DESIGN OF AUTONOMOUS UNMANNED AERIAL ROBOTIC VEHICLE FOR THE INTERNATIONAL FUTURE FLIGHT DESIGN (FFD) COMPETITON-2013

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CONTENT

- Objective & Missions
- Rules & Requirements of FFD-2013 Competition
- Design Phase of Autonomous UAV
- Production Phase of Autonomous UAV
- Flight Tests and Performances
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OBJECTIVES & MISSIONS

The primary objectives:

- ✓ To design and produce a <u>modular</u> UAV,
- ✓ To control UAV manually with Remote Control (R/C),
- ✓ To perform <u>autonomous flight including autonomous take off & landing,</u>
- ✓ To reach a fire zone in the flight arena by performing necessary manevours,
- ✓ To <u>leave the water bottles with parachutes over the intended area safely</u>
- ✓ To return back to the initial start line safely.

There are 3 different mission categories in FFD-2013 competition called as

- ➢ Mission I (Remote Control Mission)
- ➢ Mission II (Remote Control Mission)
- ➢ Mission III (Autonomous Mission with autonomous landing and take off)

A completely original radio-controlled aerial vehicle was designed and constructed for Mission I and Mission II and an original autonomous air vehicle was designed and constructed for Mission III.

The overall score of the competition is calculated to take into account the modularity, timing as well as all the scores of each missions according to their importance.

Appretiated!

Very complex, intelligently designed and optimum formula was generated by Turkish Airforce Academy to evaluate the overall score of each competitors in FFD-2013.

RULES & REQUIREMENTS

- Battery packs must weight less than 3 kg.
- All flight hardware must fit in a rectangular prism case. No other case shape will be accepted.
- The assembly and checkout time must be completed in less than 5 minutes.
- The design should be modular to get the higher scores.
- As payloads, common type of 500 ml bottle of water is used. Maximum 4 bottles are loaded .

The number of payloads for each mission is as given below:

- For mission #1, one bottle payload is required.
- For mission #2, four bottles payload are required.
- For mission #3, three bottles payload are required. For this mission, the payloads should land with parachutes and a successful landing means no leakage on the bottles.

MISSION RULES & REQUIREMENTS

According to the flight pattern, the details of each mission and general specifications can be stated as:

Mission#1

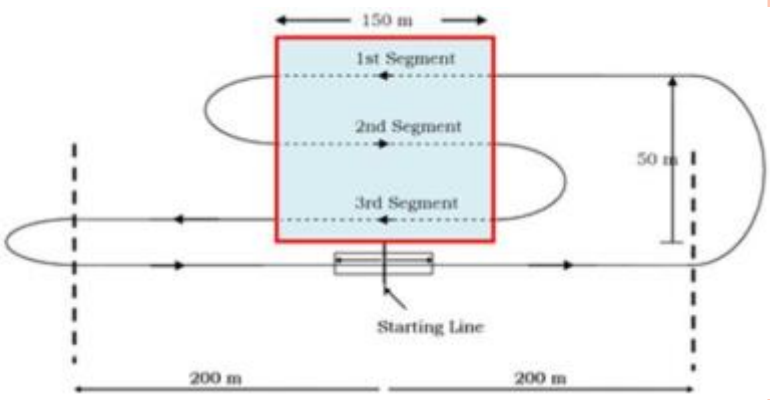
- Mission#1 includes a flight with one-bottle payload and the flight pattern is given in Figure.
- 2-Lap ferry flight is required. Second lap is complete when the aerial vehicle passes over the start/finish line while still in the air.
- The time is taken from the start of the hand launch to completion of the second lap for mission #1.

Mission#2

- It includes a flight with 4-bottle payload and the flight pattern is given in Figure.
- 1-Lap flight is required. The lap is completed when the aerial vehicle passes over the start/finish
- line while still in the air.
- Time will begin with the aerial vehicle on the start/finish line and time will end when mission is completed. Time contains payload loading and flight.
- The aerial vehicle will be "safe" (fuse removed) during the loading.

Mission#3

- It includes a flight with 3-bottle payload to the target area and dropping them in order (in each flight segment) inside the target area.
- Payload is landing with a parachute.
- A successful landing means no leakage on the bottle.



SCHEDULE

Task Name	Start	Finish
Design, Build and Fly	Sun 23.12.12	Fri 10.05.13
Start of FFD2013	Sun 23.12.12	Sun 23.12.12
Organisation and Task Planning Phase	Sun 23.12.12	Sun 13.01.13
Conceptual Design Phase	**Mon 07.01.13**	**Sun 27.01.13**
Literature Survey and Conceptual Design Phase	Mon 07.01.13	Sun 27.01.13
End of Conceptual Design	Sun 27.01.13	Sun 27.01.13
Preliminary Design Phase	**Mon 28.01.13**	**Sun 17.02.13**
Preliminary Design	Mon 28.01.13	Sun 17.02.13
End of Preliminary Design	Sun 17.02.13	Sun 17.02.13
Preregistration for Competition	Mon 25.02.13	Mon 25.02.13
Detailed Design Phase	**Mon 18.02.13**	**Sun 10.03.13**
Detailed Design	Mon 18.02.13	Sun 10.03.13
End of Detailed Design	Sun 10.03.13	Sun 10.03.13
Manufacturing	**Mon 04.03.13**	**Sun 17.03.13**
Manufacturing	Mon 04.03.13	Sun 17.03.13
End of Manufacturing	Sun 17.03.13	Sun 17.03.13
Test and Performance Analysis	**Mon 18.03.13**	**Wed 03.04.13**
Testing	Mon 18.03.13	Fri 29.03.13
Performance Analysis and Optimisation	Fri 29.03.13	Wed 03.04.13
Report Preperation and Submission	Fri 01.02.13	Fri 05.04.13
Final Tunings and Preperations	Fri 05.04.13	Fri 10.05.13
FFD-2013 Competition	Fri 10.05.13	Sun 12.05.13
Awards	Sun 12.05.13	Sun 12.05.13

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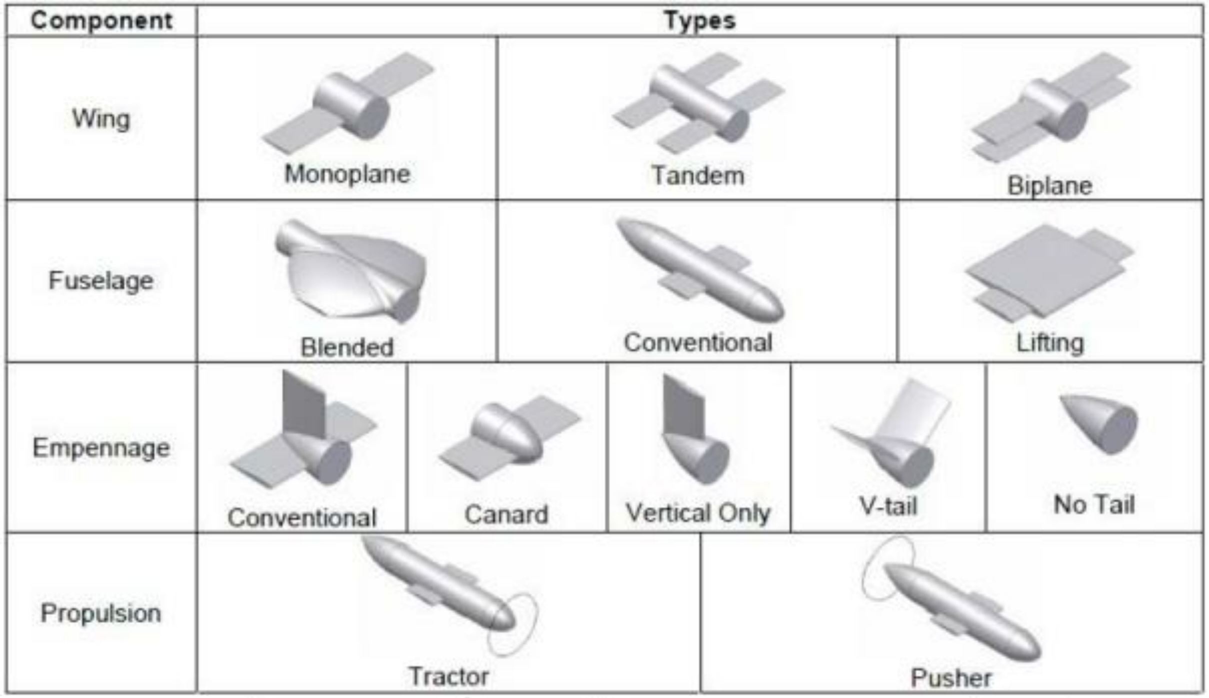
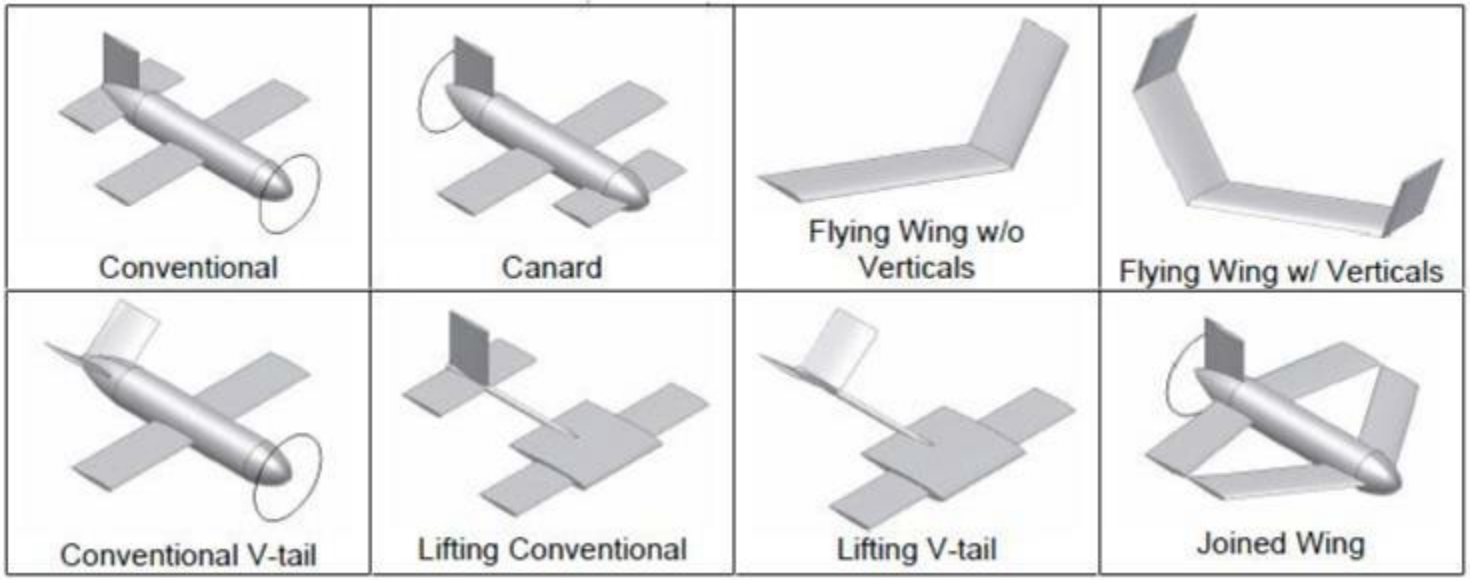
Conceptual Design & Literature Review



Component	Types				
Wing	Monoplane	Tandem	Biplane		
Fuselage	Blended	Conventional	Lifting		
Empennage	Conventional	Canard	Vertical Only	V-tail	No Tail
Propulsion	Tractor	Pusher			



USED HARWARE

- 2.4 GHz ISM band radio R/C control receiver,
- Ardupilot Mega v1.0 (APM1.0) autopilot hardware (for autonomous air vehicle),
- Global positioning system (GPS) (for autonomous air vehicle),
- Interface hardware taking its energy from one unit UBEC, Lipo battery and then regulate it to 5V for APM, receiver and servos.

SUGGESTED & USED COMPUTER PROGRAMS

- XFoil
- XFLR5
- Xplane
- Take all the affordable open source hardware and software and play with them (such as Ardupilot).

AIRFOIL SELECTION PHASE

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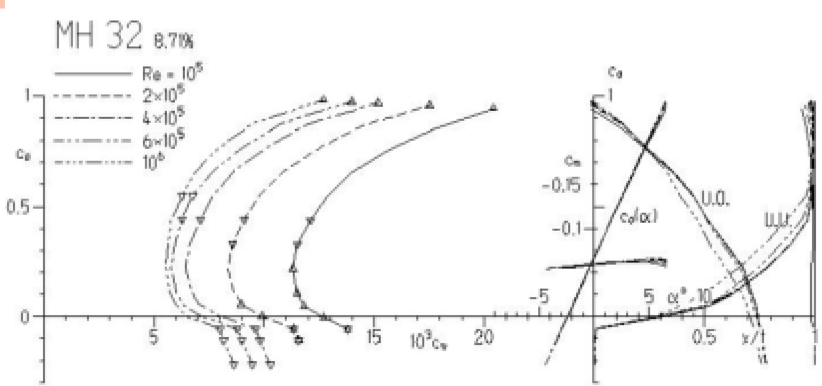
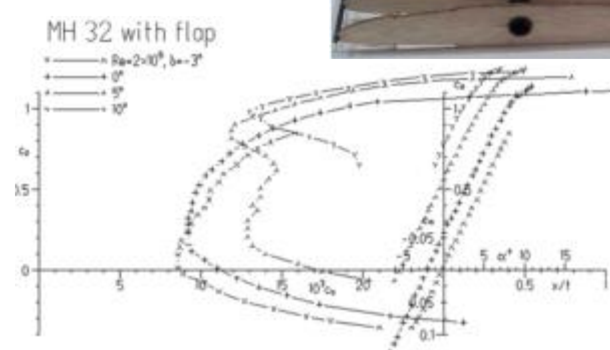
Some properties of MH-32 airfoil can be given as follows as presented in reference [7]:

- MH-32 airfoils are designed for electric powered pylon racing model aircraft (FAI class F5D).
- MH-32 airfoils can also be used for F3B and F3J sailplane models (Model «Cygnus»).

Some characteristics of this airfoil can be given as:

- Thickness: 8.66%
- Moment coefficient of cm c/4 = -0.057.
- Well suited for 22% chord flaps; -3...-4° deflection for high speed flight and up to 10° for duration tasks.
- Can be used at Reynolds numbers of 150'000 and above.



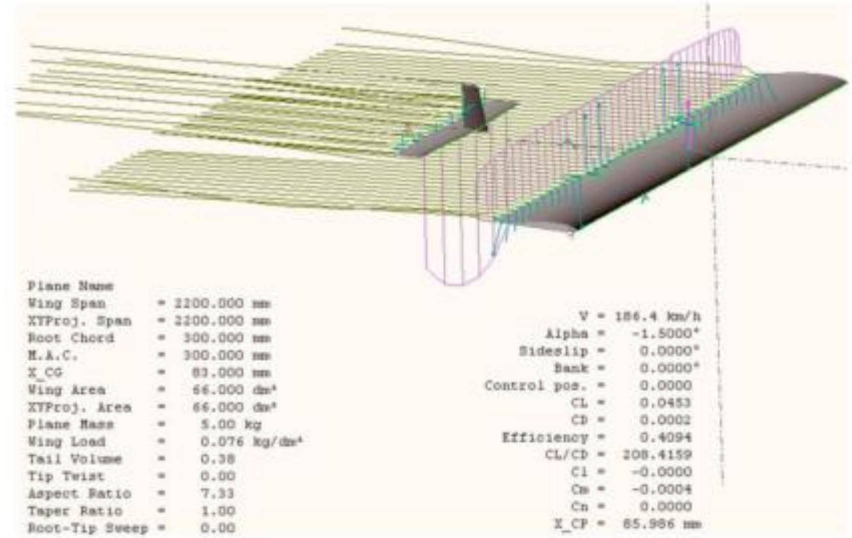


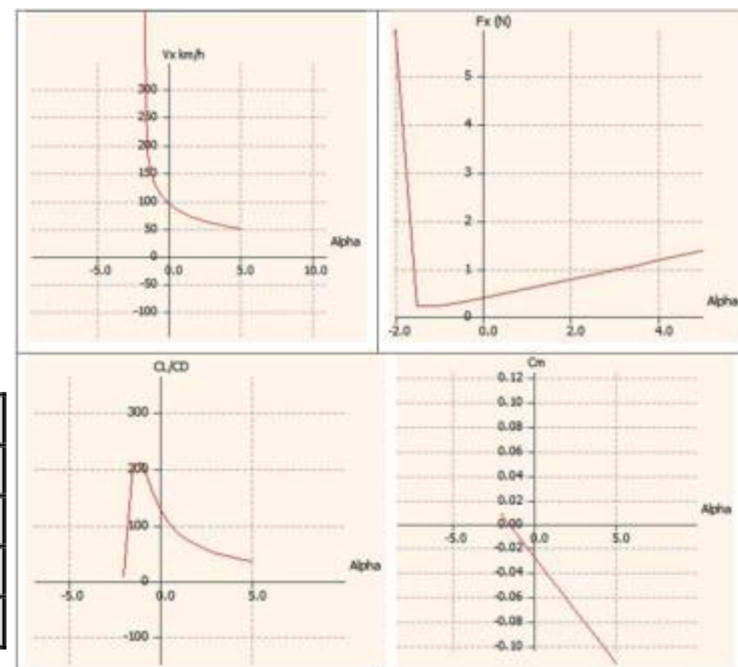
AIRFOIL SELECTION PHASE

XFLR5 is an analysis tool for airfoils, wings and planes operating at low Reynolds Numbers.

It includes:

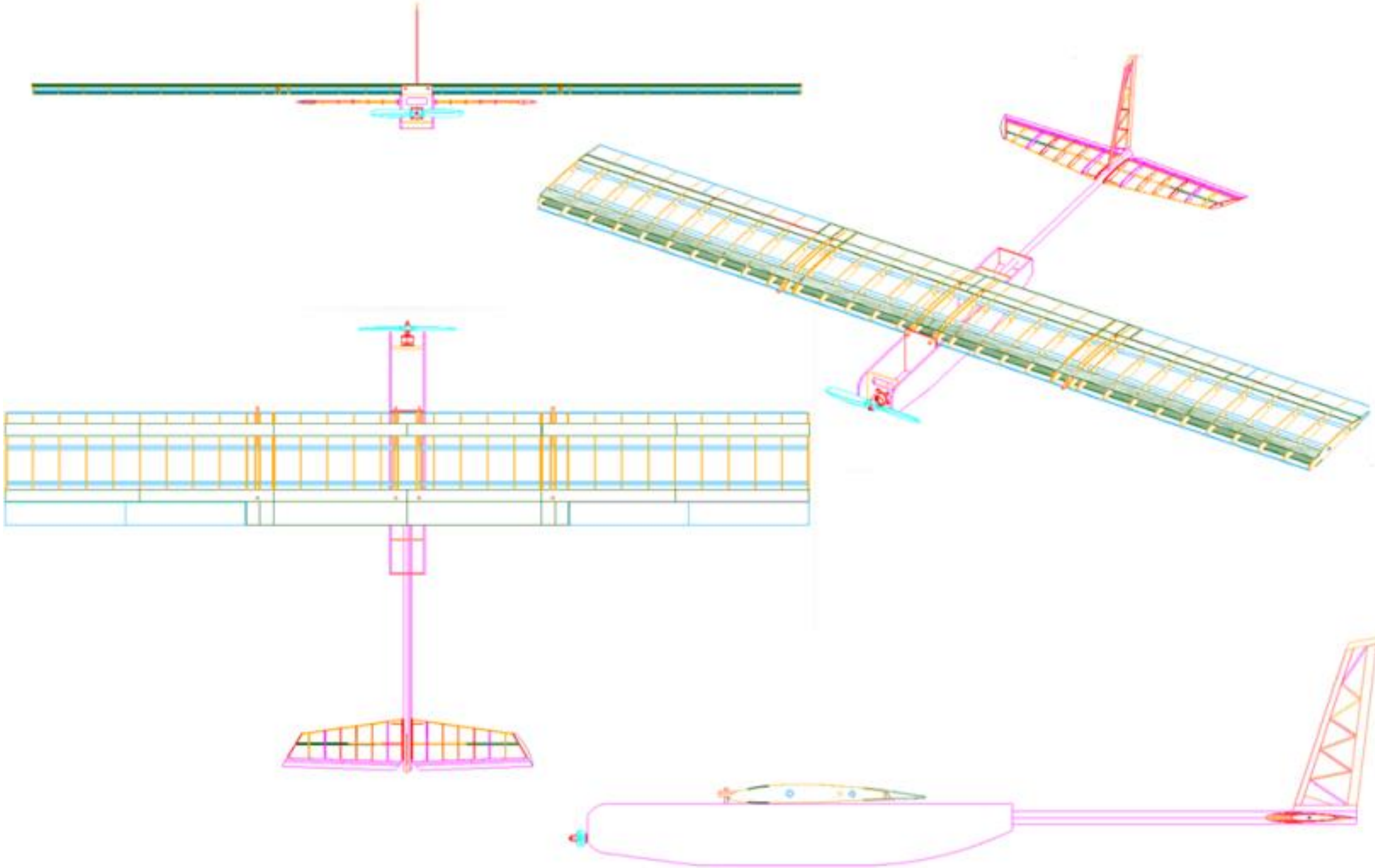
- XFoil’s direct and inverse analysis capabilities,
- Wing design and analysis capabilities based on the following methods:
  - Lifting Line Theory derived from Prandtl's wing theory.
  - Vortex Lattice Method
  - 3D Panel Method





Airfoil Types	MH114	SD7062	HQ 3,5-13
$C_{L,design}$	0.85	0.45	0.48
C_d	0.0081	0.0081	0.008
$C_{L,max}$	1.7	1.55	1.45
C_m	-0.194	-0.082	-0.1

DESIGN OF UAV



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MATERIALS & DIMENSIONS

Parts	Shape or Material Properties	Dimensions
Airfoil Material and Construction	Rectangular Wooden (Balsa)	32 cm x 3 cm MH-32 Airfoil Profile
Wing Planform	Rectangular Balsa Wood Rib Construction	225 cm x 32 cm x 3 cm
Wing Configuration	Mono-Wing without Winglets	225 cm x 32 cm x 3 cm
Spar Structure	Circular Shaft, Carbon Reinforced Fiber (CRF)	Øo x Øi x L 12 x 10 x 750 mm (Top Side) 10 x 8 x 750 mm (Bottom Side)
Tail Boom	Hollow Circular Cross Section Carbon Reinforced Fiber (CRF)	Inner Pipe Øi: 16 mm Outer Pipe Øo: 18 mm
Tail Wing Structure	Conventinal Tail Balsa Wood	Horizontal Stabilizer Vertical Stabilizer
Horizontal Stabilizer	Balsa Wood-Rib	Height x Width: 35x75 cm
Vertical Stabilizer	Balsa Wood-Rib	Height x Width: 29 x 36 cm

WING DESIGN & PRODUCTION





Parts Dimensions	Dimensions/Units
MH-32 Airfoil Profile	Span:32 cm Chord:3 cm
Main Wing	Total Length: 75 cm x 3= 225 cm Width: 32 cm Height: 3 cm
Wing Tip Rod	Diameter Ø = 3 mm, Length L =750 mm
Spar Top Side	Øout x Øin x L: 12 x 10 x 750 mm
Spar Bottom Side	Øout x Øin x L: 10 x 8 x 750 mm

TAIL DESIGN & PRODUCTION

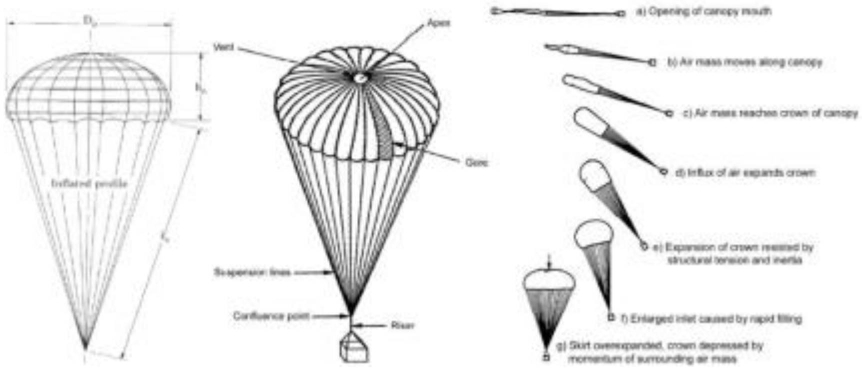
FUSELAGE & LANDING GEAR DESIGN

Fuselage Body	Rectangular Cross Section 3 mm Thick Plywood
Fuselage Floor	3 mm Thick Plywood
Fuselage Body Dimensions	LxWXH: 68 x 10.5 x 10 cm

Front wheels

Back wheel

PARACHUTE DESIGN



Parachute Type	C_D	General Application
Flat Circular Ribbon	0.45 – 0.50	Pilot, Drogue, Deceleration, Descent
Conical Ribbon	0.50 – 0.55	Pilot, Drogue, Deceleration, Descent
Lifting Conical Ribbon	0.55 – 0.65	Lifting Stores (*L/D*~0.7)
Hemisflo Ribbon	0.30 – 0.46	Supersonic Drogue
Ringslot	0.56 – 0.65	Extraction, Deceleration, Descent
Ringslot / Solid Canopy	0.85 – 0.95	Deceleration, Descent
Ringsail	0.75 – 0.90	Descent
Disk-Gap-Band	0.52 – 0.58	Supersonic Drogue, Descent
Guide Surface (Ribbed)	0.28 – 0.42	Stabilization, Pilot, Drogue, Descent
Guide Surface (Ribless)	0.30 – 0.34	Pilot, Drogue, Descent
Rotafoil	0.85 – 0.99	Drogue
Vortex Ring	1.50 – 1.80	Descent

Parachute Descent Rate Calculator [14]

- The descent rate of the load is found as 5.24 meters/sec.
- The recommended parachute diameter for the safe landing is found as ϕ 82 cm.
- The estimated descent time, assuming ejection at 60 meters is obtained as 11 seconds.

Hence, the diameter of the parachute is selected as ϕ 82 cm.

Then child umbrella is used. (COTS)

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This page allows you to predict the speed at which your rockets will descend. Note that it is only an estimate, and values will vary with wind, different air pressures, etc.

Enter rocket mass: [ ] kilograms

Enter parachute diameter: [ ] centimeters or SkyAngle™ size: ---

Choose the shape of your parachute: Round

How did you measure the size of your chute? (For hex and square chutes) Diameter (circular chutes)

(Optional) Estimate the descent time by entering the expected altitude when the parachute will open: [ ] metres

Calculate

Clear

Parachute descent rate calculator version 3.3 by Jordan Hiller.

BOTTLE RELEASE MECHANISMS

Three servos were used to release the three bottles with their corresponding parachutes.

The mechanism is as shown and the toggle switch is used to trigger the mechanism.

ACTUATORS

Manufacturer: Turnigy	Turns: Original wind is 9	ESC: 45A
Model: Turnigy SK-42-40-750 Kv: 750rpm/v	turns, Delta termination.	Cell count: 3-6
No load properties:	Resistance: 35m_Ohm	Suggested Prop:
1.4A, 11.47Volts, 8200 rpm, Kv=715.	Idle Current: 0.8A	13x8 to 14x6
1.74A, 16.56V, 11,900 rpm, Kv=719.	Shaft: 5mm	Power equivalent:
APC e 10x7, 23A, 15.42V, 9400 rpm. 354 watts.	Weight: 149g	0.40-0.61
APC e 15x4, 37.4A, 14.71V, 8000 rpm. 550 watts.	Rated Power: 600W	
*Includes mount and prop adapter accessories		

- Four servo motors for flight control surfaces (ailerons, elevator, rudder)
- Three servos for the payload release mechanisms.

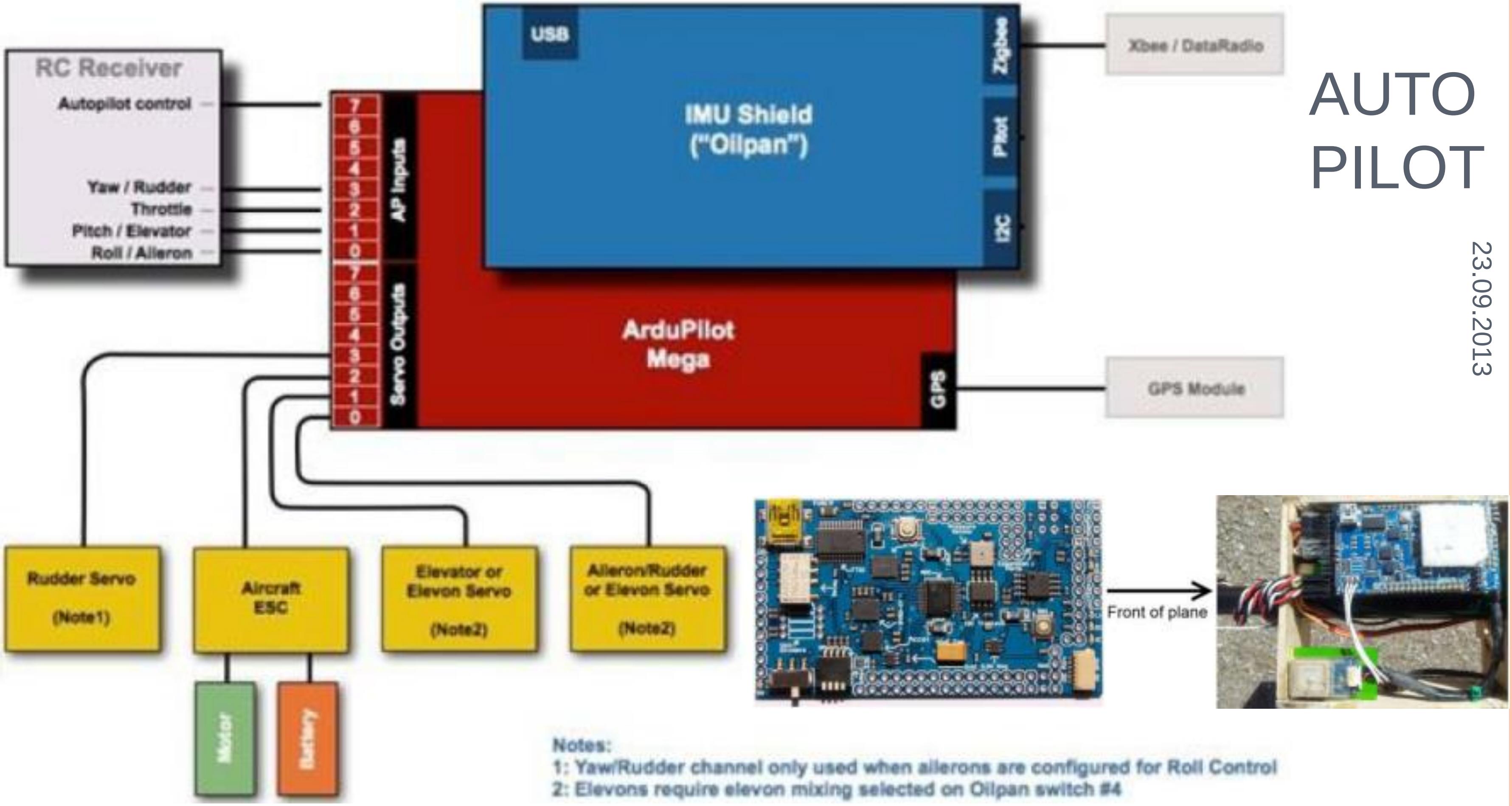
Rule of Thumb:
The tall man should release the UAV.

POWER SUPPLY

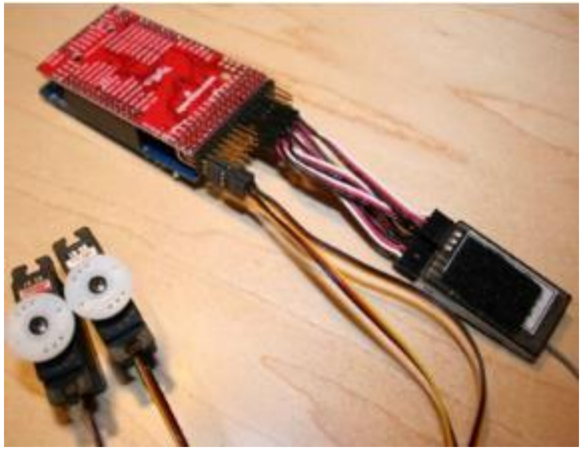
Batteries	Main Battery	Supply Battery
Type	Lithium polymer	Lithium polimer
Number of cells	4-cell	3-cell
Each cell voltage	3.7 Volt	3.7 Volt
Total voltage	3.7 x 4 =14.8 Volt	3.7 x 3 =11.1 Volt
Current (per hour)	5800 mA	2000 mA

Fuse is also used for safety purposes.

AUTO PILOT



RC Channel	Function	APM Connector (v1.0)
1	Roll	0
2	Pitch	1
3	Throttle	2
4	Yaw	3
5	Autopilot control	7



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AUTOPILOT GROUND STATION INTERFACE

ASSEMBLY & BOX

SUMMARY OF DESIGN

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Tail Boom	Hollow Circular Cross Section Carbon Reinforced Fiber (CRF)	Inner Pipe 16 mm Outer Pipe 18 mm
Tail Structure	Conventinal Tail Balsa Wood	Vertical Stabilizer and Rudder is on Horizontal Stabilizer
Fuselage Body	Rectangular Cross Section Plywood	3 mm Thick Plywood 68 x 10.5 cm (Rectangle)
Fuselage Floor	Plywood	3 mm Thick Plywood
Horizontal Stabilizer	Balsa Wood-Rib	75 x 26 cm Rectangle, with 20 degree notches from the middle
Vertical Stabilizer	Balsa Wood-Rib	14x 36,5 x 29 cm Trapezoid
Power Plant	Brushless Motor (Single)	Turnigy AerodriveXP SK 42-40 750kv brushless motor

FLIGHT TESTS & PERFORMANCES

23.09.2013

Critical Parameters	Performance Values	Critical Parameters	Performance Values
Take off speed	10 m/s	Range	Circle with 3 km radius
Cruise speed	16 m/s	Endurance	30 minutes (full loaded) 1 hour (empty)
Landing speed	12 m/s	Maximum velocity	20 m/s
Take off distance	10 m	Rate of climb	3 m/s (Loaded) 6 m/s (Empty)
Stall speeds	10 m/s	Maximum turn rate	4 m/s
Wing loadings	70 gr/dm^2	Minimum turn radius	30 m
Thrust to weight ratios	0.8	Maximum load factor	3 kg (payload) 7 kg (total)

LESSONS LEARNED

- First learn to fly manually well with remote controller,
- Know well all the functionalities and properties of the components used on UAV such as engines, autopilot,ESC, servos, mechanism etc.,
- Learn all the behavior of UAV with many flight tests under different weather conditions (still air, windy air conditions, hidden in front of sun etc.),
- Observe and feel the top and bottom side of UAV well during all the flight,
- Don't use many AAA batteries in the remote controller; one of them can be disappointing. Instead of them use packaged batteries,
- Do not forget that autopilot does not help to balance all the CG related problems, design problems or other unbalances due to the structure,
- The CG of the UAV is usually at the 1/3 of the wing chord. Check the balance of the CG before the flight and add weight to the proper location if necessary,
- Keep it simple and stupid, (very simple switch solution to release parchutes with bottles; use as possible as simple hardware solutions instead of more complex software solutions),
- Use big landing gears (It saves the life of your UAV),
- Don't fly in a crowded pist; especially if the competition is very soon.(Experienced a crash 9 days before the competition.) ,

Lessons LEARNED

- Wing load and wing profile calculation and selections are performed by just taking into account the payload load. However speed and timing is also important and should be taken into account as well. Next time while selecting wing profile, the speed and timing will also be considered.
- Read the rules and requirements of the competition very carefullly.
- Follow the grading during competition and change your UAV design by using modular parts and change your strategy if necessary. If the grading formula is too complex prepare your grading chart to follow your grade as well as the others. Since the grades of FFD-2013 is transparent, we have a chance to prepare our records. Thanks again FFD-2013 commity.
- Team work is very important. If every team member takes responsibility and do his/her job, success is the only result.
- Take all the necessary steps and phases one by one and work hard before entering into the competition. This creates self confidence and generates the belief of success.

OTHER LESSONS LEARNED (FOR LIFE)

- Although you have a team; work as if you are alone!
- Don’t try to carry three watermelon between two arms (education, competition for the hobby, work, home, etc. etc....); focus on a one thing at a time!
- Work hard all the time!
- Never lose hope and never give up!
- Be patient and cool in all the races!
- Enjoy from each moment of the competition and life!
- Follow the lessons learned rules stated above, and finally you will get the success!

CONCLUSION

- 1st Place
- 3rd Place

In FFD-2013 competiton.

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THANKS

- Thanks a lot to Turkish Airforce Academy to organize a very good competition FFD-2013 and a perfect air show,
- Thanks a lot to Ankara Model Plane Club and its very special and experienced members for all the lessons that I have learned,
- Thanks a lot to AIAC commity for the preperation of the conference and to give a chance to present all the works performed,
- Finally, thanks to you for your listening and patience.

QUESTIONS ?