-sized, multi-role, light transport aircraft from the former Eurocopter company and currently Airbus Helicopters. It has a capacity of up to 8 passengers excluding the pilot. We dimensioned it for a 4 hours mission at 1500m altitude. The pre-sizing results (see **Table 2** and **Figure 4**) show that the total weight is underestimated by 10% which is acceptable. For the rest of the parameters, the estimation is good with an error of about 4% and generally the pre-sizing gives acceptable results with a mean error of about 5%.

**Figure 3:** Dauphin AS365N : σ(0.086), b(4), DL(35 kg/m$^2$), U(218,6 m/s), Neng(2), Kpns(1.2).

| Parameter | Estimated SA365N | Real SA365N | Error |
|---|---|---|---|
| W (kg) | 3578 | 4000 | 10,55% |
| Wempty (kg) | 1976 | 2047 | 3,47% |
| D (m) | 11,41 | 11,93 | 4,36% |
| C (m) | 0,385 | 0,405 | 4,94% |
| Pins (kW) | 2 × 512,3 | 2 × 492 | 4,13% |
|  |  | Mean error | 5,49% |

**Table 2:** Presizing results for Dauphin AS365N

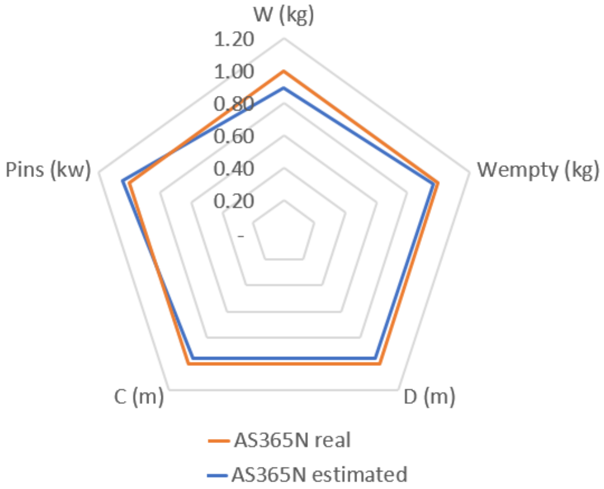

**Figure 4:** Radar diagram comparing estimated and actual specifications

The second aircraft is the H125 (see **Figure 5**), a single-engine multi-purpose light transport helicopter currently produced by Airbus Helicopters. This helicopter carries 5 passengers with the pilot. We dimensioned it for a 4 hours mission and at 3000 m of altitude. The pre-sizing gives satisfactory results (see **Table 3** and **Figure 6**). The total weight is underestimated by 10% which is still acceptable. All other parameters are correctly estimated to be within 5% error. And our pre-sizing estimated the engine power very well with a 1% error. This leaves us with an average estimation error of about 5% for this aircraft.

**Figure 5:** H125 : σ(0.054), b(3), DL(25 kg/m$^2$), U(226,6 m/s), Neng(1), Kpns(1.15).

| Parameter | Estimated H125 | Real H125 | Error |
|---|---|---|---|
| W (kg) | 2023 | 2250 | 10,09% |
| Wempty (kg) | 1122 | 1174 | 4,43% |
| D (m) | 10,15 | 10,69 | 5,05% |
| C (m) | 0,29 | 0,3 | 3,33% |
| Pins (kW) | 552 | 544 | 1,47% |
|  |  | Mean error | 4,87% |

**Table 3:** Presizing results for H125

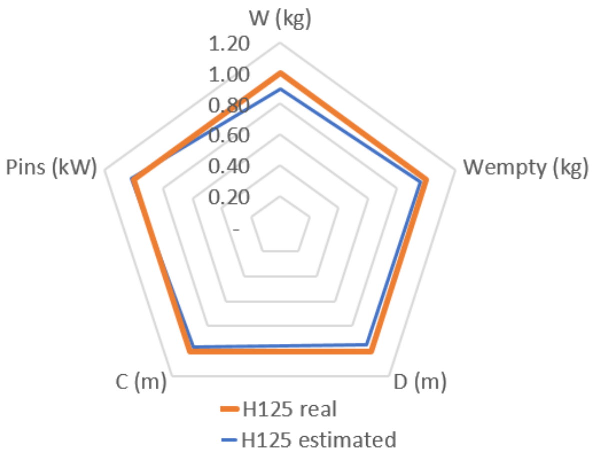

**Figure 6:** Radar diagram comparing estimated and actual specifications

To pave the way toward large capacity helicopters, the third aircraft chosen is a twin-engine heavy civil transport helicopter. The H225 (see **Figure 7**) manufactured by Airbus Helicopters can carry 19 passengers in comfortable seats plus a pilot and co-pilot. We dimensioned it for a 4 hours mission and at 1500 m altitude. The presizing results are presented in **Table 4** and illustrated in **Figure 8**. The diameter and blade chord of the main rotor as well as the power were estimated to be within 10% error. The gross weight and empty weight both are underestimated by about 15% error. Nevertheless, the average error estimated at 10% remains acceptable.

***Figure 7:*** H225 : σ(0.108), b(5), DL(53 kg/m$^2$), U(224,78 m/s), Neng(2), Kpns(1.25).

| Parameter | Estimated H225 | Real H225 | Error |
|---|---|---|---|
| W (kg) | 9269 | 11000 | 15,74% |
| Wempty (kg) | 4805 | 5593 | 14,09% |
| D (m) | 14,9 | 16,2 | 8,02% |
| C (m) | 0,51 | 0,55 | 7,27% |
| Pins (kW) | 2 × 1621 | 2 × 1567 | 3,45% |
|  |  | Mean error | 9,71% |

**Table 4:** Presizing results for H225

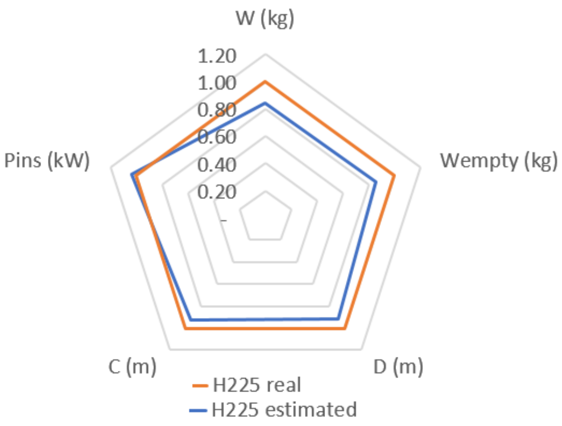

***Figure 8:*** Radar diagram comparing estimated and actual specifications

In summary, our presizing method gave satisfactory results during the validation of the previous helicopters of different sizes and tonnages. Of course, the choices made by the designers for these helicopters affect the real parameters. But globally, the calculated parameters remain in the orders of magnitude of the real parameters. No parameter has exceeded 15% of estimation error. Therefore, the method and the models used in this pre-sizing are valid.

## 4. TEST CASE FOR A NON-EXISTENT HEAVY LIFT HELICOPTER PRESIZING

The NDARC rotorcraft design tool developed by NASA has proposed a concept for a civilian transport helicopter capable of carrying 90 passengers over a flight distance of more than 1,000 km. The objective of this aircraft is to become a competitor to airplanes on short-distance flights. Compared to airplanes, the helicopter has one main disadvantage which is its speed which cannot exceed 375 km/h compared to 800 km/h for airplanes. So, the purpose is to provide a mean of transportation that allows for quick takeoff and landing. Heliports are more practical than airports as they reduce waiting times. Most importantly, helicopters do not need a runway to take off and land.[4]

This helicopter is designed to perform a mission with a capacity of 90 passengers over a distance of 1000 km with an additional fuel reserve. The mission takes into account a possible detour to a new airport 185 km away and an additional fuel reserve for 140 km.[2]

The design of the aircraft called H90 is shown in **Figure 9** and its specifications are given in **Table 5**.

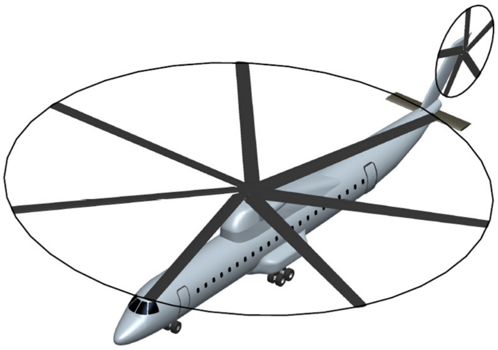

***Figure 9:*** *Illustration of the H90 helicopter design according to NASA*[1]

| Specifications of H90 | |
|---|---|
| Number of blades $\boldsymbol{b}$ | 7 |
| Main rotor diameter $\boldsymbol{D}$ | 29,86 m |
| Solidity $\boldsymbol{\sigma}$ | 0,137 |
| Disk loading $\boldsymbol{DL}$ | 48,82 kg/m$^2$ |
| Main rotor tip speed $\boldsymbol{U}$ | 198 m/s |
| Fuselage length $\boldsymbol{L_{fus}}$ | 33,2 m |
| Fuselage diameter $\boldsymbol{D_{fus}}$ | 3 m |
| Number of engines $\boldsymbol{N_{eng}}$ | 4 |
| Total weight $\boldsymbol{W}$ | 33420 kg |
| Empty weight $\boldsymbol{W_{empty}}$ | 19000 kg |
| Fuel weight $\boldsymbol{W_{fuel}}$ | 5440 kg |
| Installed power $\boldsymbol{P_{ins}}$ | 4 × 2997 kW |

***Table 5:*** *Characteristics of the H90 aircraft as specified by NDARC*

The pre-sizing of this non-existent aircraft was also carried out by our method. We refer to the device designed in this study as HA-90.

## 5. PRESIZING OF HA-90

We start the pre-sizing of HA-90 by determining the different inputs to the tool. First, the aircraft can carry 90 passengers and the number of crew for this type of aircraft is about 5.

$$N_{pas} = 90$$
$$N_{crew} = 5$$

The mission specifications to be taken as inputs for the pre-sizing are the mission time $T_{miss}$ and the altitude $Z$. This helicopter has been sized by NDARC for a cruise flight at 12000 feet corresponding to 3657km. And the mission time is considered as the time needed to cover 1000km for the mission plus 185km for a possible detour to a new airport and 140km of fuel reserve at 300km/h. Hence the mission time is approximately equal to:

$$T_{miss} = \frac{1325}{300} = 4{,}4\ h = 4h\ 24min$$
$$Z = 3657\ m$$

The parameters which are specified by NDARC and which we will adopt as inputs for the pre-sizing are:

$$DL = 48{,}82\ kg/m^2$$
$$U = 198\ m/s$$
$$b = 7$$
$$\sigma = 0{,}137$$

In the illustration of the H90 design in **Figure 9**, we notice that it features a fuselage similar to one of transport airplanes like Boeing 737 with a rotor instead of the wings. However, the statistical formulas of the weight estimate that we adopted for the pre-definition phase are valid for the classical helicopter design with the tail boom. Because of this, we have chosen to use statistical weight formulas for transport aircrafts:

- Fuselage weight $W_{fus}$
- Vertical tail weight $W_{vt}$
- Horizontal tail weight $W_{ht}$
- Main landing gear weight $W_{mlg}$
- Nose landing gear weight $W_{nlg}$

The formulas come from the weight estimates of D. P. Raymer [7] for transport airplanes:

$$(33)\quad W_{fus} = 0{,}45 \times 0{,}328.K_{door}.(2{,}2.W.N_z)^{0{,}5}(3{,}28.L_{fus})^{0{,}25}(3{,}28^2.S_{fus})^{0{,}302}(L_{fus}/D_{fus})^{0{,}1}$$

Where the length and the diameter of the fuselage, successively $L_{fus}$ and $D_{fus}$ are to be determined from the seat map shown in **Figure 10**.

$$L_{fus} = 30{,}5\ m$$
$$D_{fus} = 3\ m$$

$K_{door}$ : equals 1,12 for fuselage with 2 doors.

$S_{fus}$ : Fuselage wetted area.

$N_z$ : ultimate load factor = 1,5 × limit load factor (supposed to be equal 3).

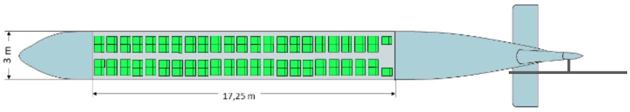

**Figure 10 :** HA-90 seat map (Seat width: 0,5m, Seat pitch: 0,75 m)

$$(30)\quad W_{ht} = 0{,}45 \times 0{,}0379\left(1+\frac{F_w}{B_h}\right)^{-0{,}25}(2{,}2.W)^{0{,}639}{N_z}^{0{,}1}(3{,}28^2 S_{ht})^{0{,}75}.0{,}428.(3{,}28.L_t)^{-0{,}296}{A_h}^{0{,}166}$$

$S_{ht}$ : Horizontal tail area.
$A_h$ : Horizontal tail aspect ratio equals ${B_h}^2/S_{ht}$.
$L_t$ : Distance from main rotor axis to horizontal tail.

The dimensions taken for the horizontal tail are given in **Figure 11**.

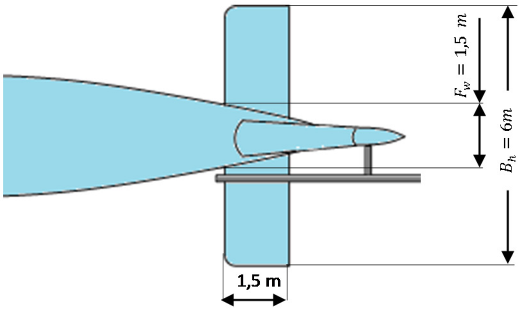

**Figure 11:** Dimensions taken for the horizontal tail

The same goes for the vertical tail:

$$(31)\quad W_{vt} = 0{,}45 \times 0{,}0026(2{,}2.W)^{0{,}556}{N_z}^{0{,}536}(3{,}28.L_t)^{0{,}375}(3{,}28^2 S_{vt})^{0{,}5}$$

$S_{vt}$ : Vertical tail area.

Finally, for the landing gear:

$$(32)\quad W_{mlg} = 0{,}45 \times 0{,}0106(2{,}2.W)^{0{,}888}{N_l}^{0{,}25}(39{,}37.L_m)^{0{,}4}{N_{mw}}^{0{,}321}{N_{mss}}^{-0{,}5}$$

$$(33)\quad W_{nlg} = 0{,}45 \times 0{,}032(2{,}2.W)^{0{,}646}{N_l}^{0{,}2}(39{,}37.L_n)^{0{,}5}{N_{nw}}^{0{,}45}$$

$N_l$ : Ultimate landing load factor = 1,5 × limit landing load factor (supposed to be equal 2).

$L_m$ and $L_n$ : Successively lengths of main and nose landing gear (1m).

$N_{mw}$ and $N_{nw}$ : Successively number of main landing gear wheels (4×2) and nose landing gear wheels (2) (see **Figure 7**).

$N_{mss}$ : Number of main gear shock struts (2).

## 6. Presizing results and confrontation with NDARC

Comparison between the results obtained from the proposed model with the results obtained by H90 in [1],(see Table 6) shows an acceptable agreement. The technology factor 0.79 presented in [7] has not been taken into account. All the parameters are shown on the radar diagram in Figure 12. All values in the diagram are scaled with respect to those of H90.

Aside, from the $W_{fuel}$ fuel weight, the values obtained by this study are extremely close to those obtained by H90. The deviation of the parameters of HA-90 compared to those of H90 does not exceed 8%, giving an average relative deviation of 4%.

HA-90 presents a deviation of approximately 60%, on the fuel weight $W_{fuel}$. An interpretation formulated by Tremolet [2] concerns the quantity of fuel used by H90. It is more optimistic than our evaluations. This goes to the technological factor adopted by NDARC which increases the engine performance compared to the current one. Therefore, the values of the fuel mass of HA-90 seem more realistic. The last parameter we calculated by our method of presizing is the engine power. This one is well estimated at 5% of the difference compared to H90.

| Parameter | **H90** | **HA-90** | **deviation** |
|---|---|---|---|
| W (kg) | 33420 | 35699 | 7% |
| Wempty (kg) | 19000 | 19118 | 1% |
| Wfuel (kg) | 5440 | 8956 | 65% |
| D (m) | 29,86 | 30,5 | 2% |
| C (m) | 0,918 | 0,94 | 2% |
| Lfus (m) | 33,2 | 30,5 | 8% |
| Hfus (m) | 6 | 6 | 0% |
| Pins (kW) | 4 × 2997 | 4 × 2858 | 5% |
| Average relative deviation | | | 4% |

**Table 6:** Design Comparison

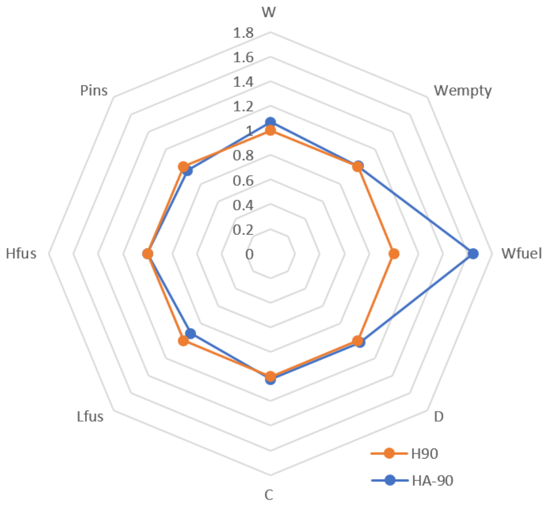

**Figure 12:** Validation of HA90 pre-sizing results

## 7. CONCLUSION

The new presizing method for heavy lift helicopters introduced in this study combines the statistical laws of conventional helicopters and airplanes for the estimation of the different parameters. Analytical laws are also used based on the blade element theory.

The final results are coherent and realistic, and this is despite the use of extrapolation on data composed of existing aircraft in service even knowing that a huge part of them doesn't represent the desired solution. This method can be improved by taking into account the technology factor used in [3]. It can be extended to other heavy lift helicopters designs.

To sum up, this new method provides a fast and rational presizing tool designed for heavy lift helicopters.

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