THE LIFESAVER DESIGN

LifeSaver A and LifeSaver B

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1. UAV Name

The team chose the name of “LifeSaver” because it highlights the aircraft aim on which the team focused its attention during all the design: fly in all-weather conditions enduring to possible critical failures in order to carry precious cargo and save precious lives.

2. Design requirements

The project is focused on the design of a VTOL UAV which allows the user to vertically take off, fly for a range of 100 kms and vertically land to the designed landing point carrying on board a minimum cargo weight of 3,4 kgs.

It is clear that the 80% of the airborne time is spent by the UAV in flight cruise and the remaining 20% time is allocated to the vertical operations (take offs and landings).

With this requirement the team chose to join the capability of an airplane to fly at least at 80 km/h with the capability of an multi-rotor hovering, vertical take offs and landings.

3. UAV airframe description

The project is proposed in two versions:

- LifeSaver A and
- LifeSaver B

LifeSaver A is composed by:

- Main fuselage
- Main wing with trapeze shape
- V tail
- A couple of cruise ducted engine assembly. Each assembly is composed by
  - Two counter rotating motors
  - Two propellers
  - One duct
- A couple of hover engine assembly. Each assembly is composed by
  - two counter rotating motors
  - two counter rotating propellers
- A tail engine assembly to control the pitch. The assembly is composed by:
  - A motor
  - A propellers
- Fixed landing gear
- Cargo box

LifeSaver B is composed by:

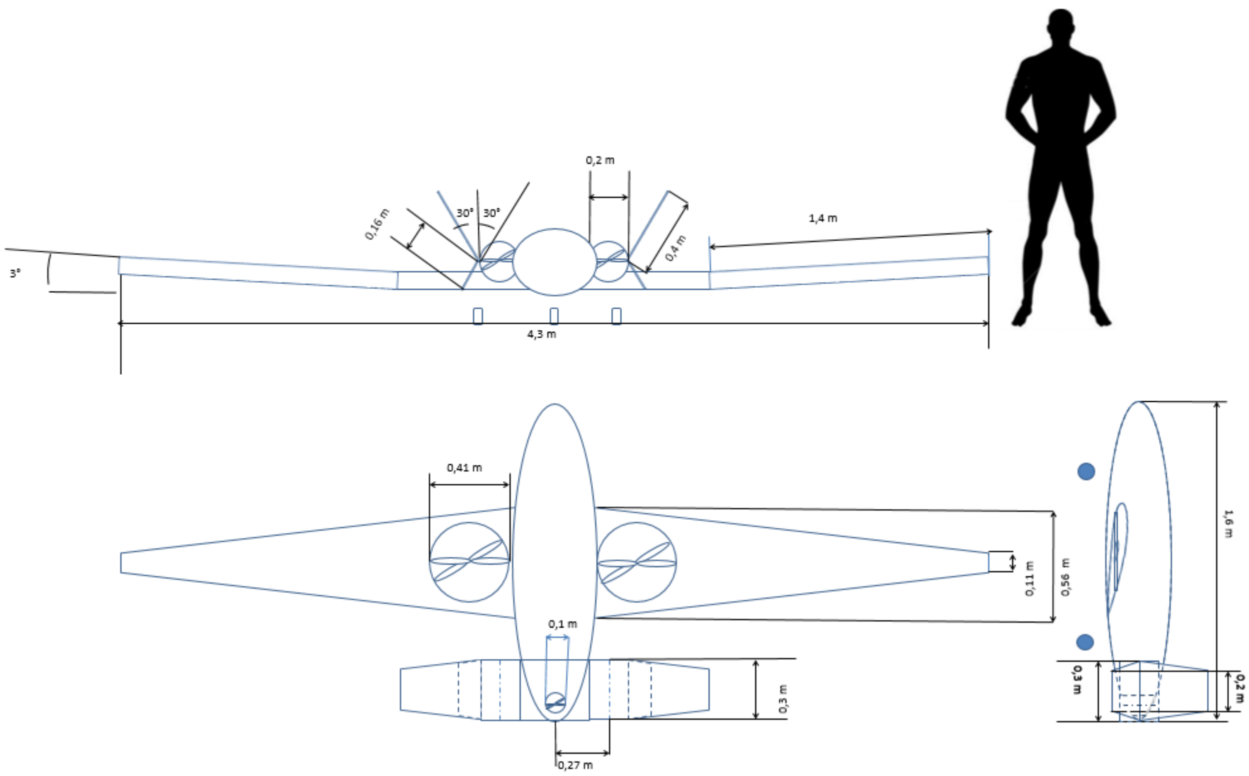
- Main fuselage
- Main wing with trapeze shape
- V tail
- A couple of cruise ducted engine assembly. Each assembly is composed by

    - Two counter rotating motors
    - Two propellers
    - One duct
- Two couples of hover engine assembly. Each assembly is composed by
    - two counter rotating motors
    - two counter rotating propellers
- Fixed landing gear
- Cargo box

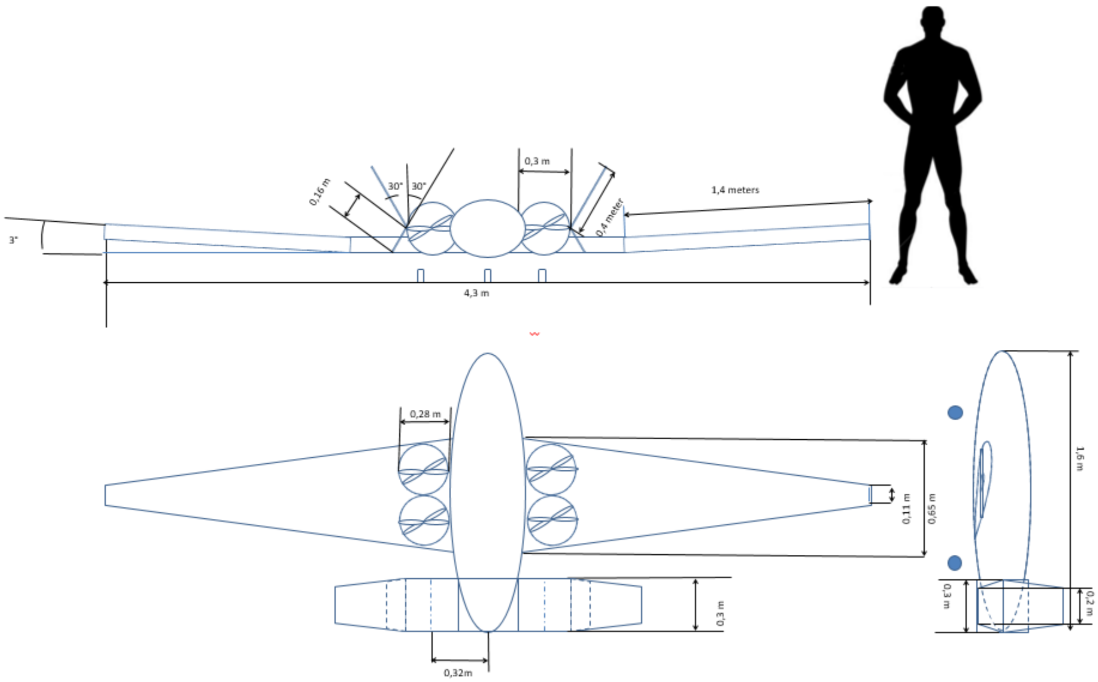
Due to the CG location which must be neutral, the components location of configuration A are different from configuration B. For further information please refer to chapter 15.

In the following pictures are shown the UAVs with the main dimensions.

<u>LifeSaver A</u>



LifeSaver B



4. Wing design

LifeSaver – Configuration A

Lift propellers are located inside the wing (in two nacelles) as close as possible to the fuselage in order to minimize the bank momentum caused by an engine failure.

Considering the lift propeller disk loading equal to 47 and considering a couple of 2 counter rotating propellers, comes out that the disk diameter is equal to 0,41m.

Considered:

- Weight=24,9 Kg,
- Air density=0,954 kg/m3,
- Wingspan=4 m;
- V = 22 m/s,
- Wing loading=15

Came out that the wing surface must be equal to 1,6 m2 but considering the location of the lift propeller (on the wing roots) the available surface must be reduced by the total lift discs area and sot the wing surface is 1,39 m2, the Aspect ratio is 11,46.

The team chose NACA 2412 which provide the required lift coefficient of 0,76 with a pitch angle of 6 degrees and a maximum lift coefficient of 1,2.

Considered all the above mentioned data, the stall speed is equal to 7,73 m/s @ 0 meters ASL.

LifeSaver – Configuration B

Also for configuration B lift propellers are located inside the wing (in four nacelles in order to improve the hovering control) as close as possible to the fuselage in order to minimize the bank momentum caused by an engine failure.

Considering the lift propeller disk loading equal to 50 and considering two couples of 2 counter rotating propellers, comes out that the disk diameter is equal to 0,28m.

Considered:

- Weight=24,9 Kg,
- Air density=0,954 kg/m3,
- Wingspan=4 m;
- V = 22 m/s,
- Wing loading=16

Came out that the wing surface must be equal to 1,55 m2 but considering the location of the lift propeller (on the wing roots) the available surface must be reduced by the total lift discs area and sot the wing surface is 1,307 m2, the Aspect ratio is 12,23.

The team chose NACA 2412 which provide the required lift coefficient of 0,81 with a pitch angle of 8 degrees and a maximum lift coefficient of 1,2.

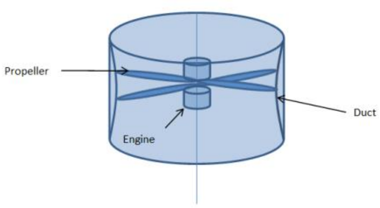
Considered all the above mentioned data, the stall speed is equal to 7,9 m/s @ 0 meters ASL.

5. Power plant design

LifeSaver – Configuration A

Power plant, as shown in the following picture, is mainly composed by:

- Lift engines for configuration A (x4 – Mod. C5055/08 purchasable here www.cmodels.it)
- Cruise engines (x4 – Mod. C2822/27 purchasable here www.cmodels.it)
- One tail engine dedicated to the pitch control (x1 – Mod C2822/25 purchasable here www.cmodels.it)



Lift engines are ducted fans each one composed by:

- 2 counter rotating propellers
- 1 duct designed to maximize the thrust
- 2 motors

Every lift engine of LifeSaver configuration A is required to supply a maximum of 8,5 kgs of thrust in order to supply at least 25 kgs with three engines in case of one engine failure.

Supposing that:

- The Thrust coefficient of the propeller is equal to 0,09
- Air density equal to 0,954 kg/m3
- Propeller diameter equal to 0,4 m for configuration A

From the propeller thrust formula comes out that the rotor speed for configuration A must be equal 192 rounds/sec.

Even in this case the tip velocity is much lower than the speed of sound avoiding compressibility troubles.

Cruise engines are ducted fans each on composed by

- 2 propellers
- 1 duct designed to maximize the thrust
- 2 motors

Every cruise engine is required to supply a maximum of 2 kgs of thrust

Supposing that:

- The Thrust coefficient of the propeller is equal to 0,09
- Air density equal to 0,954 kg/m3
- Propeller diameter equal to 0,2 m

From the propeller thrust formula comes out that the rotor speed must be equal 377 round/sec.

Even in this case the tip velocity is much lower than the speed of sound avoiding compressibility troubles.

Tail engine is composed by:

- One motor
- One propeller

The engine and the 0,1 meter propeller diameter supply 1kg of thrust which is enough to control the pitch during hover flight.

<u>LifeSaver – Configuration B</u>

Power plant is mainly composed by:

- Lift engines for configuration B (x8 – Mod. C3536/08 purchasable here www.cmodels.it)
- Cruise engines (x2 – Mod. LC3542-6T purchasable here www.myrcmart.com)

Lift engines are ducted fans each one composed by:

- 2 counter rotating propellers
- 1 duct designed to maximize the thrust
- 2 motors

Every lift engine of LiveSaver Configuration B is required to supply a maximum of 3,6 kgs of thrust in order to supply more than 25 kgs in case of one engine failure (3,1 kgs in case of "all engines operative")

Supposing that:

- The Thrust coefficient of the propeller is equal to 0,09
- Air density equal to 0,954 kg/m3
- Propeller diameter equal to 0,28 m for configuration B

From the propeller thrust formula comes out that the rotor speed for configuration A must be equal 255 rounds/sec instead

Even in this case the tip velocity is much lower than the speed of sound avoiding compressibility troubles.

Cruise engines are ducted fans each on composed by

- 2 propellers
- 1 duct designed to maximize the thrust
- 2 motors

Every cruise engine is required to supply a maximum of 4 kgs of thrust

Supposing that:

- The Thrust coefficient of the propeller is equal to 0,09
- Air density equal to 0,954 kg/m3
- Propeller diameter equal to 0,3 m

From the propeller thrust formula comes out that the rotor speed must be equal 237 round/sec.

Even in this case the tip velocity is much lower than the speed of sound avoiding compressibility troubles.

6. V-tail design

The design point of the V-tail is the capability to contrast the yaw generated in case failure to one cruise engine.

This design is applicable both for configuration A and B.

Supposing that the total engine thrust to fly at 22m/s is about 83N, the team assume the necessary trust to fly at 12 m/s is 41N in case of single engine failure.

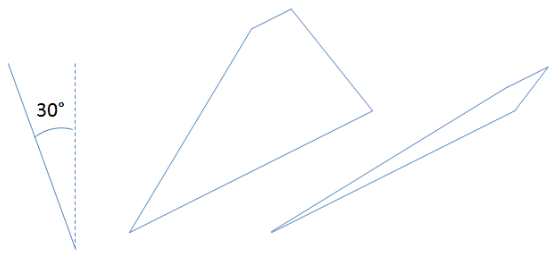
The team suppose that the UAV must fly at low speed (12 m/s) with one engine delivering a thrust of 41N.

Considering:

- The V-tail angle of 30 degrees (on the vertical)
- The thrust arm of 0,29m
- The yaw force arm equal to 0,6m
- The Maximum Lift Coefficient of 1,2 (adopting a symmetric airfoil profile - NACA 0009 @12°)

Comes out that Yaw force is 10N for each V-tail surface.

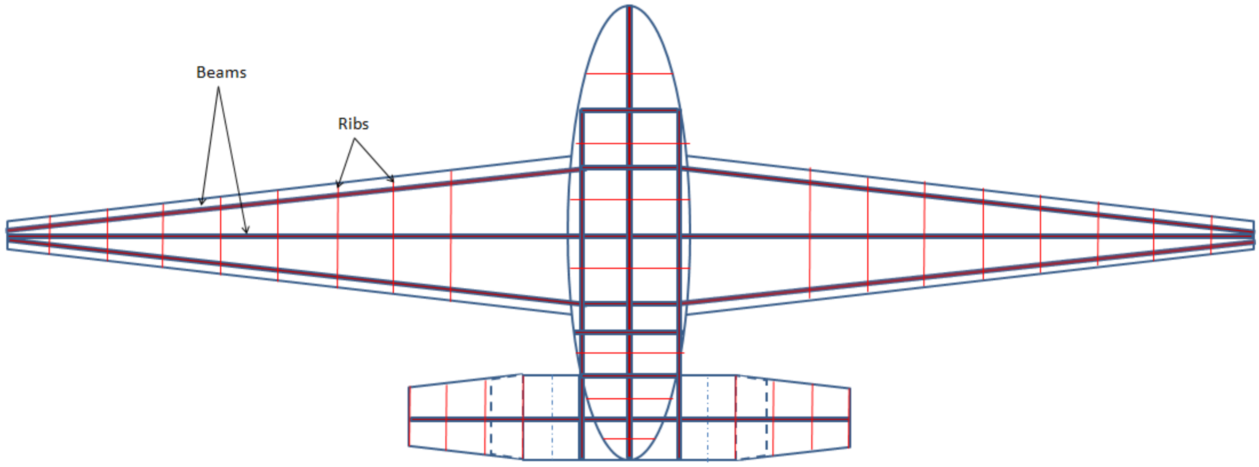
From the lift formula (also considered the 30° angle of the V-tail) comes out that the Total V-tail surface must be equal to 0,14 m2.



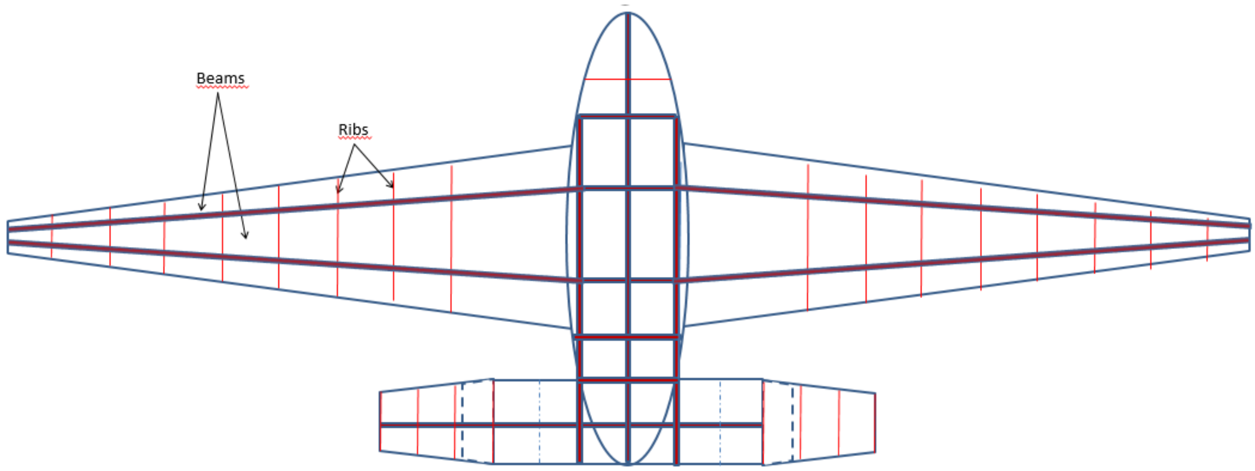
7. Wing Structure and fuselage design

Wing and fuselage structures are composed of beams and ribs according to the picture reported here below.

LifeSaver A



LifeSaver B



Note: dedicated structural analysis must to be conducted (possibly in a later phase) in order to maximize the structure strength and minimize the weight.

The material chosen for the structure is carbon fibre composite which maximize the strength but reduces the weight.

The estimated airframe weight is 5,5 kgs but might be increased up to 6,7 kgs thanks to the batteries weight which is lower than what estimated in the frame sheet.

8. Energy storage and batteries use

Required battery power for configuration A is 1073 Wh and batteries should have a maximum weight of 8,136 kgs.

Required battery power for configuration B is 1082 Wh and batteries should have a maximum weight of 8,2 kgs.

The team considered to design the power supply system in accordance with the configuration B requirements using 6 cells LiPo batteries in order to have the highest voltage possible (6 x 3,7volts = 22,2 Volts). This results in the need of 49 Ampère.

Adopting a battery with 6200 mAh, 22.2V, 50 C (purchasable here: http://www.jonathan.it/batterie/pacchi+lipo/6+celle/fullpower/447718_batteria-lipo-6s-6200mah-50c-gold-edition-v2-spina-tipo-xt60.html) comes out that the UAV needs for 8 battery packages.

Considering that the weight of every single battery pack is 0,835 kg, it results in a total weight amount of 6,68 kgs which is at least 1,2 kgs lower than the allocated weight.

The UAV user is free to choose how to allocate the remaining 1,2 kgs for:

- Using it for extra payload (increasing the maximum payload weight up to 5,3 kg for 100 kms range or at least 7,5 kg for 60 kms range)* or
- Using 2 additional batteries (4200 mAh, 22.2V, 50 C purchasable here: http://www.jonathan.it/batterie/pacchi+lipo/6+celle/fullpower/447713_batteria-lipo-6s-4200mah-50c-gold-edition-v2-spina-tipo-deans.html) to extend of the 21% the range of the UAV
- Using the extra weight for the structure design

* See chapter 12

9. Catastrophic event mitigation

The starting point of the aircraft design is the flight safety.

In order to reduce at minimum the catastrophic effects of a possible engine failure to the cruise engine or to the lift engines the team chose to adopt a pair of counter rotating propellers driven by two different engines.

In order to maximize the cruise engine trust, the team chose to adopt ducted fans, optimized for the design cruise speed.

This design allows to:

- Minimize the probability of a double motor failure (on the same aircraft axis) and

- Minimize the effect of a single motor failure (on the same aircraft) because the working motor can however produce thrust

In case of one lift engine failure during hovering, the other engine(s) assembly compensates the amount of power lost and, thanks to the flight management computers, the engines located on the opposite wing plus the cruise engines compensate the differential torque in order to maintain the heading during the hovering.

In case of one cruise engine failure during cruise, he Vtail is designed to compensate the yaw. In LifeSaver A the yaw is compensated also by the remaining three engines.

Moreover the V tail have the aim to give the aircraft the roll, yaw and pitch controllability during flight.

In case of failure to the tail engine (only available for configuration A), the aircraft control in hovering is degraded but do not affect the flight safety.

The aircraft is also equipped with one emergency parachutes which might be used in case of loss of control.

10. Landing gear and breaking power

The set of wheel located on the aircraft belly provide the aircraft the capability to perform rolling take off and landings.

In order to reduce the weight, braking power is provided by the forward flight engines in reverse mode.

11. Flight dynamic

<u>Hovering flight – LifeSaver A</u>

During hover mode, the thrust is provided by the two sets of coaxial and counter rotating propellers which can controls also the lateral translation parallel to y axis.

Directional control on x axis is provided by the forward flight engines. Instead the directional control on z axis is provided by the lift engines.

The control of pitch is provided by the tail engine.

<u>Hovering flight – LifeSaver B</u>

During hover mode, the thrust is provided by the four sets of coaxial and counter rotating propellers which can controls pitch, bank and yaw

<u>Cruise flight – LifeSaver A and B</u>

During cruise flight, the pitch and roll controllability are provided by the V-tail.

Yaw controllability is provided either by the engines and the Vtail.

In case of very slow cruise flight the extra lift required might be provided by lift engines.

This design allow the structure to be less complex avoiding the installation of complicate flap mechanisms.

Headwind – LifeSaver A and B

Aircraft is able to sustain 10 knots of head wind thanks to its amount of thrust of 8 kgs (78 N)

Crosswind – LifeSaver A and B

Crosswind during forward flight is managed through the V-tail and differential thrust of the cruise engines.

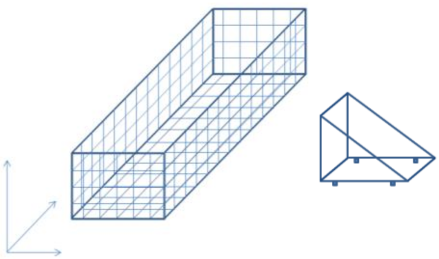
Crosswind during hovering is managed by the amount of lift propeller thrust.

The amount of power generated by the lift propeller equal to 28 kgs (274N) allow a maximum bank angle of 26 degrees in order to contrast the crosswind during hovering.

12. Cargo Bay design

Cargo bay is designed with modular concept and it is applicable both to LifeSaver A and B:

- Cargo bay is accessible from the top and the rear fuselage
- Cargo bay can store a cargo with maximum dimensions up to 0,74 x 0,34 x 0,24 meters
- Using the standard cargo box the UAV can safety store a payload with maximum weight of 4,23 kg allowing a range of 100 kms (6,45 kg for a range of 60 kms)
- Inside the cargo box, railings are installed in order to safely fix the payload to the box (avoiding changes to the CG) by using the apposite chocks

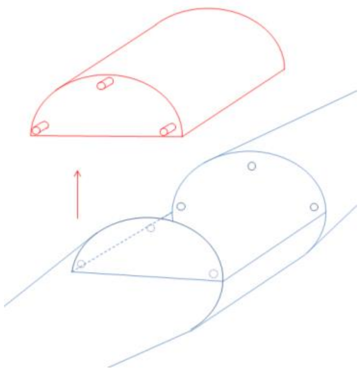


Cargo Box and chock

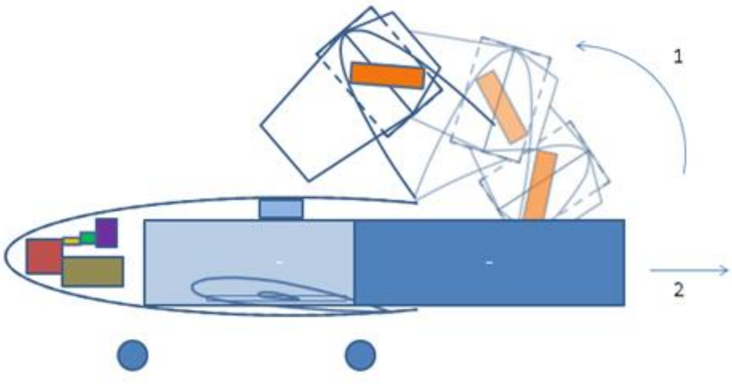
13. Access to the cargo bay

Access to the cargo bay is guarantee in two ways both for LifeSaver A and B:

1) By unlatching the apposit hooks and removing the apposite fairing on the top or on the botton of the fuselage as shown in the next figure.



2) By unlatching the apposite hooks and rotating the rear part of the fuselage

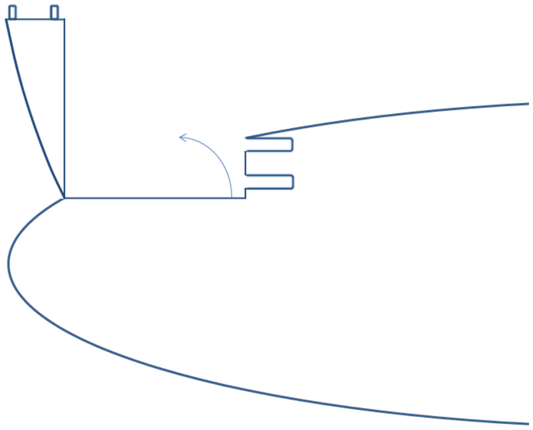


The fairings and the rear part of the fuselage can be safely latched/unlatched/detached from the fuselage by using the apposite hooks (shown in the following picture and purchaseable here: www.jonthan.it/accessori/fissaggio.html)

14. Aircraft nose design

Aircraft nose is composed by transparent polycarbonate which allow the host of the camera inside the fuselage increasing the aerodynamic performances of the UAV.

It is applicable both to LifeSaver A and B granting the access to camera (and also to the avionic) by unlatching the hooks (same concept of the access to the cargo bay) and rotating the fairing as shown in the following picture:



15. Main component locations

Components are located so that the center of gravity stands on the fuselage symety axis in order to have the vertical thrust point coincident with UAV weight resultant.

LifeSaver A					
Component	**Weight [kg]**	**CG-distance* [m]**	**Length [m]**	**Width [m]**	**Height [m]**
Air data system	0,127	+0,44	0,042	0,078	0,049
Camera	0,483	+0,678	0,097	0,095	0,097
Flight control computer	0,58	+0,544	0,17	0,18	0,08
Internal measurement unit	0,0575	+0,56	0,1	0,03	0,04
ADS-B	0,115	+0,6	0,089	0,046	0,018
Antenna**	0,13	0	0	0	0
Flight termination parachute	1,02	-0,052	0,28	0,12	0,05
Flight termination launcher	0,18055	-0,62	0,2	0,055	0,055
Communication system	0,575	+0,508	0,057	0,098	0,086
Cargo box	Up to 5 kg	0	0,74	0,34	0,24
Cruise engines and V tails	1,5	-0,593			
Tail engine	0,05	-0,74	0,1	0,1	0,1
Batteries	Up to 8 kg	0	0,16	0,05	0,05

LifeSaver B					
Component	**Weight [kg]**	**CG-distance* [m]**	**Length [m]**	**Width [m]**	**Height [m]**
Air data system	0,127	+0,44	0,042	0,078	0,049
Camera	0,483	+0,678	0,097	0,095	0,097
Camera	0,483	+0,544	0,17	0,18	0,08
Flight control computer	0,58	+0,56	0,1	0,03	0,04
Internal measurement unit	0,0575	+0,6	0,089	0,046	0,018
ADS-B	0,115	0	0	0	0
Antenna**	0,322	+0,08	0,28	0,12	0,05
Flight termination parachute	1,02	-0,088	0,2	0,055	0,055

LifeSaver B					
Component	Weight [kg]	CG-distance* [m]	Length [m]	Width [m]	Height [m]
Flight termination launcher	0,18055	+0,508	0,057	0,098	0,086
Communication system	0,575	0	0,74	0,34	0,24
Cargo box	Up to 5 kg	-0,593			
Cruise engines and V tails	1,5	-0,74	0,1	0,1	0,1
Batteries	Up to 8 kg	0	0,16	0,05	0,05

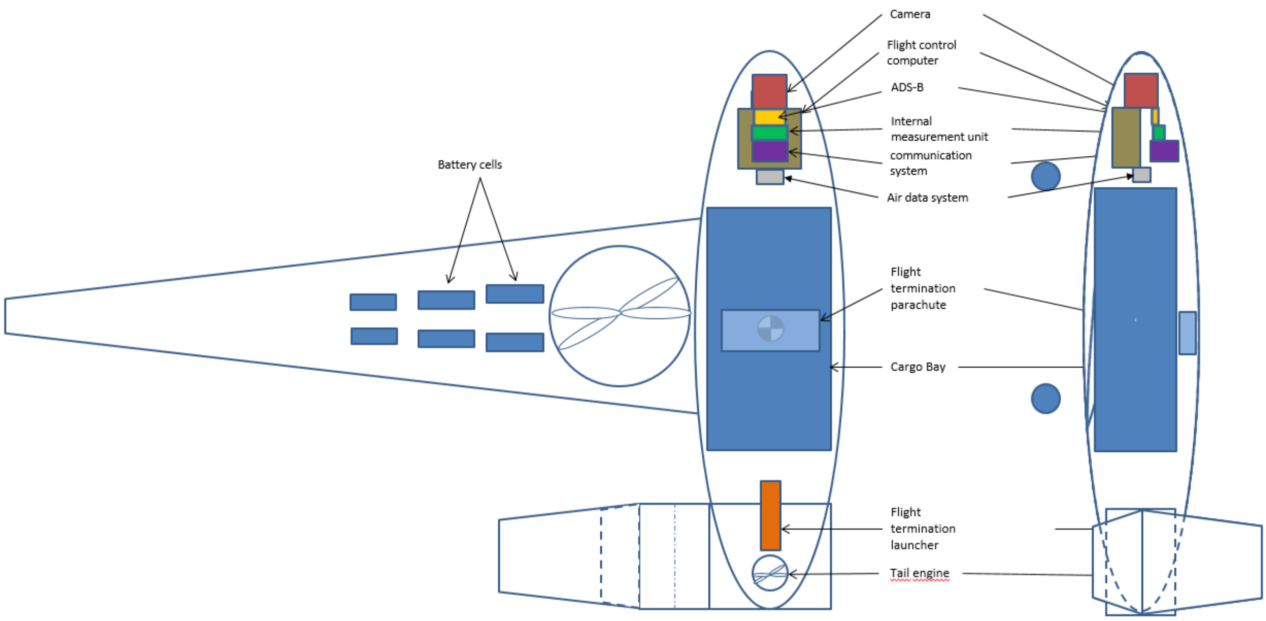
*CG located on the x axis at 0,8 m from the UAV nose.

** Antenna CG must be coincident with the aircraft CG

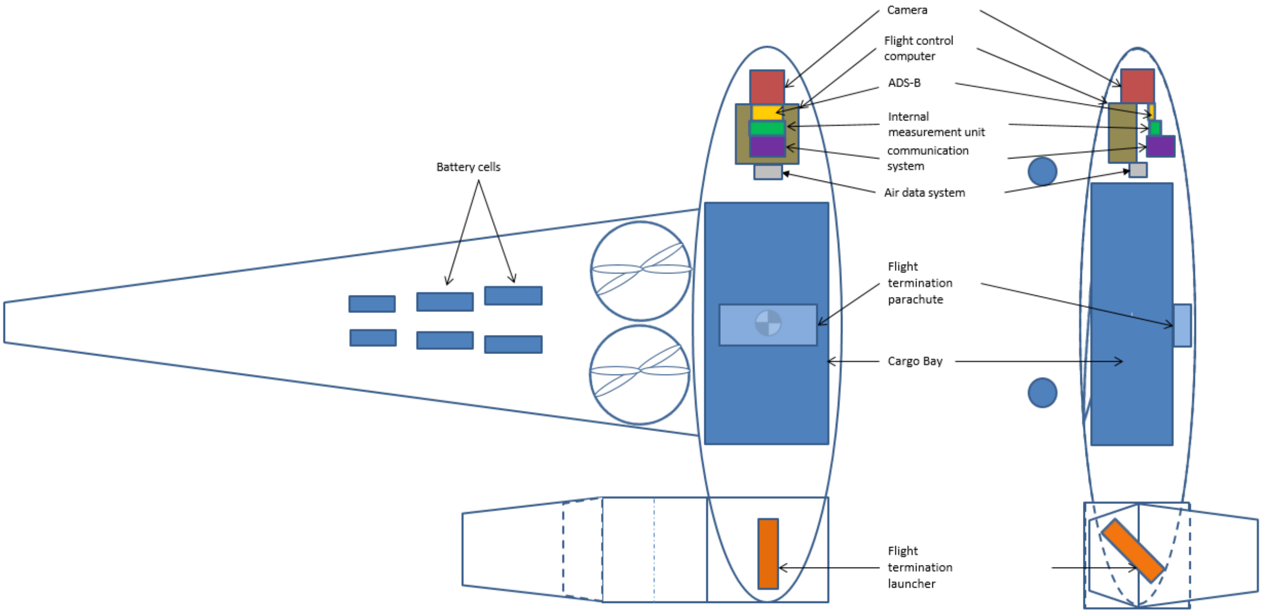
Battery cells are located iside the wing in order to not affect the CG longitudinal location.

It is essential to have te same battery weight either on the left and right wing.

<u>LifeSaver A</u>

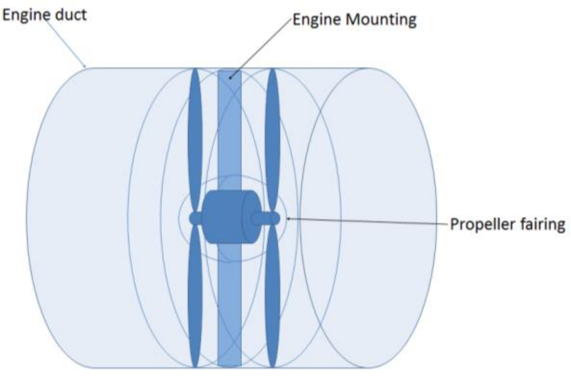


LifeSaver B



16. Waterproof design

Engines are designed with special fairings in order to be waterproof as showed in the following picture.



Avionics, batteries, engine controllers, ground station receiver and flight computers are installed in the fuselage in a waterproof container.

An alternative to the waterproof container is the silicon rubber (purchasable here http://www.resinboat.it/index.php?main_page=advanced_search_result&search_in_description=1&zenid=suv552qv100ujc0go7djpjiom4&keyword=gomma+siliconica&x=0&y=0) where the electric components are sunk.

This second solution find its extensive use in the design of remotely controlled submarines because is weight saver

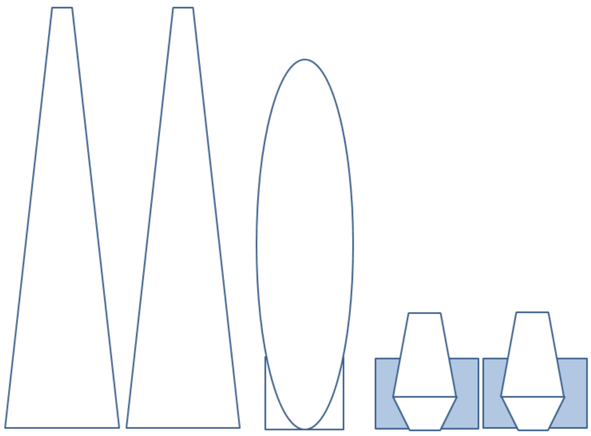
All the electric components are connected with waterproof connectors (purchasable here: http://shop.rc-electronic.com/FITTINGS-AND-CABLES/Heat-shrinkable-Sleeves/Heat-shrinkable-tube-with-hot-melt-adhesive-for-MPX-20-pieces.htm?shop=k_emcotec_e&SessionId=&a=article&ProdNr=A84031&p=45

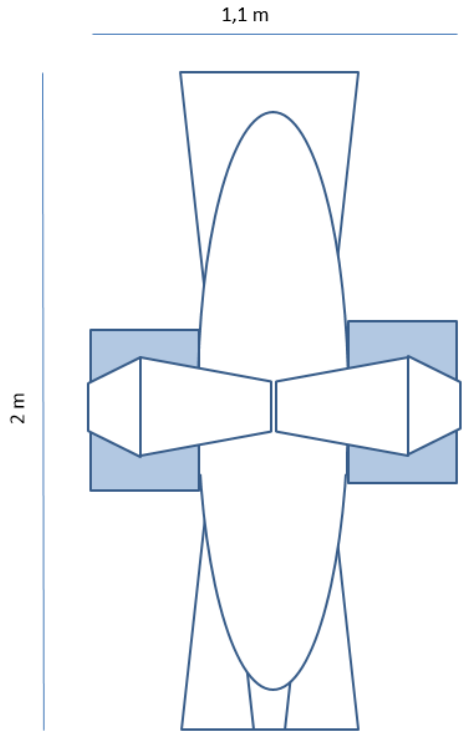
17. Transportability

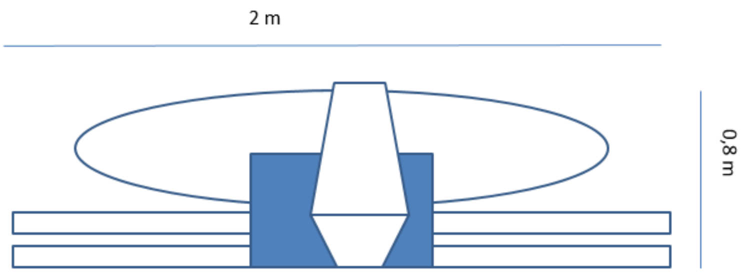
The UAS is composed of 5 main component:

- Fuselage (x1)
- Wing (x2 halves)
- Forward flight engines and V-tail (x 2)

This design makes easy the process to assembly and disassembly the UAV in order to transport it as a cargo itself.







18. Aircraft optional equipment

The aircraft may be also equipped with solar cells located on the wings to recharge the batteries and extend the range during sunny days.

Further design might be investigated in order to include a reciprocating engine connected to an DC generator in order to recharge the batteries on the ground or extend the flight range.

19. Certification of the UAV

The team has also prepared a set of documents which are necessary to ask and achieve the approval of the UAV from Competent Aviation Authority.

These documents are:

- Operators manual (which can be Tailored in accordance with the size and complexity of the operator)
- Flight test checklists (designed to guide the user through the flight tests and record the results of the UAV performance which are necessary to produce the UAV Flight Manual)
- Flight test report (designed to summarize the results of the flight test checklists)
- UAV Flight manual

20. Differencies between LifeSaver A and LifeSaver B

Wing Design		
	LifeSaver A	Life Saver B
Wing loading	15	16
Wing profile	NACA2412	NACA2412
Wing pitch	6	8
Wing span	4m	4m
Root chord	0,56 m	0,65 m
Tip chord	0,1 m	0,1 m
Aspect ratio	11,46	12,23
CD0	0,03	0,032 (due to the bigger cruise engines)

Power plant Design		
	LifeSaver A	Life Saver B
Lift engines	X4 – Mod. C5055/08 Total weight: KV:	X8 – Mod. C3536/08 Total weight KV:
Cruise engines	X2 – Mod. C2822/27 Total weight: KV:	X2 – Mod. LC3542-6T Total weight: KV:
Tail engine	X1 – Mod. C2822/25 Total weight	N/A
Lift propellers	X4 – propellers diameter 0,41m	X8 – propellers diameter 0,28 m
Cruise propellers	X4 – propellers diameter 0,2 m	X2 – propellers diameter 0,3 m
Tail engine propeller	X1 – propeller diameter 0,1 m	N/A

Structure Design		
	LifeSaver A	Life Saver B
Fuselage	Fuselage are equivalent with exception of the tail cone which , for configuration A hosts the tail engine	
Vtail	Vtail is equivalent for both the configurations	
Wing	Composed by three beams and equally spaced ribs	Composed by two beams and equally spaced ribs.

Energy storage design		
	LifeSaver A	Life Saver B
Batteries models	Energy storage is the same for both the configuration and is composed of: 8 x 6200 mAh, 22.2V, 50 C. In addition the user can add 4 extra batteries (4200 mAh, 22.2V, 50 C) to extend the range without affecting the payload weight.	

Performances and flight dynamics		
	LifeSaver A	Life Saver B
Max payload weight	4,11 kg @ 100 km of range 6,34 kg @ 60 km of range	4,23 kg @100 km of range 6,45 kg @ 60 km of range
Max speed	Estimated 22 m/s during cruise	Estimated 22 m/s during cruise
Stall speed at 0 m asl	7,7 m/s	7,9 m/s
Event of one lift engine failure	The remaining three engines provide 8,5 kg of thrust each . Yaw is controlled by cruise engines	The remaining 7 engines provide 3,5 kg of thrust each. Yaw is controlled by differential torque on the lift engines and by differential thrust of the cruise engines.
Event of one cruise engine failure	The remaining three engines provide the necessary thrust to compensate yaw and guarantee enough speed to continue the flight near the cruise speed. Vtail also help to control the yaw.	Only one engine provides the thrust to guarantee the flight at a speed lower than the required cruise speed. Yaw generated by differential thrust is compensated by the Vtail only
Event to tail engine failure	Degraded pitch control during hovering. Required a rolling landing	N/A

21. Conclusions

Safety Operations and Requirement Respect were the design points of the UAV.

The aircraft is proposed in two configurations:

- LifeSaver A
- LifeSaver B

The aircrafts, in both their configurations, satisfy the requirements as shown in the following table:

Requirement	How the requirement has been satisfied	References
The design shall be capable of vertical take-off and landing	4 or 8 counter rotating propellers capable to provide a maximum of 28 kgs of thrust with air density equal to 0,954 kg/m3	See frame sheet
The aircraft shall include at least one fixed wing for forward flight	One fixed wing as per design	See chapter 3,4 and 7
Maximum take-off mass (MTOM) shall be below of 25 kg: Vehicle weight when fully loaded < 25 kg	Maximum take-off mass equal to 24,9 kgs	See frame sheet and chapter 4
The maximum wing span shall be below 5 meters and the maximum aircraft length shall be below 4 meters	Maximum wing span equal to 4,3 meters	See chapter 3, 4 and 17
The aircraft shall be modular for the ease transportation.	Aircraft composed by 5 macro components	See chapter 17
The maximum length of the individual part shall not be longer than 2 meters	Maximum leghts: - Fuselage: 1.6 meters - Half wing: 2 meters	See chapter 17
Payloayload requirement: 5kg payload: > 60 kg range	At least 6,34 kg (A configuration) or 6,68 (B configuration)	See frame sheet
Payloayload requirement: 3kg payload: > 100 kg range	4,11 kg (A configuration) or 4,52 kg (B Configuration)	See frame sheet
Payload bay shall be located near the aircraft center of gravity	Payload located on the CG	See chapter 17
Minimum payload bay dimension shall be 450 x 350 x 200 mm	Cargo bay can store a cargo with maximum dimensions up to 0,74 x 0,34 x 0,24 meters	See chapter 12
The payload bay shall be located and accessible form the lower side of the aircraft and must be interchangeable with payload bay of the same size and same interface.	Payload is accessible from the top of the fuselage by removing the top fairings and from the rear part of the fuselage.	See chapter 13
The cruise speed in fixed wing mode shall be at least 80 km/h	Aircraft designed for a cruise speed of 80 km/h	See frame sheet
Max speed shall not exceed 194 km/h	Maximum speed electronically limited	/
The aircraft shall use at least 4 direct drive lift rotors/propeller but no more than 10 direct drive lift rotors/propellers	Total of 9 propellers and 9 motors for version A Total of 10 propellers and 10 motors for version B	See frame sheet and chapter 5
For energy storage off the shelf rechargeable batteries shall be used	Rechargeable batteries only will be used	See chapter 8
Have reserved weight, space and power for the items outlined in the Ignition Kit and in the guidelines	Required components fit in the fuselage	See chapter 15
Capable of sustained flight in all flight states while experiences 10 m/s head and cross wind	Enough power available to sustain 10 m/s of headwind and crosswind	See chapter 11
Keep it super simple	Simple design considered as starting point	/