ASE 446 - INTRODUCTION TO HELICOPTER AERODYNAMICS AND DESIGN

Term Project

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Introduction

This is a civilian air ambulance design project guided by a competitor study. With standard equipment, the vehicle's job is to transport one patient, two paramedics, and a pilot. [1] The operation has been chosen for a specific city. The vehicle's technical specifications are chosen, and the justifications are provided. The design requirements are also shown. There is competitor research in the project's second section. There is a list of many helicopter models that are also utilized as air ambulances. The third part of the project is to apply the blade element theory for the weight estimation of a helicopter as well as the estimation of rotor performance in forward flight. Performance calculations are done with MATLAB. Additional design aspects have also been mentioned in the last part of the project. Rotorcraft configuration and avionics used in the project are explained. Finally, the 2d view and dimensions of the air ambulance are given as a drawing and the design characteristics are tabulated.

Design requirements

The goal of this section is to introduce the vehicle's design requirements and to determine configurations for the civil ambulance helicopter with design requirements.

Table 1.1: Given requirements. [1]

Cruise Speed	230 km/h
Hover ceiling OGE	2500 m ISA
Range	> 500 km
Empty weight fraction	< 0.45
Main rotor tip speed	< 195 m/s
Tail rotor tip speed	< 180 m/s
Cooper Harper rating	≤ 3.5 (Level I Handling Qualities)
Useful payload	1 pilot + 2 paramedics + 1 patient + special equipment

In Table 1.1, minimum design criteria are shown. These values are a guide for the design of the air ambulance, and the design process aims to achieve the highest level of efficiency with the values given.

Table 1.2: Chosen requirements.

City of operation	Cambridgeshire, United Kingdom
Rotorcraft configuration	Conventional
Range	600 km
Cruise speed	250 km/h
Main rotor tip speed	190 m/s
Tail rotor tip speed	175 m/s
Engine type	Simple Turboshaft
Average passenger weight	85 kg
Special equipment weight	75 kg
Crew and passenger capacity	4 person

Table 1.2 shows the chosen characteristics of the civil ambulance helicopter, including the operating city, range, cruising speed, and engine type.

Competitor study

In this part of the project, air ambulances operating in similar environments are compared. Tables 2.1 and 2.2 show general data and performance characteristics for Eurocopter, EC-135, EC-145MD Explorer, AS365 Dauphin, Bell 429 GlobalRanger and AW-169. Throughout the entire design process, these are the main references for comparing parameters.

Table 2.1: General characteristics table of competitor helicopters.

	EC-135 [4]	**EC-145[6]**	**MD Explorer[7]**	**AS365 Dauphin[8]**	**Bell 429 GlobalRanger[9,10]**	**AW-169[11]**
Crew and passenger capacity	c 2, p 4-6	c 2 , p 9	c 1-2, p 6	c 1-2, p 11-12	c 1, p 7	c 1-2, p 8-12
Length	10.2 m	13.03 m	9.86 m	13.73 m	12.70 m	14.65 m
Width	2.65 m	3.20 m	2.85 m	3.25 m	2.67 m	2.53 m
Height	3.51 m	3.45 m	3.66 m	4.06 m	4.04 m	4.50 m
Main rotor diameter	10.2 m	11 m	10.31 m	11.94 m	11 m	12.12 m
Number of blades	4	4	5	4	4	5
Empty weight	1460 kg	1,792 kg	1,531 kg	2,389 kg	1,925 kg	2570 kg
Maximum gross weight	2,835 kg	3,585 kg	2,835 kg	4,300 kg	3,175 kg	4,600 kg
Power plant	2 x SAFRAN ARRIUS 2B2 Plus or Pratt & WhitneyPW206B3	2 × Turbomeca Arriel 1E2 turboshaft	2 × Pratt & Whitney Canada PW206E turboshaft	2 × Turboméca Arriel 2C turboshaft	2 × Pratt & Whitney Canada PW207D1 turboshaft	2 × Pratt & Whitney PW210A
Horsepower	633 hp	740 hp	550 hp	838 hp	625 hp	1000 hp
Fuel Capacity	560.4 kg	723.0 kg	602 L	897 kg	814 L	972 kg
Unit cost	US $1.33 M	US $4.9 M	US $7.2 M	US $4.8 M	US $1.32 M	US $8.0 M

Table 2.2: Performance characteristics table of competitor helicopters

	EC-135 [4]	**EC-145[6]**	**MD Explorer[7]**	**AS365 Dauphin[8]**	**Bell 429 GlobalRanger [9,10]**	**AW-169[11]**
Cruisespeed	254 km/h	246 km/h	248 km/h	269 km/h	280 km/h	268 km/h
Maximum speed	287 km/h	268 km/h	260 km/h	306 km/h	287 km/h	306 km/h
Range	635 km	680 km	543 km	827 km	676 km	816 km
Service ceiling IGE @MTOW	3,045 m	5,240 m	5,300 m	4,640 m	4,270 m	5085 m
Rate ofclimb	7.62 m/s	8.1 m/s	5.1 m/s	8.9 m/s	7.8 m/s	8.3 m/s
Maximum operating altitude	6,095 m	5,485 m	5,635 m	5,865 m	6,100 m	5,460 m
Disc loading (MTOW)	34.70 kg/m^2	37.73 kg/m^2	33.94 kg/m^2	38.40 kg/m^2	33.56 kg/m^2	39.89 kg/m^2

Sizing

Part 1. Gross Weight Estimation

In this part, weight estimation is made using specific formulas. Estimation of the gross weight of the helicopter using the weight group's methodology includes main rotor group, tail rotor group, power plant group, power plant section group, mechanical drive system group, flight control group, landing gear group, fuselage group, forward propulsion group and other fixed components and equipment. First, a disk loading is selected, while assuming gross weight, cruise speed and solidity values. Component weight elements are calculated using MATLAB to get the new gross weight. This process is repeated until convergence. Thereafter, this process is repeated by selecting a new disk loading.

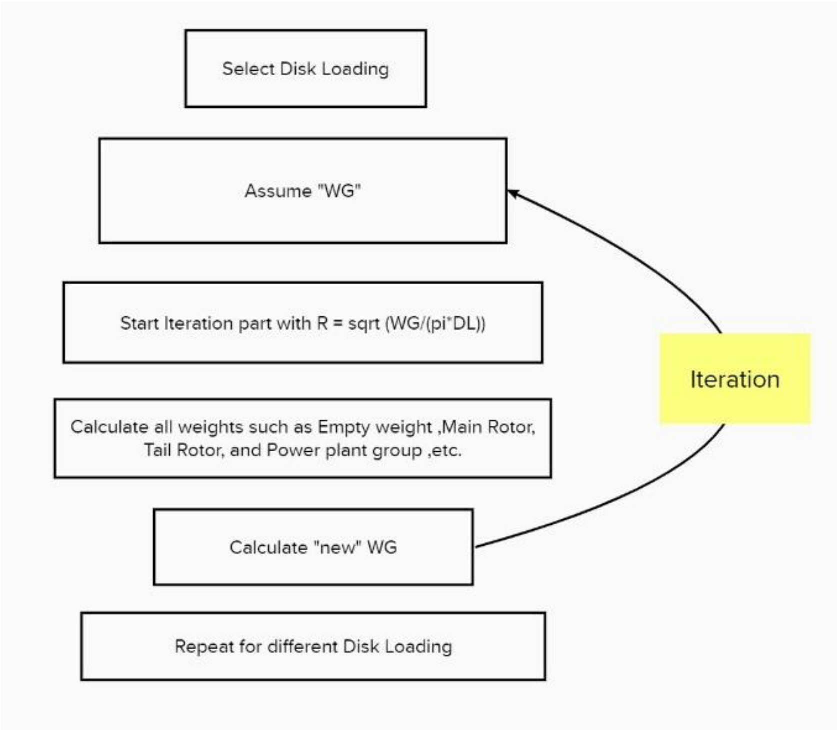


Figure 2.1.1 Algorithm for weight estimation

1. **Main Rotor Group**

To calculate weight of the main rotor group, gross weight, radius of the main rotor and the solidity values are used into the equation below.

$$W_R = 1.7 W_G^{0.342} R^{1.58} \sigma^{0.63}. \tag{2.1.1}$$

2. **Tail Rotor Group**

To calculate weight of the tail rotor group, gross weight, radius of the tail rotor and the solidity values are used into the below equation. Radius of the tail rotor can be written in terms of radius of main rotor in the equation.

$$W_{TR} = 7.12\left(\frac{W_G}{1000}\right)^{0.446} R_{TR}^{1.62} \sigma_{TR}^{0.66}. \tag{2.1.2}$$

3. **Power Plant Group (Free Shaft Turbine)**

To calculate weight of power plant group, HP available is used as in the below formula.

$$\mathrm{W_T} = 0.166\, HP. \tag{2.1.3}$$

4. **Power Plant Section Group**

To calculate weight of power plant section group, gross weight and the angular speed of the main rotor are used as in the below equation.

$$\mathrm{W_{PS}} = 0.00155 \mathrm{W_G}^{1.07} \omega^{0.54}. \tag{2.1.4}$$

5. **Mechanical Drive System Group**

$$\mathrm{W_{DS}} = 42.4 \left(\frac{HP\ x\ R}{\mathrm{V_T}}\right)^{0.763}. \tag{2.1.5}$$

6. **Flight Control Group**

$$\mathrm{W_{FC}} = 0.0226 \mathrm{W_G}^{0.712} \mathrm{V_C}^{0.653}. \tag{2.1.6}$$

7. **Landing Gear Group**

To calculate weight of the landing gear group, gross weight is used in the equation below.

$$\mathrm{W_{LG}} = 0.0475 \mathrm{W_G}^{0.975}. \tag{2.1.7}$$

8. **Fuselage Group**

To calculate the weight of the fuselage group, gross weight and radius of the main rotor are used. Weight of the fuselage is calculated using the equation below for transport helicopters.

$$\mathrm{W_F} = 0.37 \mathrm{W_G}^{0.598} R^{0.942}\ (transport). \tag{2.1.8}$$

9. **Wing Group (No ailerions or flaps)**

To calculate weight of the wing group, gross weight and angular speed of te main rotor are used in the equation below.

$$\mathrm{W_C} = 0.00272 \frac{\mathrm{W_G}^{1.4}}{\omega^{0.8}}. \tag{2.1.9}$$

10. **Forward Propulsion Group**

$$\mathrm{W_P} = 0.146 \frac{\mathrm{W_G}}{1_\mathrm{p}}. \tag{2.1.10}$$

11. Constant (Specified) Empty Weight Items

$$W\ f\ (\mathrm{W_{G0}}) = \mathrm{W_6} + \mathrm{W_7}. \tag{2.1.11}$$

$$W\ f\ (\mathrm{W_{G0}}) = 81.5\mathrm{W_{G0}}^{0.712} + 38.2\mathrm{W_{G0}}^{0.975}$$

$$\emptyset_{01}\ f\ (\mathrm{W_{G0}}) = 81.5\mathrm{W_{G0}}^{-0.288} + 38.2\mathrm{W_{G0}}^{-0.025}$$

$$W\ f\ (\mathrm{W_{G0}}, \omega) = \mathrm{W_1} + \mathrm{W_2} + \mathrm{W_4} + \mathrm{W_8} + \mathrm{W_9}.$$

Assuming parameters without weight estimation are shown in table 2.1.1. According to this table, the human weight was found to be 86.18 kg from research. [12]

Table 2.1.1 Assumed Parameters

Main and Tail Chord	0.3 m
Weight of Fuel	450 kg
Weight of Crew	4*86.18 kg [12]
Cruise Speed	66.87 m/s
Main Rotor Omega	440 RPM

Three different disk loading values have been selected for comparison. Criteria to be satisfied when selecting the disk loading value; the lowest possible gross weight. Disk loading is selected at the beginning. And then, when the take-off gross weight calculated by the iterative method is compared with the main rotor radius. It can be observed that as the disc loading increases, a decrease in the take-off gross weight and main rotor radius occurs. Though this seems favourable, it has the downside of increasing vibrations and decreasing hover efficiency. Since the air ambulance is designed taking passenger comfort into account, excessive vibrations are not tolerable. On the other hand, a low disc loading comes with increased weight and rotor radius. This reduces vibrations and increases hover efficiencies, but complicates design and increases power requirements. In order to optimise selection, a trade-off is performed and the intermediate disc loading of 31.736 $\mathrm{kg/m^3}$ is selected for the design.

Table 2.1.2 Three different disk loadings with radius and weight

DL [$\mathbf{kg/m^2}$]	14.647	31.736	43.942
$\boldsymbol{R_{MR}}$ **[$\boldsymbol{m}$]**	6.7193	4.1606	3.4442
$\boldsymbol{W_{TOGW}}$ **[kg]**	2077.6	1725.9	1637.6

In Table 2.1.3, the empty, fuel, payload, and TOW of weight are shown and calculated with MATLAB code.

Table 2.1.3: Empty, fuel, payload, and TOGW of weight

UNIT (kg)	W_{empty}	$W_{payload}$	W_{fuel}	W_{TOGW}	K	$W_{fraction}$
Weight	926.60	350.00	450.00	1725.90	4.32	0.54

In Table 2.1.4, the weight of 11 parts of the helicopter, such as the main motor group, has been calculated with MATLAB code and added to the table.

Table 2.1.4: Weight of main parts of the helicopter in the empty weight

UNIT (kg)	W_R	W_{TR}	W_P	W_{PS}	W_{MD}	W_{FC}	W_{LG}	W_{FG}	W_{WG}	W_{FP}	W_{CE}
Weight	52.33	15.52	20.83	5.94	63.04	39.54	30.26	116.65	12.88	25.57	37.73

Correction Factor with following formula,

$$K = W_{e(approx)}/W_e \qquad 2.1.12$$

Dividing the Approximate empty weight given as the data in Part 2 and the empty weight found by MATLAB iteration, K has been found as 4.3168.

Part 2. Power Required

Using the equation below, induced velocity is found,

$$v_{\mathrm{i}}^2 = -\frac{1}{2}V^2 + \frac{1}{2}\sqrt{V^4 + 4\left(\frac{T}{2\rho A}\right)^2}. \qquad (2.2.1)$$

Using each induced velocity values, induced power values are calculated using the equation below,

$$P_i = k v_i T. \qquad (2.2.2)$$

Using the equation below, profile power is calculated,

$$P_o = \frac{1}{8}\sigma C_{D_0}\rho A(\Omega R)^3\left[1 + K\left(\frac{V}{\Omega R}\right)^2\right]. \tag{2.2.3}$$

Using the equation below, parasite power is calculated,

$$P_p = \frac{1}{2}\rho(V)^3 f. \tag{2.2.4}$$

Using the equation below, miscellaneous power is calculated,

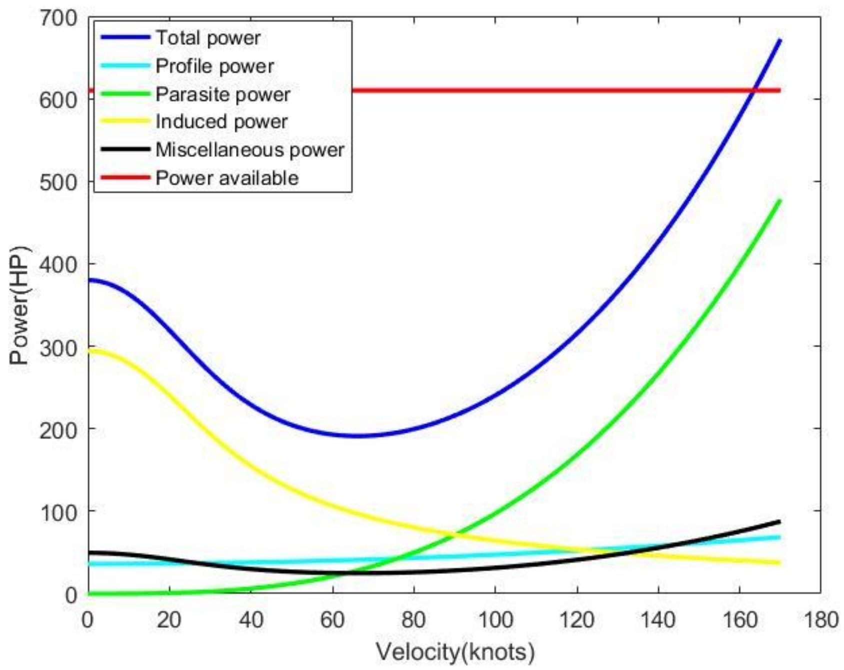
$$P_{Misc} = 0.05(P_i + P_o + P_p). \tag{2.2.6}$$

Substracting the profile power, profile power, induced power and miscellanneous power, total power is found.

$$P_{total} = P_i + P_o + P_p + P_{Misc}, \tag{2.2.5}$$

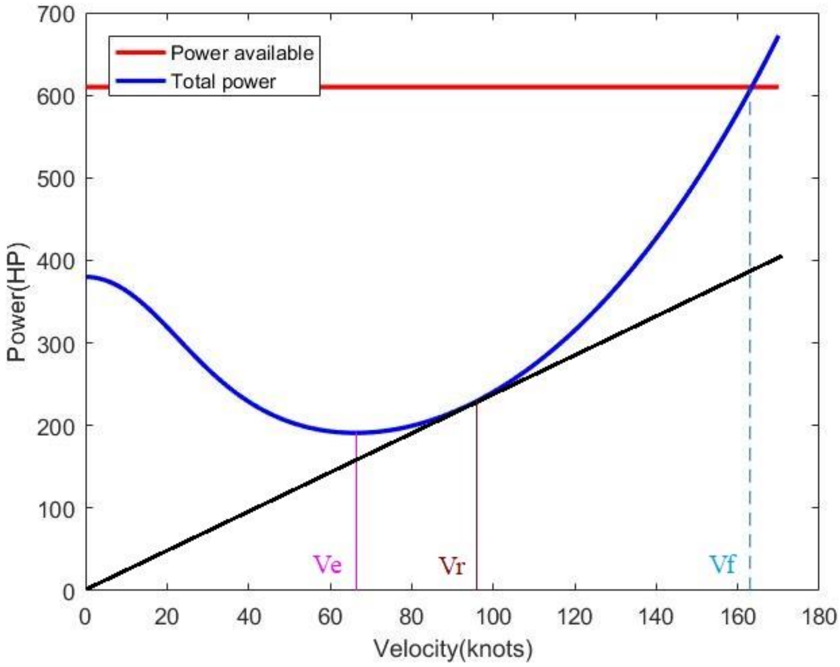
Expansion of the above total power formula.

Calculated with specific formulas in Matlab and the power requirements and forward velocity are plotted.



Graph 1.1 Velocity vs Power graph including total power components.

Thanks to the power requirements and forward velocity curve, maximum endurance velocity, velocity for maximum range, and maximum velocity in level flight were calculated and graphed.



Graph 1.2 Velocity vs Power graph with velocities of different performance parameters.

In Table 2.2.1, the total power, induced power, profile power, parasite power, miscellaneous, and, power available are taken from MATLAB and then are filled in the table.

Table 2.2.1 Total power with induced power, profile power, parasite power, and miscellaneous

UNITS (kW)	P_i	P_o	P_p	P_M	P_{total}	$P_{available}$
Power Max	219.49	51.13	356.49	65.39	501.29	454.88

In Table 2.2.2, the velocity for maximum endurance, velocity for maximum range, and maximum velocity are shown with data from MATLAB code.

Table 2.2.2 Velocity for maximum endurance, Velocity for maximum range, and Maximum velocity

UNITS (m/s)	$V_{Endurance,Max}$	$V_{Range,Max}$	$V_{Flight,Max}$
Velocity	33.43	46.3	83.85

Part 3. Engine Selection

In this section, the engine selected for this helicopter is introduced and the reasons for selecting this engine will be explained. After calculating the weight of the air ambulance helicopter, the power requireded is calculated as 610 hp, ie 454.88 kW.

Figure 3.1 3D model of Pratt & Whitney Canada PW207D1 engine. [13]

The selected Pratt & Whitney Canada PW207D1 satisfactorily provides for the power requirement. In addition, the engine can efficiently generate the power required for cruise flight. The power requirements for the mission and the power performance of this helicopter are summarized and performance analysis is given.

Table 3.1 The main performance characteristics of this engine. [14]

Type	Turboshaft
Overall Length	0.93 m
Overall Width	0.54 m
Overall Height	0.62 m
Maximum Continuous Power, Sea Level	455 kW
Continuous OEI Power	509 kW
Dry Weight	110.9 kg

Additional Design Aspects

Part 1. Rotorcraft Configuration

1. Landing Gear

For the ambulance helicopter that will be designed, the weight and the cost are the main concerns. Skid type landing gear is selected for the design. Skids weigh less and they need very little maintenance. Also, skids are streamlined, making them more aerodynamically efficient. Having skid type landing gear, helicopter should operate under hover power because downwash can be created by the power during ground movements and this leads to dangerous conditions for other aircraft and personnel around.

Figure 4.1 Example of an ambulance helicopter with skid type of landing gear. [15]

2. Hub Type

Hub type that is used on the ambulance helicopter designed is semi-rigid hub type. Due to simplicity and cost taking priority in design, with manoeuvrability not being of major concern for the ambulance helicopter, semi-rigid type hub is used. Semi-rigid type of hubs have just 2 blades and are easy to maintain. As a result of this, they cost less than other hub types.

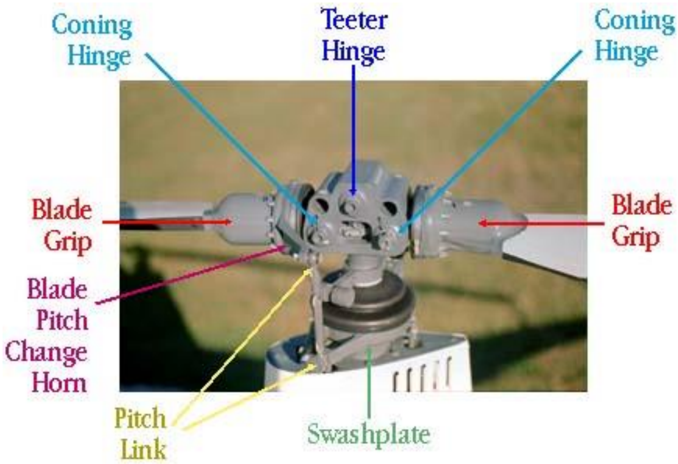


Figure 4.2 Example of a Semi-rigid Hub type [16]

3. Tail Rotor Type

The tail rotor that is chosen in the design of the ambulance helicopter is Fenestron type Tail rotor. First reason for choosing Fenestron type Tail rotor is safety. Fenestron reduces the probability of accident due to contact with blades during ground operations. Second reason is less sound and vibration. Fenestron provides less sound and vibration during flight. Therefore, the vibration that is created from the semi-rigid hub is reduced a bit using the Fenestron. Also, Fenestron provides more anti-torque control efficiency and less power demand during forward flight.

Figure 4.3. Example of a Fenestron [17]

4. Rotor blade design

For the rotor blade, symmetrical airfoil is chosen because it provides better stability than non-symmetrical airfoils and it is much simpler. Also, most of the light helicopter uses symmetrical airfoils.

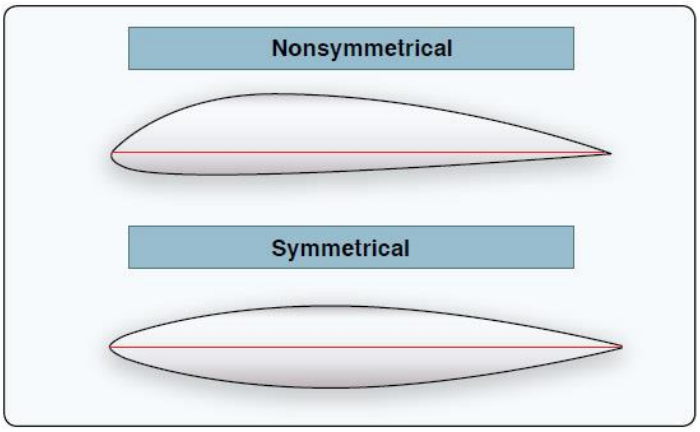


Figure 4.4. Example of a symmetrical and nonsymmetrical airfoil. [18]

5. **Empennage Design**

Forward mounted stabilizer is used for the empennage design to increase the nose stability of the helicopter. Helicopter that is being designed is an ambulance helicopter and it should be stable in order to keep the patients safe.

Figure 4.5 Example of a front mounted horizontal stabilizer. [19]

Part 2. Avionics

The helicopter is a civil air ambulance helicopter configured to transport one patient, two paramedics and one pilot. The purpose of the helicopter requires precise navigation. As such, an immaculate avionic suite is required in order to assist the pilot. For this purpose, the Bell BasiX-Pro Integrated Avionics System has been selected.

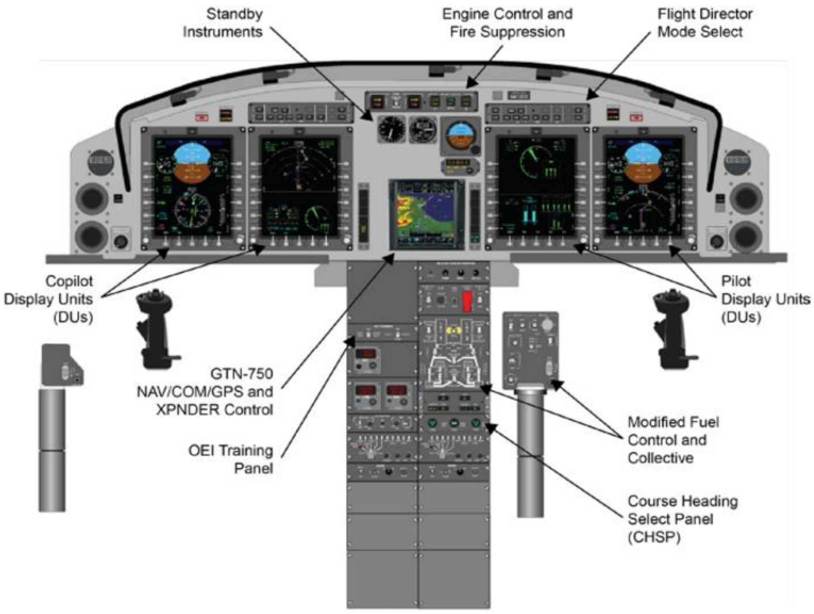


Figure 4.6 Standard configuration of the Bell BasiX-Pro Integrated Avionics System [20]

The Bell BasiX-Pro Avionics System has been specifically designed to meet the requirements of twin engine helicopters. The system is highly flexible and configurable to meet various operating and customization needs. The system takes advantage of the latest in display, computer processing, and digital data bus technology to provide a high degree of redundancy, reliability, and flexibility

Drawing

The drawing view of the preliminary design of the helicopter is shown below. Drawings are made in accordance with the ISO standard via Autodesk Inventor Professional 2022. In this drawing, determined the overall dimensions of EMS Helicopter, diameter of the blade, diameter of the Fenestron, and also other length of important parts like horizontal stabilizer and doors.

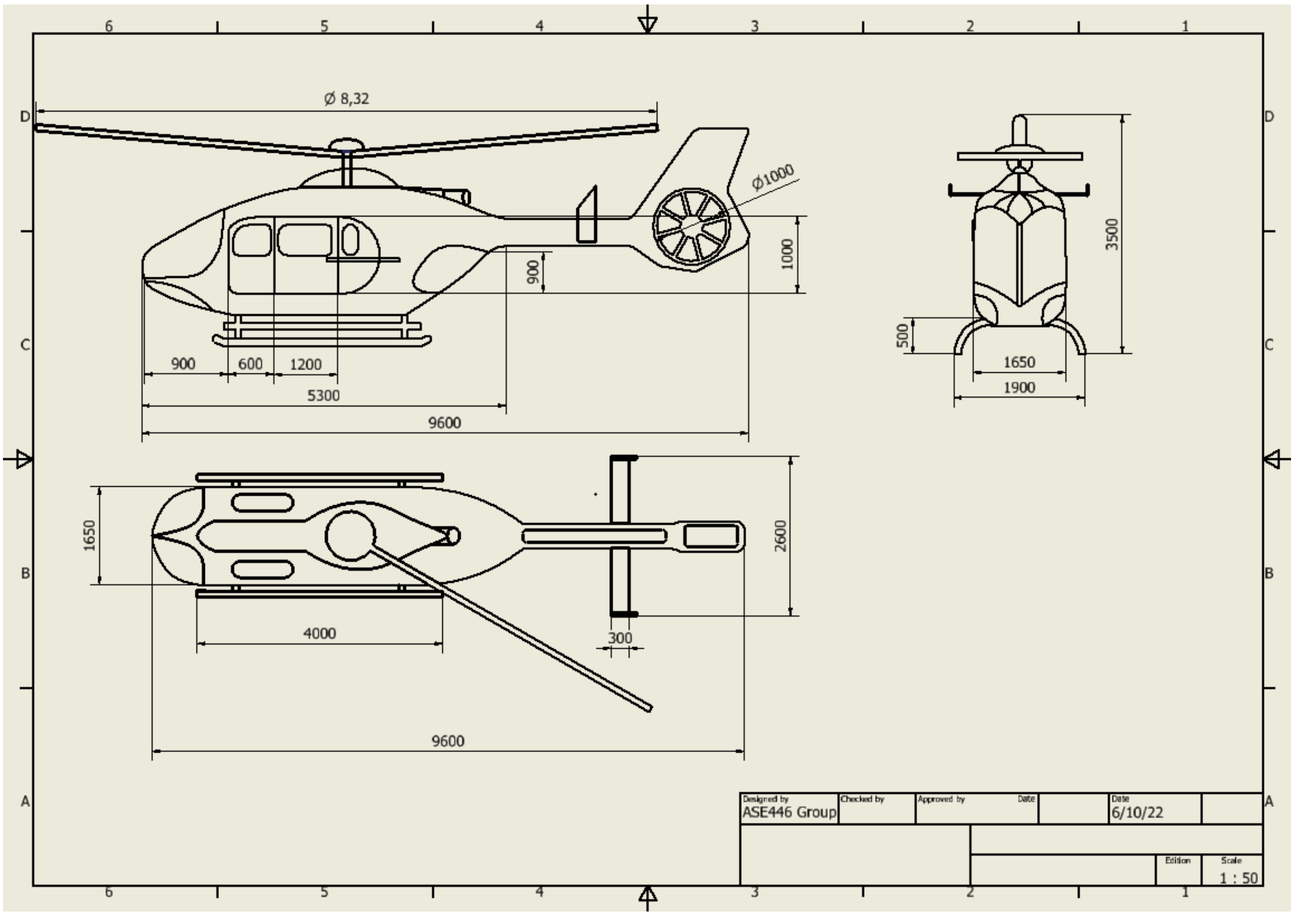


Figure 5.1: Drawing Paper of Air Ambulance Helicopter: Front View - Top View - Left View

This Figure 5.1 drawing of the designed helicopter overall length 9.6 m overall width 1.9 m overall height is 3.5m. It has forward mounted stabilizer on the tail which. The diameter of the main rotor 8.32 m and the diameter of the Fenestron type tail rotor is 1 m. The helicopter fuselage is kept as possible as small to decrease the drag, weight and cost.

Cabin Layout

In the preliminary design, the factors which take priority in the design of the cabin are: maximize space efficiency, medical transport with best practices in a short time, ergonomics and flexible configurations for different conditions, decrease the cost and maintenance and safety.

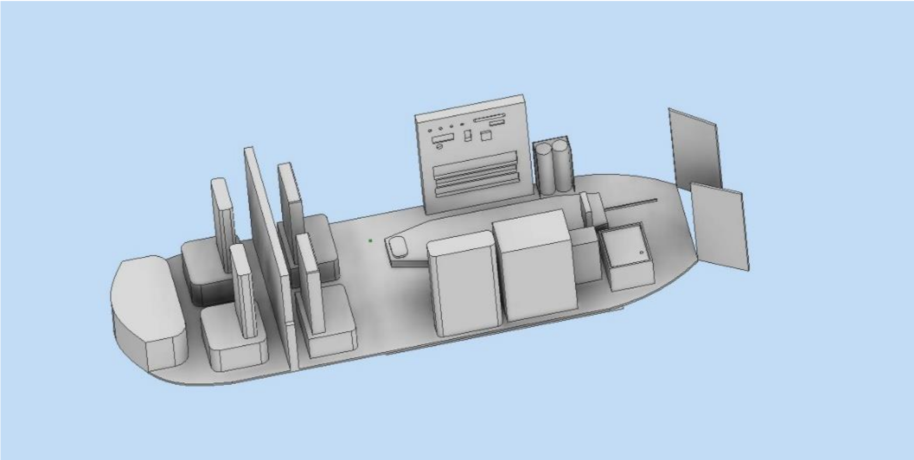


Figure 5.2 Cabin Layout shown in 3D

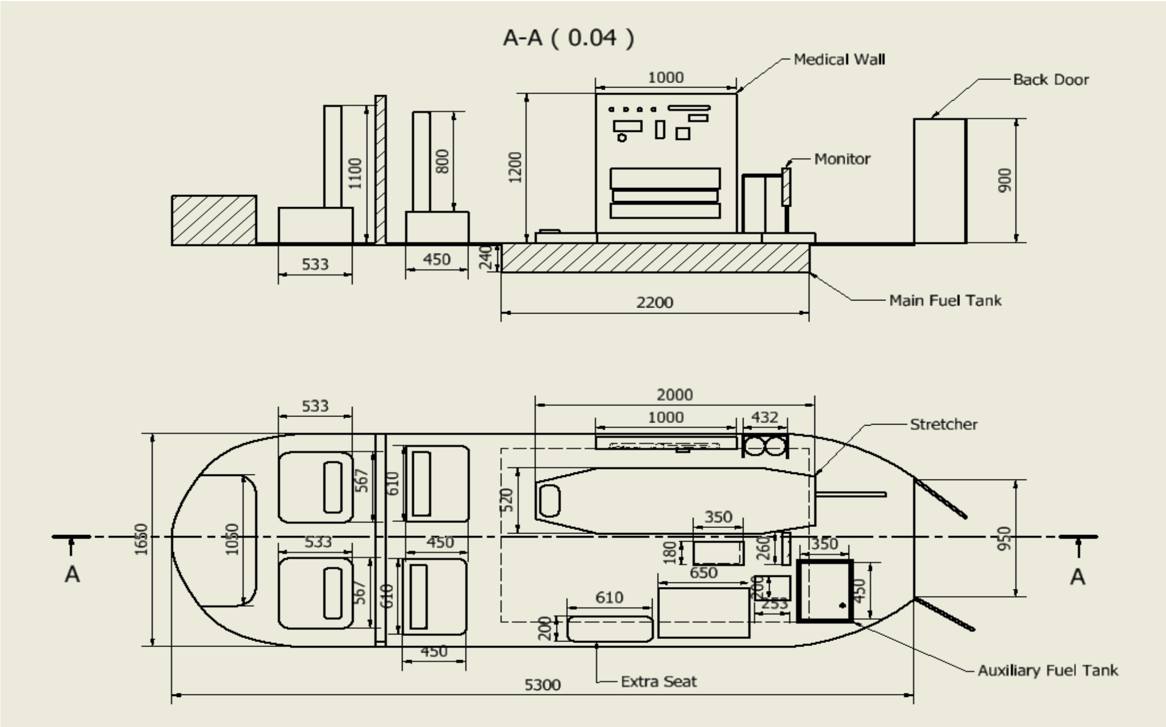


Figure 5.3 Cabin Layout shown in 2D with dimensions

It is clearly seen that on the Figure 5.3, front it has 2 seats for pilots: one is extra for second pilot to increase safety in the event of an emergency. The helicopter cabin is separated into 2 parts with a sliding door to not disturb and adversely affect the pilot. In this way, it is expected that the pilot can focus better and have a high level of concentration. One auxiliary fuel tank is positioned back of the cabin and it is contained with tubes to main tank which has 740 liter capacity under the floor.

Table 5.1 Some important parts with size and weight

		Height	Width	Depth	Weight
Pilot seat	x2	1100 mm	533 mm	567 mm	14.65 kg
Stretcher	x1	80 mm	1950 mm	490 mm	12 kg
Folding type seat	x3	1050 mm	45 0mm	610 mm	10 kg
Oxygen rottle rack	x1	500 mm	432 mm	261 mm	12.24 kg
Medical wall	x1	1000 mm	1200 mm	200 mm	15 kg
Center cabinet	x1	900 mm	650 mm	400 mm	35 kg

For the passenger region, 2 seats are planned for paramedics and 1 extra foldable seat for an extra paramedic or doctor if needed. There are 2 sliding doors from each side of the helicopter left and right. This design helps to transfer the patient to the helicopter from any side of the helicopter. Also, it is possible to enter the cabin from the back door. The door can be opened up to 180 degree. This design helps to transfer the patient in very short time. The floor is integral floor which provides stretcher sliding until the inlet of the cabin. With these designs, any delays should be minimized.

Medical Equipment

The helicopter has been planned taking into account all the important medical equipment required for an air ambulance. The medical wall includes incubators, ventilators etc.

Figure 5.4 Medical Wall [21]

Center cabinet which includes: infusion hook, infusion pumps, blood pressure cuffs, incubators, intubation equipment, ECG Monitor with defibrillator, coagulometer. The cabin has other medical equipment such as Oxygen Rottle Rack, suction unit, Ultrason Scanner.

Conclusion

Given initial requirements and mission requirements an air ambulance helicopter is designed. The city of operation is chosen as Cambridgeshire and mission requirements are specified accordingly. The minimum technical values are illustrated in table 1.2 with provided justifications. During the whole design process competitor study is used as guidance. Data of 6 air ambulance helicopters are shown in table 2.1 and 2.2. The Blade element theory is applied for the sizing. First a performance analysis is done which is continued with weight estimations. This process is repeated until acceptable and efficient values for the design are obtained. The weight estimations are done using specified formulas for each component of the rotorcraft using an initial guess and estimated values which are tabulated in 3.1.1 for different disk loadings. The scheme is an iterative code using MATLAB that continues until an error tolerance is obtained. A correction factor is then calculated by comparing the obtained weight to the estimated weight. Take off gross weight is found as 1725.90 kg and the empty weight as 926.60 kg. The last process of the performance is calculated using the obtained weight value. It uses blade element theory in forward flight that is integrated into a iterative MATLAB code. The power components are illustrated as HP vs velocity in knots in graph 3.1. The velocity ranges from 0 to 180 knots. From the total power required, the maximum endurance, range and velocity are found which are shown in graph 3.2 and found parameters are tabulated. These procedures are crucial for the early design of a helicopter since they provide information on the weight and predicted performance of the aircraft. Additional design choices for rotorcraft configuration and the avionics are done. Hub type is chosen as semi-rigid, tail rotor as fenestron, landing gear skids, rotor blades symmetrical, and empennage as forward mounted stabilizer. All design choices are explained and justified. The avionics is the Bell BasiX-Pro Integrated Avionics System for explained reasons in the report. The 2D drawing is briefly explained and design choices with estimated lengths justified.

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Appendix

Weight Estimation Code

```
clc
clear
close all
format short

%%% Given Values %%%
HP            = 610;            % HP avaielable (hp)
WeightEmpty   = 4000;           % Approximate empty weight (including oil and standard
avionics) (lb)
WeightFuel    = 992.08018;      % Standard fuel (lb)
WeightP       = 770;            % Pilot, passenger and baggage (lb)
Vtip          = 623.35958;      % Rotor tip speed (ft/s)
RPM           = 440;            % Main rotor RPM (rpm)
omega         = RPM*pi/30;      % Angular velocity (rad/s)
Rmax          = Vtip/omega;     % Rotor radius (ft)
chord         = 0.984251969;    % Blade chord  (ft)
chord_tr      = 0.984251969;
Nb            = 2;              % Number of blade
L1            = 17.3884514;
H1            = 11.4829396;
W1            = 5.41338583;

%%% Guess Disk loading, Initial guess weight, guess Solidty, and guess Cruise speed %%%
DL             = 9;              % Assumed disk loading
guessWeight    = 1000;           % Initial guess
Vc             = 130;            % Crusise speed knots

for i=1:100
R = sqrt(guessWeight/(DL*pi));
A = pi*(R)^2;                   % Area of rotor (ft^2)
Ablade = pi*(chord)^2;          % Blade area of rotor (ft^2)% New radius value
Sigma  = (Nb*chord*R)/A;        % Solidty
R_tr  =0.2*R;
A_tr = pi*(R_tr)^2;
Ablade_tr = pi*(chord_tr)^2;
Sigma_Tr = (Nb*chord*R)/A_tr;
DL1 = guessWeight/A;
WR   = 1.7*(guessWeight^(0.342))*(R^(1.58))*(Sigma^(0.63));         % Main rotor group
%WT    = 22.2*((guessWeight/1000)^1.26)/(DL^(0.81));
WT   = 7.12*((guessWeight/1000)^0.446)*(R_tr^1.62)*(Sigma_Tr);      % Tail rotor group
WPP  = 0.166*(HP);                                                  % Power plant group
WPS  = 0.00155*(guessWeight)^(1.07)*(guessWeight/(pi*R^2))^(0.54);  % Power plant
section group
WMD  = 42.4*((HP*R)/Vtip)^(0.763);                                  % Mechanical drive
system group
WFC  = 0.0226*(guessWeight)^(0.712)*(Vc)^(0.653);                   % Flight control
group
WLG  = 0.0475*(guessWeight)^(0.975);                                % Landing gear group
%WFG   = 0.37*(guessWeight^0.598)*R^0.942;
WFG  = 0.0382*(guessWeight^0.598)*(L1^0.942)*(W1^0.453)*(H1*0.295); % Fuselage group
WWG  = 0.00272*(guessWeight^1.4)/(DL^0.8);                          % Wing Group
WFP  = 0.146*((guessWeight)/(guessWeight/A)^(0.8));                 % Forward propulsion
group
```

```
WCE  = 0.1*( WR+WT+WT+WPS+WMD+WFC+WLG+WFG+WWG+WFP);                   % Constant empty
weight items
We   = WR+WT+WPP+WPS+WMD+WFC+WLG+WFG+WWG+WFP+WCE;                     % Iterarion empty
weight
guessWeight = We+WeightFuel+WeightP;
end

%%% Resul Part %%%
WR=WR*0.45359237
WT=WT*0.45359237
WPP=WPP*0.45359237
WPS=WPS*0.45359237
WMD=WMD*0.45359237
WFC=WFC*0.45359237
WLG=WLG*0.45359237
WFG=WFG*0.45359237
WWG=WWG*0.45359237
WFP=WFP*0.45359237
WCE=WCE*0.45359237
We=We*0.45359237
WeightFuel=WeightFuel*0.45359237
WeightP=WeightP*0.45359237
W_total = We+WeightFuel+WeightP
Wfraction = We/W_total
K = WeightEmpty/We
R=R*0.3048
Rmax=Rmax*0.3048
```

Power Requirement Code

```
clc
clear
close all
format short

Weight       = 1725.9;          % Max TOGW (kg)
g            = 9.81;            % Gravity (m/s)
W            = Weight*g;        % Weight TOGW (N)
HP           = 610;             % Power available (hp)
R            = 4.1606;          % Rotor radius (m)
chord        = 0.3;             % Blade chord  (m)
RPM          = 440;             % Main rotor RPM (rpm)
omega        = RPM*pi/30;       % angular velocity (rad/s)
Rho          = 1.225;           % Air denstiy (kg/m^3)
CDo          = 0.01;            % Drag coefficient: CDo
k            = 1.15;            % Correction factor
K            = 4.3168;          % Correction factor
A            = pi*(R)^2;        % Area of rotor (m^2)
f            = 0.016*A;         % Equivalent flat-plate area (m^2)
Nb           = 2;               % Number of blade
Sigma        = (Nb*chord*R)/A;  % Solidty
T            = W;               % Thrust (N)
Vknots       = 0:1:170;         % Velocity (knots)
Vtip         = omega*R;         % Tip speed (m/s)

for i=1:length(Vknots)
    V (i)        = Vknots(i)*0.514444444;
% Velocity (m/s)
    Vi(i)        = sqrt(-0.5*(V(i)^2)+0.5*sqrt((V(i)^4)+4*((T/(2*Rho*A))^2)));
% Induced velocity (m/s)
    Pi(i)        = (k*Vi(i)*T)*0.00134102209;
% Induced power (hp)
    Pi_plot      = [Pi];
    Po(i)        =
((1/8)*Sigma*CDo*Rho*A*((omega*R)^3)*(1+K*(V(i)/(omega*R))^2))*0.00134102209;  % Profile
Power (hp)
    Po_plot      = [Po];
    Pp(i)        = (0.5*Rho*(V(i)^3)*f)*0.00134102209;
% Parasite Power (hp)
    Pp_plot      = [Pp];
    Pmisc(i)     = ((Pi(i)+Po(i)+Pp(i)))*0.15;
% Miscellaneous power (5% of total power) (hp)
    Pmisc_plot   = [Pmisc];
    Ptotal(i)    = Pi(i)+Po(i)+Pp(i)+Pmisc(i);
% Total Power (hp)
    Ptotal_plot = [Ptotal];
    HP(i)        = 610;
% Avaible power (hp)
    HP_plot      = [HP];
end

%%% Plots part for Part 1a %%%
figure(1)
plot(Vknots,Ptotal_plot,'b-', 'LineWidth',2)
hold on
plot(Vknots,Po_plot,'c-', 'LineWidth',2)
plot(Vknots,Pp_plot,'g-', 'LineWidth',2)
```

```
plot(Vknots,Pi_plot,'y-', 'LineWidth',2)
plot(Vknots,Pmisc_plot,'k-', 'LineWidth',2)
plot(Vknots,HP_plot,'r-', 'LineWidth',2)
legend('Total power','Profile power','Parasite power','Induced power','Miscellaneous power','Power available','Location','northwest')
% Legend for Part 1b
xlabel('Velocity(knots)')
ylabel('Power(HP)')

%%% Plot part for Part 1b %%%

[A,I]     = min(Ptotal);
V_Emax    = V(I)*0.592484;            % Velocity maximum endurance
Find_max = find(Ptotal - HP < eps);
Point_x  = Vknots(Find_max);
Point_y =  HP(Find_max);
VRmax_x    = max(Point_x);           % Velocity maximum range
VRmax_y    = max(Point_y);

figure(2)
plot(Vknots,HP_plot,'r-', 'LineWidth',2)
hold on
plot(Vknots,Ptotal_plot,'b-', 'LineWidth',2)
line([VRmax_x ;VRmax_x],[0;VRmax_y],'linestyle','--');
legend('Power available','Total power','Location','northwest')
xlabel('Velocity(knots)')
ylabel('Power(HP)')
```