TEKNOFEST

HAVACILIK, UZAY VE TEKNOLOJİ FESTİVALİ

HELİKOPTER TASARIM YARIŞMASI

ARA TASARIM RAPORU

TAKIM ADI: HUMMINGBIRDS

TAKIM ID:

TAKIM ÜYELERİ:

ABDULKADİR ERDOĞAN

BERKCAN GÜLŞEN

ERTUĞRUL GÖKKURT

MEHMET TALHA TINASTEPE

Musa BATIR

DANIŞMAN ADI: DR. NILAY SEZER UZOL

TAKIM LİDERİ ADI SOYADI: BERKCAN GÜLŞEN

İçindekiler

1. DESIGN DESCRIPTION

We are designing a tiltrotor and tiltwing helicopter. Tiltrotor is the one of several V/STOL aircraft which gives us opportunity to have the greatest improvement in productivity over the normal helicopters. Because with tiltrotor system; it hovers with excellent fuel economy that it can perform skyhook which is important for us. Also, it has reasonably low downwash velocities so that material, men and the landing site can remain functional below it. It can take off with significant payload increases at overload gross weights by making short take off runs when airstrips are available.**[1]**

It also differs from the helicopters, it can, by tilting its wing-tip mounted rotors forward, fly quietly and easily at speeds twice those of a helicopter with better fuel economy, ride qualities, and lower vibration. By tilting rotors and wings, lift components of the wing and the rotor can be added for low speed maneuvering which makes it good at loiter operation. In addition to tilting rotor and tilting wing explained above, we have also detailed design features;

1-Torsionally stiff wing and stiff pylon to wing attachment to have sufficient stability margin at low technical risk.

2-Forward swept wing planform to have sufficient clearance for flapping in maneuvers and gust encounters.

3-Gimbaled, stiff-in plane, over-mass-balanced proprotor used because proprotor loads not sensitive to flapping and air and ground resonance problems avoided also blade pitch-flap-lag instabilities and stall flutter problems avoided.

4- Large tail volume, H configuration used to obtain good damping of dutch roll and short-period flight modes.

For the high cruise speed, we must decrease the drag and increase the thrust. So, by keeping the wing straight to have less drag and tilting the rotor forward for the thrust, we reach our goal more efficiently. For the takeoff and landing; by tilting its wing to the best aerodynamically efficient point, we have faster take-off and more safer landing operations. You can see the approximate position (due to external factors like gusts) of the wings and rotors at forward flight at figure 14.

With our design we have the highest productivity of all V/STOL aircraft options in terms of high speed, fuel economy and carrying cargo for a given mission.

2. SUB-SYSTEMS

2.1.HYDRAULIC SYSTEMS:

We decided to install separate hydraulic systems for our tiltrotor-tiltwing helicopter design. We have determined the hydraulic systems we use as primary flight control systems and utility systems. Primary flight control systems are powered by a hydraulic pump driven from each main-rotor transmission. The utility system would be powered by a hydraulic pump driven from the interconnect shaft, adjacent to the fuselage so that hydraulic power is available as long as the rotors are rotating. As an example of the systems we think of as utility systems, we can give the system that enables the loading ramp to be opened and closed. Flight Control Systems supply power to the elevator, horizontal stabilizer, aileron, rudder, and brakes.

2.2.ELECTRICAL SYSTEMS

An aircraft electrical system provides electrical power to the avionics, hydraulics, lighting, and other subsystems. The electrical system of helicopter consists of multiple AC and DC systems, AC/DC convertors, lead for redundancy, a single lead acid battery, frequency generators, and interior/exterior lighting. These electrical systems provide the necessary electrical power to our tiltrotor-tiltwing helicopter design.

2.3.PNEUMATIC SYSTEMS

Pneumatic systems are often compared to hydraulic systems, but such comparisons can only hold true in general terms. The pneumatic system provides compressed air for pressurization, environmental control, anti-icing, and in some cases engine starting. The pneumatic system that we decided to use in our design uses compressed air from the engine compressor. This compressed air is cooled with a heat exchanger using outside air. This cooling air is taken from a separate inlet located in the body.

2.4.EMERGENCY POWER SYSTEM

When designing a tiltrotor-tiltwing helicopter, we also considered flight safety. For this reason, we have installed an emergency power system in our design. The emergency power system will be activated if there is any power loss while the helicopter is on the ground or in the flight. To do this, some form of emergency hydraulic power is required to use it in an emergency. Also, electrical power must be retained until systems are restarted. We installed the Monopropellant emergency power unit, which uses a monopropellant fuel, such as hydrazine, to operate systems in emergencies.

2.5.AVIONICS

We made a detailed literature review for avionics. During this search, we determined the avionic systems used in the operations of tiltrotor-tiltwing helicopters and required for our mission profile. The determined avionics are listed below.

- **Radios:** VHF voice radios and omnidirectional radios were used to communicate with the ground and other aircraft. These radios will provide frequencies, codes, modes of operation, channels and voice control for the pilot.
- **Navigation:** A high-accuracy navigation system is essential for successful mission completion. For this, navigation consists of gyroscopes, accelerometers, GPS and associated electronic components that provide predictions of the aircraft's attitude and predictions of the velocity vector and position vector of the aircraft in an Earth-fixed reference frame.
- **Flight Control Computers:** Flight control computers increase safety and reduce pilot workload and assist the pilot in bad conditions. Autopilot is used to support flight in bad weather and degraded visual environments. For these reasons we have used these systems.
- **Radar:** An air radar is equipped on the helicopter for all terrain and navigation maps. We designed the helicopter nose to hold the radar.

2.6.HUMS

Our design helicopter uses a Health and Usage Monitoring System (HUMS) to continuously check the status of critical systems in the aircraft. One of the most important aspects of the health and usage system is the maintenance interface. The total operating costs of our tiltrotor-tiltwing helicopter design are reduced thanks to HUMS.

2.7.RAIN AND ICE PROTECTION SYSTEM

It is an important system for the helicopter we designed to fly safely. For this reason, we have installed the rain and ice protection system in our design. This system is for protection against ice accumulation at the leading edges of the blades and motor inlets at high altitudes.

The helicopter is designed for a pilot. The helicopter cockpit is designed to minimize the pilot workload and all controls and displays are task-oriented and consistently placed. At the same time, the helicopter was designed to have a modified controller for the tilting wing.

2.8.CARGO LOADING AND DELIVERY SYSTEM

In our case, we will load 250 kg cargo to our helicopter, and we will unload this cargo to the given coordinates within the 5 minutes while hovering. The coordinate can be between the hills so exact location unloading can be difficult. The aim of this project is designing helicopter that can do this given mission perfectly so cargo loading and delivery system must work perfectly. For cargo loading; after researches, we decided to use ball transfer system with the crane pulley system. Loading 250kg cargo to the helicopter is not easy and fast thing, maybe it can take hours to place the cargo into the helicopter with the ancient ways but by using BCP (Ball Crane Pulley) we can load the cargo in minutes. On the surface we have rolling balls to make the loading easily and after loading we have stabilizers and restraints on the surface to keep the cargo. We can see the basic loading system configuration in figure 1.

Rolling balls, stabilizers and restraints can be seen in figure 2.

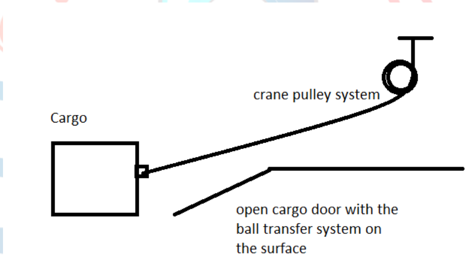

Figure 1 Basic Cargo Loading System

Figure 2 Rolling balls, stabilizers and restraints on the surface

For cargo delivery system we decided to use computer-controlled system which is consist of advanced electronics and hardware. Our system replaces the current mechanically operated and labor-intensive system with the computer-controlled cargo handling and airdrop system. During hover, cargo will be delivered using parachute, parachute will be open automatically due to the distance from the ground. Then by using integrating monitoring and wireless operation parachute will be controlled and cargo will be delivered to the given coordinate automatically with higher accuracy. We did researches and find out that this kind of delivery systems are being developed nowadays so we can create this system working with related fields engineers. If we can make use of this system;

1-It will save time and money by reducing all logistic operations through the use of automation and systems integration.

2-It will be safer when unloading cargo to the ground.

3-As discussed above the coordinate can be given on complicated area so helicopter may not get close enough to deliver the cargo manually but by using our system it is possible to do the mission accurately.

4-It will reduce human error.

5-It will be faster so if in the area there is a war, it minimizes our helicopter combat exposure.

So, this system gives a great solution to current industry standards through the use of technology and automation for cargo delivery system.

3. PROPULSION SYSTEM AND LOCATION

We will use turboshaft engine as expected. A turboshaft engine is a form of a gas turbine which is optimized to produce shaft power. These engines are used in applications which requires a sustained high-power output, high reliability, small size and light weight like helicopters. Produced shaft power is used for the rotation of the rotors and with the help of the shape and rotation of the rotors we can generate lift to make VTOL and hover. As we discussed by changing the rotor and wing position(tilting) to the best aerodynamically effective position we can make VTOL more efficiently (in terms of SFC, velocity etc.) and we will fly faster at cruise.

For the tiltrotor's location according to the researches; usually rotors are mounted on rotatable engine pods at the tip of the wings, but we can also have engine mounted in the fuselage with drive shafts transferring power to rotor assemblies mounted on the wingtip's configuration. We chose the first configuration because, in our design; our rotors are tilting with the rotatable engine pods so in the vertical take-off and forward flight position we are decreasing the area that wind encounters with our wing-rotor configuration in other words we are decreasing the drag force. For the second configuration, since the engine is mounted to the fuselage, we cannot change the radial position so we can have more drag because of the fixed engine configuration so we chose the rotors are mounted on rotatable engine pods at the wingtip configuration.

3.1.FUEL SYSTEM

The fuel system is designed to be integrated into the wing and fuselage. The system consisted of separate fuel tanks. Fuel tanks were designed to be linked to each other in different sizes and positions at the wing and fuselage. Tanks are designed to withstand fall and crash effects. Engine fuel is supplied to the adjacent engine by the left and right feed tanks. All other tanks are transferred to these feed tanks. In order to ensure that the fuel is transported equally to the feed tanks, two booster pumps were installed on the fuselage and one on each wing.

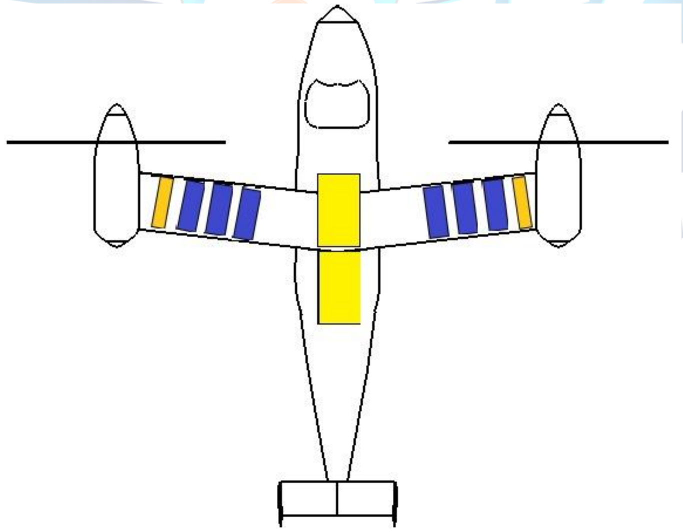

Figure 3 Fuel system

3.2.EFFECT OF THE CARGO VOLUME

For 250kg cargo volume we calculated the fuselage dimensions as; width is 1.72m, height is 1.85m and the length of the fuselage is 10.51m. When we look at the cargo volume effect on the performance; before unloading the cargo, our helicopter will carry extra 250kg and because of the volume of the cargo, helicopter is designed larger so for satisfying the required speed and time, our SFC will be higher at the first part of our mission. After unloading we will satisfy the required flying parameters (speed, time) with lower SFC.

4. ROTOR SYSTEM

4.1.HUB DESIGN

We decided to use a stiff in-plane gimbaled hub rotor design for our design. Because this hub design has many positive contributions to our HB-1 design. The stiff in-plane gimbaled hub design we use is the hub design with patent number US20090175725A1 as seen in the photo.

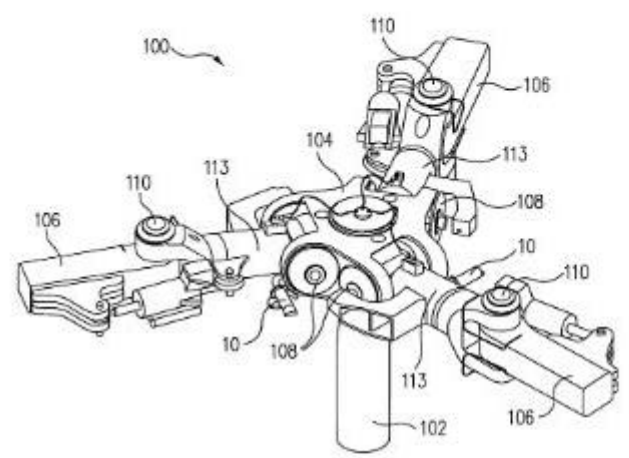

Figure 4: Stiff, In-plane Gimbaled Hub, US Patent #20090175725A1

This hub design we have has large flapping angles, contributing to our design by providing enough control power for hover. At the same time, the design reduces the Coriolis effect often encountered with blade flapping and provides a greater pitch-flap coupling to aid rotor stability.

4.2.GEAR BOX

The propulsion system uses gearboxes to efficiently accomplish all aspects of the propulsion envelope desired in tiltrotor operations. The engines each have swashplates much like those needed in helicopters, controlling the angle of attack of each rotor blade. A proprotor gearbox provides mounting for the proprotor on the nacelle and uses speed reduction to allow the proprotor to spin at lower rpm while the engine spins at higher rpm, under normal operating conditions. The tail drive shaft is not needed as there is no rotor in the tail of the HB-1 helicopter. Thus, the weight of the gear box system is less compared to the weight of the normal helicopter gear box.

5. PERFORMANCE & CALCULATIONS

Empty weight and take-off weight calculations are done according to the Aircraft Design book which written by Daniel P. Raymer. Calculations are done by using following formula and historical trends in the Raymer's book [2]. It is determined that helicopter can carry payload up to 500 kg.

$$W_0 = \frac{(W_{crew} + W_{payload})}{(1 - \frac{W_{fuel}}{W_0} - \frac{W_{empty}}{W_0})}$$

Empty weight fraction and fuel fraction of the helicopter are calculated as an initial step. For the empty fuel fraction following formula and empirical data is used.

$$\frac{W_{empty}}{W_0} = A.{W_0}^{C}.K$$

Where;

A=0.96

C=-0.05

K=1

Above parameters are taken from the empirical data for the desired design.

For the fuel fraction calculation following formula is used for each mission segment. For Teknofest regulations, there are 6 mission segments which are warm-up and takeoff, climb, cruise, hoover, cruise and descend and landing. For the warm-up and takeoff, climb and descend empirical fractions are used. For other segments following formulas are used (Breguet range equation and endurance equation).

- Hoover

$$\frac{W_i}{W_{i-1}} = exp\frac{-EC}{{}^{L}/_{D}}$$

- Cruise

$$\frac{W_i}{W_{i-1}} = exp\frac{-EC}{V.({}^{L}/_{D})}$$

After finding all mission segments, fuel fraction is calculated as follows;

$$\frac{W_n}{W_0} = \frac{W_1}{W_0}\frac{W_2}{W_1}\cdots\frac{W_n}{W_{n-1}}$$

$$\frac{W_f}{W_0} = 1 - \frac{W_n}{W_0}$$

Then takeoff weight is solved iteratively by using Excell. The results are:

Empty Weight [kg]	**Take-off Weight [kg]**
2662.20327	4209.059

As compared to the competitor study we obtained a lighter helicopter. That provides as small engine, less fuel fraction and lower overall cost of the helicopter.

Wing, fuselage, horizontal tail, vertical tail sizing's are calculated according to the Daniel P. Raymer's approach [2] and Mohammed H. Sadrey [3]. At first aspect ratio of the wing is found from the historical data fort he certain type of the helicopter. Then according to the weight estimation, initial sizing of the wing is calculated.

At first aspect ratio of the wing of the helicopter when it is the A/C mode. Following formula is used.

$$AR = a.M_{max}{}^{C}$$

Aspect ratio is found as 7.8. According to the competitor study aspect ratio is very close to reference helicopter's AR value. Then wing area, the chord of the wing and wingspan are calculated by following formulas

$$S_{wing} = \frac{W_0}{W_0/S_{wing}}$$

$$AR = \frac{b^2}{S_{wing}}$$

For the tail arrangement H-tail configuration is chosen. For this configuration aspect ratios of the horizontal and vertical tails are found as 3.27 for horizontal tail, 2.33 for the vertical tail. Then tail volume coefficients are calculated. Then by using following formulas tail areas, spans and chord distributions are found.

- Horizontal tail

$$S_{HT} = \frac{\overline{c_w} \cdot c_{HT} \cdot S_w}{L_{HT}}$$

$$b = \sqrt{A.S_{HT}}$$

$$c = \frac{S_{HT}}{b}$$

- Vertical tail

$$S_{VT} = \frac{b_w \cdot c_{VT} \cdot S_w}{L_{VT}}$$

$$C_{rootHT} = \frac{2 \cdot S_{HT}}{b \cdot (1 + \lambda)}$$

$$C_{tipHT} = \lambda \cdot C_{rootHT}$$

Generally, the larger the diameter of the propeller, engine will be more efficient. Diameter should be kept as long as possible. But the limitation on the length is the propeller tip. Propeller tip speed should be kept below sonic speed. By using Raymer's approach [2], the propeller diameter can be found as function of horsepower. Propeller diameter is calculated by using below equation which is compared to maximum diameter obtained from propeller tip-speed considerations.

$$d = 18\sqrt[4]{Hp}$$

Rotor diameter is found as 2.5298 meters.

Wing Span [m]	9.1399
Wing Chord [m]	1.1717
Wing Sweep (degree)	-6.5
Horizantal Tail Span [m]	2.3414
Horizantal Tail Chord [m]	0.7160
Vertical Tail Span [m]	1.644
Vertical Tail Chord (Root/tip) [m]	0.94 / 0.47
Fuselage [m]	10.511

Cruise speed estimation is done due to Daniel P. Raymer's book. At first lift coefficient and zero-lift drag coefficient then wing loading are calculated with respect to initial sizing of the helicopter. For an unaccelerated flight, summation of the all forces must be zero. Therefore, lift must equal to weight. Cruise speed can be calculated by the help of this approach. For the stall speed, calculations must be repeated with respect to maximum lift coefficient and stall wing loading.

$$V_{cruise} = \sqrt{\frac{2}{\rho C_L}\left(\frac{W}{S}\right)_{cruise}}$$

Where;

$$\left(\frac{W}{S}\right)_{cruise} = q\sqrt{(\pi A e C_{D0})}$$

Lift coefficient is taken at the design angle of attack where the lift to drag ratio of the airfoil is highest. Zero lift drag is calculated based on the mostly skin-friction drag plus a small separation pressure drag. To calculate the parasite drag (zero-lift drag) following equation is used.

$$C_{D0} = C_{fe}\frac{S_{wet}}{S_{ref}}$$

Where; C_{fe} is the equivalent skin friction coefficient. To calculate the parasite drag, wetted area and the reference area of the helicopter must be known. At this step dimensions of the helicopter is known. Wetted are and the reference area values are taken from the cad drawing of the helicopter from Catia program.

Cruise speed and the stall speed are found as follows.

Cruise Speed [km/h]	543.6
Stall Speed (when in airplane mode) [km/h]	173

Range and flight time calculation is done according to Breguet range equation and endurance equation [2]. Integrating the instantaneous range with respect to the change in helicopter weight yields the Breguet's range equation (given below). At final range is calculated as 823 km which meets the Teknofest specifications.

$$R = \int_{w_i}^{w_f} \frac{V(\frac{L}{D})}{CW} dW = \frac{V}{C}\frac{L}{D}\ln\frac{W_i}{W_f}$$

Flight time is calculated as 183 minutes with maximum capacity of 543 km/h cruise speed and payload of 500 kg during all the flight. For the given mission segment in Teknofest, flight time will be higher with 250 kg of payload and the Cargo drop.

Fuel fraction estimation is done by using historical values from reference [ref] for cruise and hoover segments and for all mission profile. Mission segments involves all weight lost during the mission. Also, there is %6 allowance for reverse and trapped fuel. Fort he calculated performances of the helicopter; fuel fraction due to take-off weight is 0.228607.

Total fuel consumption [kg]	962.206863

Aircraft maximum speed limits the choice of the powerplant [2]. And our design mach number is less than 1. So, turboshaft engine type is selected for the tilt rotor. And we know that TEI is producing Turkey's first indigenous turboshaft engine. TS1400 turboshaft engine is selected for powerplant of the tilt rotor. Technical specifications are expressed in the below.

SLS ISA TO Power	1400 shp
SLS ISA 30 sec OEI Power	1660 shp
TO Power / Weight	8.54 shp/kg
Service Ceiling	20000 ft
Output Shaft Speed	23000 rpm

From linear momentum theory, induced velocity in the rotor plane is calculated at the sea level on a standard day.

$$v_i = \sqrt{\frac{T}{2*\rho*A}} = \sqrt{\frac{(\frac{4209.05}{2}*9.81)}{2*1.225*19.63}} = 20.72\ m/s$$

Ideal power per rotor is calculated.

$$P_{ideal} = T*v_i = 20645.4*20.72 = 427.772\ kW = 581.608\ \text{hp}$$

$$FM = \frac{Ideal\ Power}{Induced\ Power + Profile\ Power}$$

By the help of the Leishmen figure of merit is assumed as 0.75.[4]

The actual power required per rotor to overcome induced and profile losses will be:

$$P_{actual} = \frac{581.608\ hp}{0.75} = 775.48\ hp$$

Result is multiplied by two to account for both rotors. Also, transmission losses are assumed to be as 5 %.

$$P_{actual} = 1550.96*1.05 = 1628.508\ hp$$

Selected turboshaft engine is satisfying power requirements of the tilt rotor both for two engines operative and one engine inoperative cases.

Same procedure is applied for the 4000 m hover case.

$$v_i = \sqrt{\frac{T}{2*\rho*A}} = \sqrt{\frac{(\frac{4209.05}{2}*9.81)}{2*0.8194*19.63}} = 25.33\ m/s$$

$$P_{ideal} = T * v_i = 20645.4 * 25.33 = 523.012\ kW = 711.1\ hp$$

$$P_{actual} = \frac{711.1\ hp}{0.75} = 948.13\ hp$$

$$P_{actual} = (948.13 * 2) * 1.05 = 1991.08\ hp$$

Tilt rotor can hover at 4000 m when no problem exists at the engines. But tilt rotor cannot hover at this altitude when one engine inoperative.

5.1.FUEL TYPE

At present time, the most common fuels used in both military and commercial aircrafts are Jet A and JP-8 (Jet A-1). They are much a like but Jet A-1 has lower freezing point than Jet A. Jet A-1 has a freezing point -58°F, Jet A has a freezing point -40 °F. The other difference is the mandatory addition of an anti-static additive to Jet A-1. It is clear that Jet A-1 has advantages in terms of cold weather performance and also weight considerations. Both of them are kerosene type fuels. For the fuel analysis, Jet A-1 is used. Some important fuel parameters are mentioned at below.

Parameters	Jet A-1
Density at 15 Celsius	0.803 kg/l
Specific Energy	43.15 MJ/kg
Energy Density	34.7 MJ/l

Total fuel consumption is calculated at the previous parts.

Total fuel consumption [kg]	962.206

Necessary volume at each wing for fuel is determined as 0.599 m^3.

The fuel tanks locations are presented in the following figures. The fuel tanks located in the wings and the cabin of the helicopter. The blue tanks define the fuel tanks in the wing, and green ones define the feed tanks. Similarly, the yellow ones presents the fuel tanks located in the cabin.

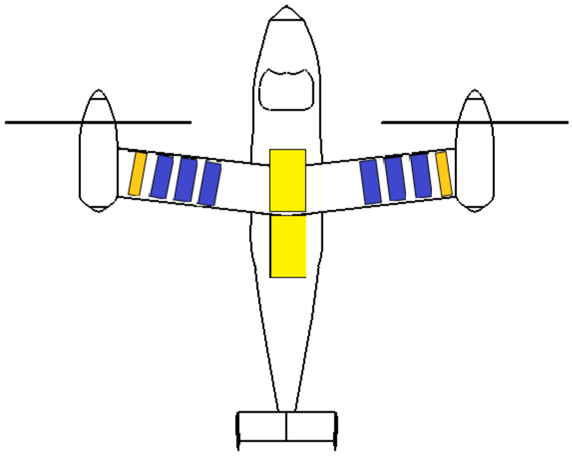

Figure 5 Fuel tank locations

5.2.COCKPIT DESIGN

In cockpit design process, there are numerous considerations to fulfill the mission requirements. In this document, some considerations taking an account for our helicopter design will be explained briefly.

It is critical to enable the pilot to control the helicopter by using components existing his/her environment. Here, several conditions for optimum cockpit designing are written item by item.

(1) Number of Pilots and Crew Members
(2) Pilot/Crew Mission
(3) Pilot/Crew Comfort/Hardship Level
(4) Pilot Personal Equipment
(5) Control Equipment
(6) Measurement Equipment
(7) Cockpit Integration

Our helicopter cockpit is designed by following the conditions itemized above. The number of pilots and crew members depend on the customer's order or based on the airworthiness/mission requirements. According to Teknofest Specifications, our design should contain one pilot as a crew. For this reason, it is important to consider workload factors, the accessibility, ease and simplicity of operation of all necessary flight, power, and equipment controls. Pilot/Crew Comfort/Hardship Level involves providing the pilot with an opportunity in the sense of reasonable cockpit environment such as cockpit space, pressure, temperature, humidity and noise. In short, allowing the pilot to have a comfortable environment during the mission is our purpose. Likewise, Pilot Personal Equipment contains the items that required for the pilot comfort and safety. The pilot seat is the one of the examples in terms of the transferring his/her weights to it. The other consideration in the cockpit design is the control equipment. It can easily come out that the moving the control surfaces and move the throttle is critical in the design. The pedals to control rudder, the stick to control the elevator and aileron should be designed by considering anthropometric measurements. Similarly, the measurements of the helicopter velocity, altitude etc. (flight parameters) should be screened to the pilot to ensure a successful flight.

In the final cockpit design, the various requirements mentioned so far will form our cockpit. It is the crucial point should be thought that the anthropometric characteristics, which means that the specified average human weights or heights should be considered. In our cockpit design, the values for these parameters published by NASA is taken into consideration. Our goal is to manufacture this helicopter for using the Asia, the averaged heights and weights are taken with respect to the Asians. The anthropometric consideration in cockpit sizing is done with respect to the Figure 9**.**

6. FIGURES

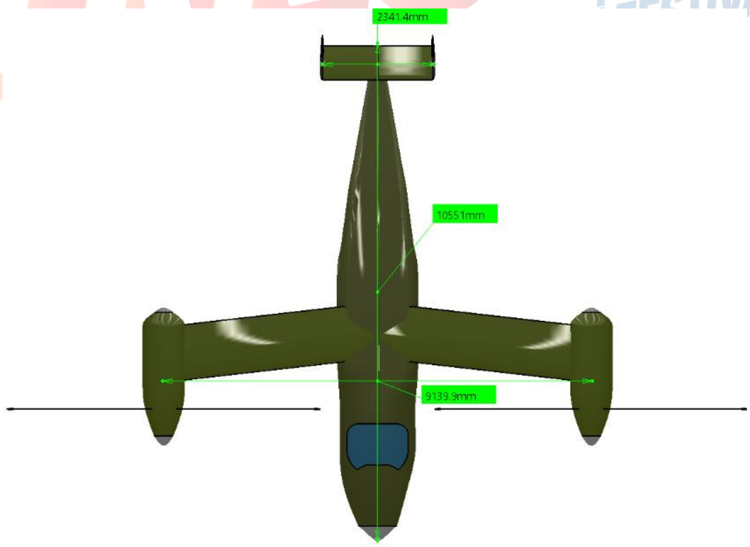

Figure 6 Dimensions of the Helicopter HB-1. (Top View)

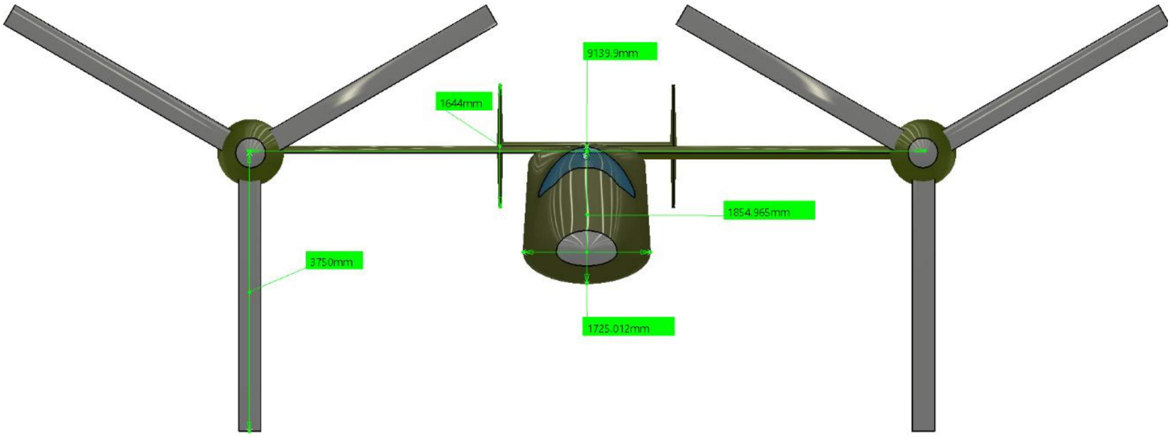

Figure 7 Dimensions of the Helicopter HB-1. (Front View)

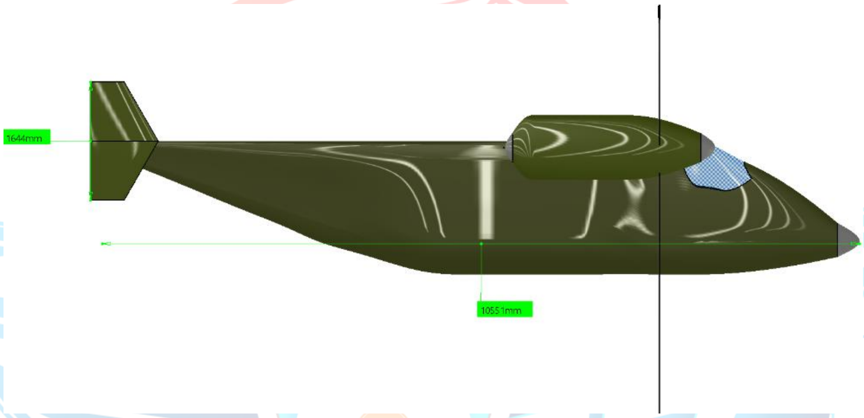

Figure 8 Dimensions of the Helicopter HB-1. (Left View)

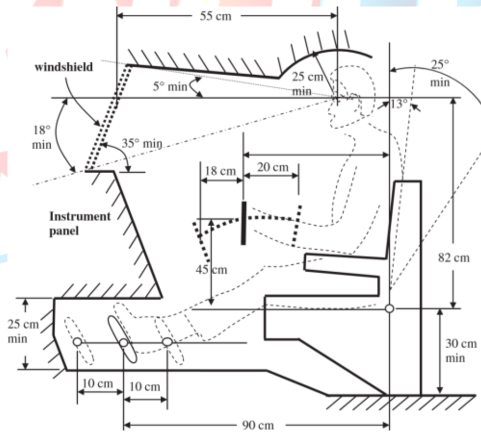

Figure 9 Anthropometric Cockpit Design.**[3]**

Figure 10 Cargo Dropping in Hover.

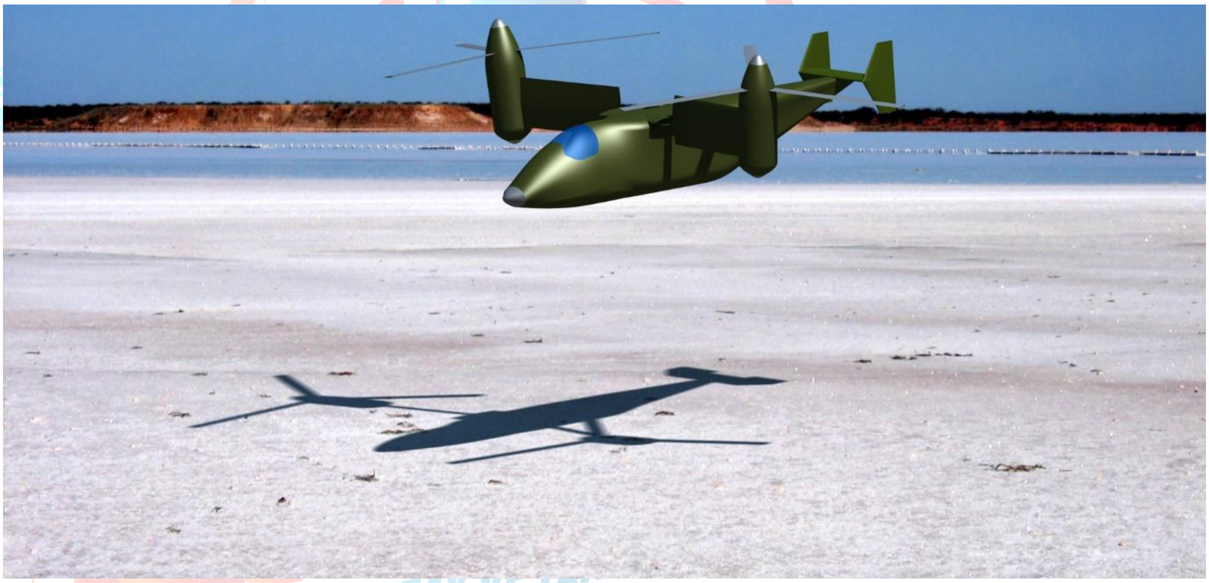

Figure 11 HB-1 in Helicopter Mode.

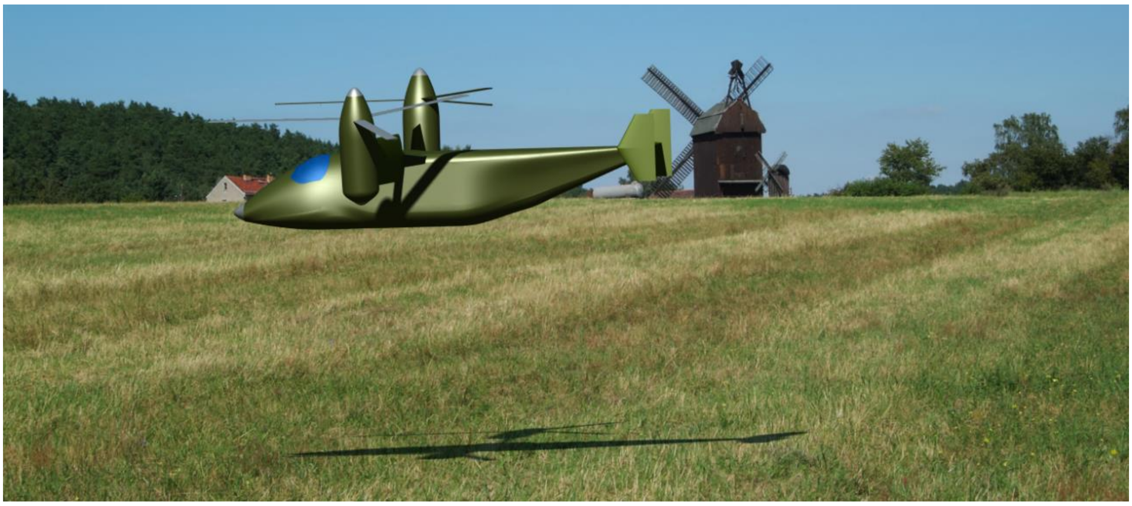

Figure 12 Helicopter in Take-off.

Figure 13 Helicopter in form change.

Figure 14 Helicopter in cruise.

7. REFERENCES

[1] Federal Aviation Administration, U.S. Department of Transportation, Helicopter Flying Handbook: FAA-H-8083-218

[2] Raymer, D. p. (n.d.). Aircraft Design: A Conceptual Approach. American Institute of Aeronautics and Astronautics.

[3] Mohammad Sadraey, Aircraft Design-A Systems Engineering Approach, A John Wiley & Sons, Ltd., Publication, Chapter 5 Wing Design:203-206, 2013

[4] J. Gordon Leishman, Principles of Helicopter Aerodynamics, 2000