APPENDIX II

HEM 1-X Concept Evaluation Details

Short description of the design possibilities and reasons behind the decisions taken.

Wing location

- High wing
- Mid wing
- Low wing
- Parasol wing

To the designer's experience, a configuration with inherent lateral stability during fixed wing flight is highly desirable when designing a cargo aircraft. In this particular case however, there is an unfamiliarity regarding the design and flight dynamics behavior of rotor VTOL aircraft during the Vertical Takeoff and Landing procedures. For this reason, the priority was set to designing the layout in such a way so that the UAV would be stable under gusts during the Vertical Takeoff/Landing phase. In our design the rotors cannot fit inside the wing. Therefore, a configuration with rotors above the C.G. was selected, and the wing had to be in mid or low wing configuration. By design definition, the aircraft is flexible in carrying various cargo scenarios. Therefore, the C.G. was set to be in the geometric center of the cargo so that the drone's flight behavior would not be dependent on a specific cargo. To reduce aerodynamic interaction between the rotors and the wing during both VTOL and cruising phase, as well as the stalling behavior of the aircraft, the rotors and the wing should not be in the same plane. This led to a low mounted wing which also results to further benefits regarding the cargo accessibility and structural integrity which are well illustrated by CAD figures of the aircraft.

Wing type

- Rectangular
- Tapered
- Delta
- Swept back
- Swept forward
- Elliptical

A hybrid wing-rotor configuration could not be developed due to high the propeller size requirements. As such, the wing's planform design was based on aerodynamic efficiency considerations. However, it is evident by the Multi-Disciplinary discussions and analyses provided in this report that wing design was subject both to structural and manufacturing costs considerations. This Multi-Disciplinary approach leads to an overall superior design compared to a design based in aerodynamic efficiency alone.

The concept outlined here does not require any sweep angle. This would be useful for a flying wing configuration or in a design where directional stability is attained by the use of hybrid winglets/vertical stabilizers (e.g. a sweptback canard configuration). The tapered planform was preferred over the elliptic one, a mature decision made entirely on Multi-Disciplinary considerations. An elliptic planform can provide the optimum aerodynamic efficiency minimizing induced drag. However, the lifting requirements of this configuration are very low especially in high speed cruise conditions, as one can understand by the performance related figures. As such, the induced drag is not the dominant source of drag in this case. On the other hand however, designing an elliptic planform raises manufacturing difficulties. This translates to manufacturing costs and extra weight which in turn increases induced drag. Determining the appropriate AR value to optimize our design is by far more beneficial to improving aerodynamic efficiency as well, than to maximizing the Oswald efficiency factor. Finally, it should be noted that in case it is required, an elliptic lift distribution can be also attained by a means of aerodynamic or/and geometric twist. A moderate taper ratio in the order 0.85, was found to be the optimum value as it improves the aerodynamic efficiency compared to an orthogonal wing. Furthermore, it does not pose structural difficulties, and does not allow aerodynamic interaction with the VTOL rotors during VTOL phase. A taper ratio value in the order of 0.45-0.5 would offer limited –if any-aerodynamic benefits, but the higher chord lengths near the wing root would lead to a reduction of the VTOL rotors efficiency as they would partially block their wake.

High lift device

- Plain flap
- Split flap
- Slotted flap
- Kruger flap
- Leading edge slot

The design of the high lift device is partially guided by considerations regarding the robustness and safety of the aircraft and partially guided by the need of operational envelope flexibility. In an unfortunate event of a rotor failure, the aircraft will have to land –or glide to land- as a conventional aircraft would. This case defines a gliding and landing velocity range which the design teams wants to be low enough to allow easy and safe landing by the pilot. Also, in cases where high speed operation is not mandatory (e.g. non-emergency pharmaceutical transport cases), the UAV should be able to operate in low and moderate velocities, under minimum power consumption. For that, we have to ensure that the high lift device can provide the appropriate lift coefficient increments to allow for this desired velocity range –the behavior and requirements of the aircraft in this velocity range under 10m/s of headwind also guided this design. An important consideration when designing a high lift system for a UAV aircraft is the influence of the Reynolds number on the aerodynamic efficiency and behavior of this high lift configuration. The efficiency of each of the proposed configurations is dependent on the Reynolds number in a distinctive way. We should ensure that the high lift device provides the required lift coefficient values as a well as a smooth stalling behavior in the corresponding Re conditions. For the "emergency" case of a conventional takeoff, minimizing drag while ensuring the desired lift values is also important. The configuration once again should be as simple as possible while satisfying the above design considerations so that no significant extra weight is introduced. By comparing experimental data of various airfoils we could assess their corresponding behavior for split, slotted and plain flap. Out of these, the plain flap was selected mainly due to its simplicity - which will not lead to extra weight- while a numerical analysis and the team's experience ensures that it satisfies the design considerations. Once again, a Multi-Disciplinary design approach helps improving the overall performance. The slotted flap provides an aerodynamic advantage in a specific Re number range, but our team considered the required kinematic/electronic deployments system under manufacturing costs, weight and robustness considerations and it was evident that the simple solution of the plain flap was the optimum in this case.

Sweep configuration

- Fixed wing
- Variable sweep

The aircraft does not require sweep as the operational velocity falls in the low subsonic region. Furthermore, the layout does not require sweep to increase the longitudinal or lateral stability. Hence zero sweep was set.

Shape

- Fixed shape

The UAV was designed to be as simple as possible to avoid extra costs and non-robust experimental solutions. Therefore, the wing is fixed, and flight control is attained by conventional control systems.

Structural configuration

- Cantilever
- Strut-braced (a. faired, b. un-faired)

The selection of the structural configuration is inherently multidisciplinary and both cantilever and strut-braced approaches share their own advantages and disadvantages. At an initial design stage, it can be argued that the existence of external, strut-braced rotors can be exploited and be extended to support the wing as well. However, after thorough consideration and calculations, this solution was found to be not beneficial. Extra struts increase the structural weight while adding to the aerodynamic drag. Furthermore, even more additional struts would have to be braced inside the fuselage structure. This increases the complexity of the fuselage structure which arises ergonomic and space requirements issues (batteries and electronics should have enough space for storage as well as for cooling). The final reason for not choosing a strut-based wing is modularity. The drone is designed in a modular philosophy. This means that it has to be disassembled easily and can fit to a typical 1.5mx0.8mx0.75m transport box. Adding struts result to extra connectors, extra structural considerations and a more complex assembly/disassembly process.

Tail Configuration

Aft of forward

- Aft conventional tail
- Canard (foreplane)
- Three surfaces

The design of the longitudinal stability control configuration interacts a lot with the dimensions of the rotors. Since modularity and the ability to easily store and transfer the parts of the aircraft is of high importance, the design of the tail configuration is based in minimizing the design interaction with other aspects of the design as the CG location and the rotor assemblies. In the conceptual design stage, we took advantage of the structured required for mounting the rotors by mounting the tail configuration near the rotors. This led to an efficient inverted U wing. Preliminary design considerations and longitudinal stability analyses finalised the relative position of the tail in respect to the rotors. A double boom specifically for mounting the tail was designed, and as such the empennage structure does not interact with the pusher motor or the VTOL rotors. Apart from leading to a simple and easy to construct configuration, this also allows us to keep the fuselage as single part with a length under 1m.

Horizontal and vertical tail

- Conventional
- V-tail
- T-tail
- H-tail
- Inverted U

Attachment

- Fixed tail
- Moving tail
- Adjustable tail

A fixed tail with a conventional elevator/rudder was preferred over a more complex, heavier and difficult to predict moving tail. Previous design and prototype testing experience has shown that a moving tail can also lead to less smooth pitch changes due to the increased associated lift slopes per angle of attack.

Engine and the aircraft cg

- Pusher
- Tractor

An analysis was conducted to determine the power requirements for the VTOL and thrust providing motors. At an early design stage, the mass of the batteries and the motors are not known in accuracy. Hence, a weight-power formula for the motors as well as a weight-capacity formula for the batteries was developed. This allowed the parametric estimation of the weight of the aircraft, which in turn led to the determination of the optimum number of thrust and VTOL motors. For the fixed flight motors this number was 2. Apart from power efficiency and weight reduction, using 2 thrust motors also makes the aircraft more robust and safe as it can keep the aircraft in forward flight phase even after the potential failure of one engine of the engines. To avoid asymmetry in such a case, the motors were set in a tractor and pusher configuration. This also maximizes the airfoil velocity around the (aerodynamically shaped and lifting) fuselage body.

Number of engines and rotors

- Single-engine
- Twin-engine
- Tri-engine
- Four engine
- Multi-engine

Rotors

- Four engine
- Multi-engine

The parametric analysis of the aircraft characteristics showed that the weight of the aircraft would not decrease significantly when 6 (or more) rotors of less power were used instead of 4. Therefore, it was decided that 4 VTOL motors was the optimum choice for our aircraft since a higher number would create the need for extra mountings. In turn, this might lead to a weight penalty while increasing the complexity of the design and reducing the ergonomic and transportation benefits of the 4 rotor configuration. It should be also noted that, it was examined that the 4 rotors of our design specifications were more than adequate in tackling gusts of 10m/s during the VTOL phase.

Engine location

- In front of nose/fuselage aft (inside)
- Inside fuselage mid-section
- Inside wing
- Top of the wing
- Under wing
- Inside vertical tail
- Side of fuselage at aft section
- Top of the fuselage

Landing Gear Configuration

1. **Landing gear mechanism**
   - Fixed (**a.** faired, **b.** un-faired)
   - Retractable
   - Partially retractable

To meet the demanding mission requirements, the configuration should be as aerodynamically efficient as possible –without sacrificing the overall efficiency due to interdisciplinary interaction. In this case, a conceptual design for retractable landing gears was developed and the analysis showed limited weight increase which does not worsen the design's performance.

2. Landing gear type

- Tricycle type (or nose gear)
- Tail gear (tail dragger or skid)
- Bicycle (tandem)
- Multi-wheel
- Bicycle (side-by-side)
- Float-equipped
- Removable landing gear

Since the configuration uses a spacious fuselage with an inverted U empennage, it makes engineering sense to use a modification of typical tricycle landing gear set up. As only the VTOL operation is necessary a typical landing leg similar to quad /hex copter can be used. This modification can be redesigned in later stages of design including wheels for convectional take-off and landing. The retractable landing gear is necessary in order to reduce the landing system's drag during horizontal flight at higher speeds (>22 m/s).

The necessary ground stability is satisfied while there is space to be used for retracting the landing gear inside the fuselage.

Fuselage configuration

Shape

- Circular, rectangular etc
- Lifting body, bullet shaped 2
- Openings, cargo payload

The main consideration in designing the fuselage, is providing enough space for all the systems and the cargo bay while ensuring easy access by the UAV user. Sufficient cooling of the heated parts (motors, batteries etc.) is also critical. The rotor structure system within the fuselage is also a significant factor in its sizing. An additional consideration is its length which should not exceed the transporter box respective dimension. The above lead to a wide body conventional fuselage with specifically designed curved surfaces in the fore and aft body, and a canopy to allow easy access in its interior. Special care is also taken to ensure that the required propeller efficiency is met. This meant that the frontal area near the tractor and pusher had to be minimized and the overall shape had to be smooth and aerodynamically shape to avoid flow separation, vortices and phenomena related to bluff bodies.

Manufacturing-Related Items Configuration

Materials for structure

- Metal (often aerospace aluminum)
- Wood and fabric
- Composite materials
- Significant weight reduction
- Metal and composite materials

Composite materials approved my aeronautical society for its structural performance at fatigue, thermal cycling etc. Lightweight components to reduce mass and inertia.

Assembly technique

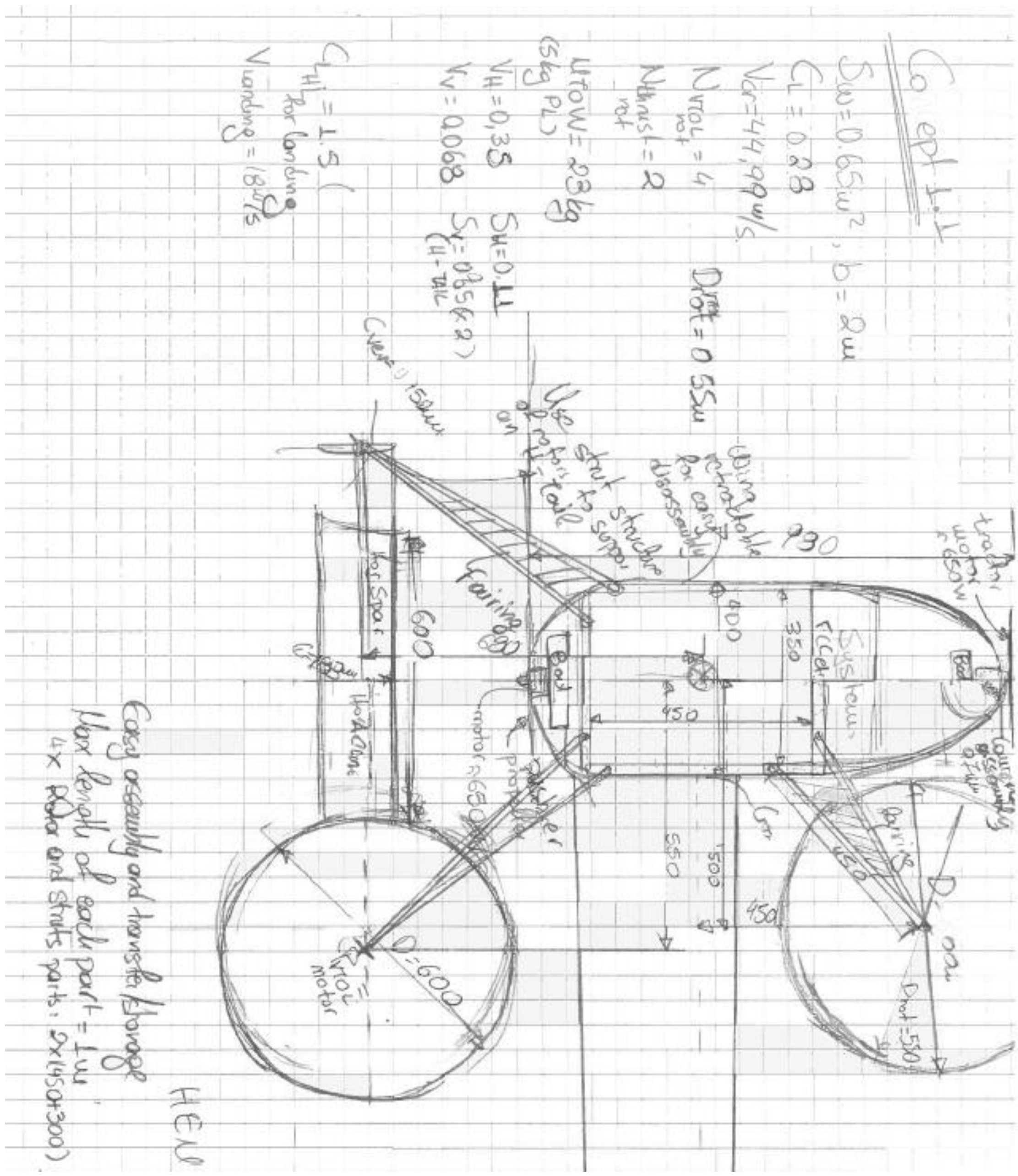
- Kit-form
- Semi-kit form
- Modular

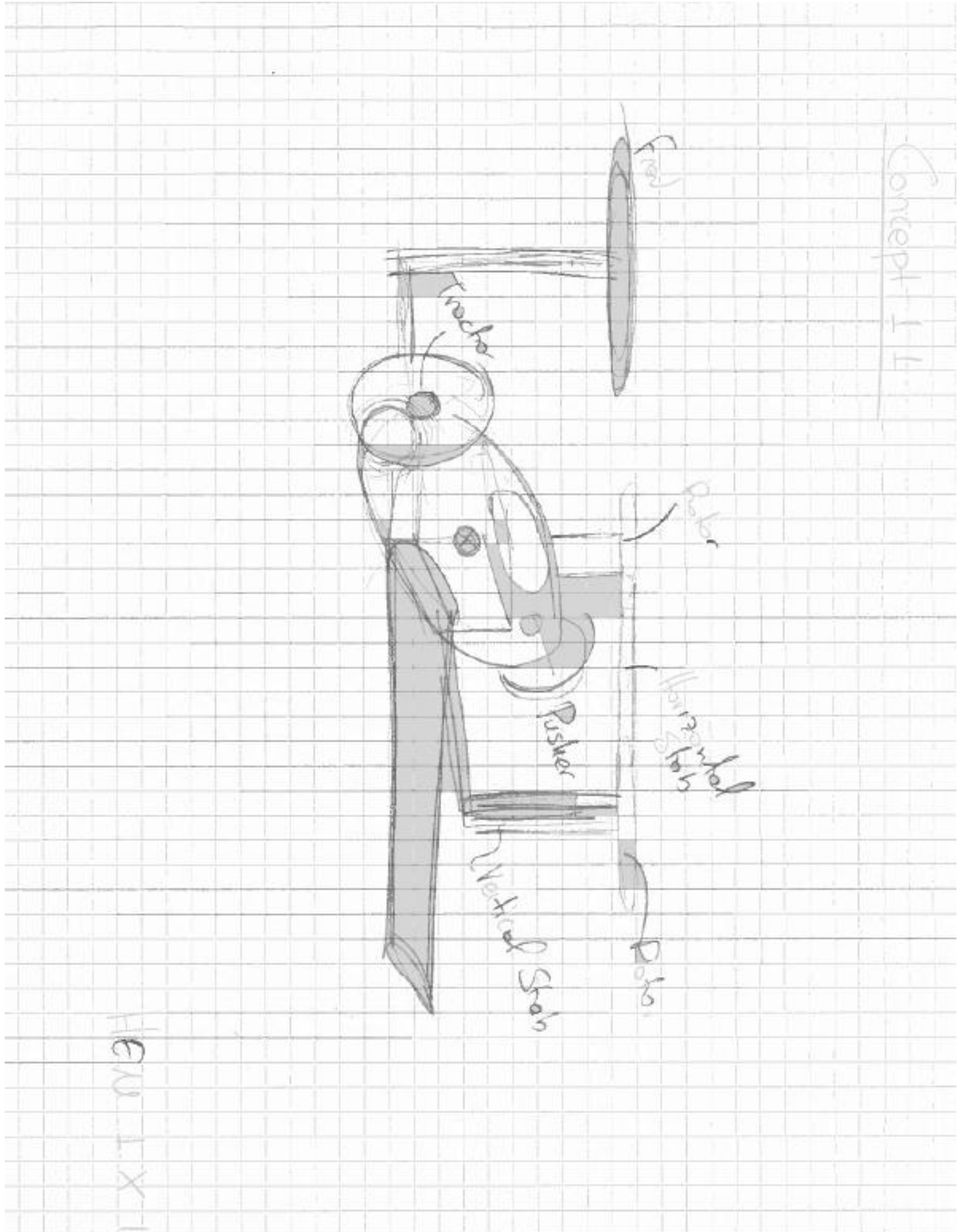
Primary control surfaces

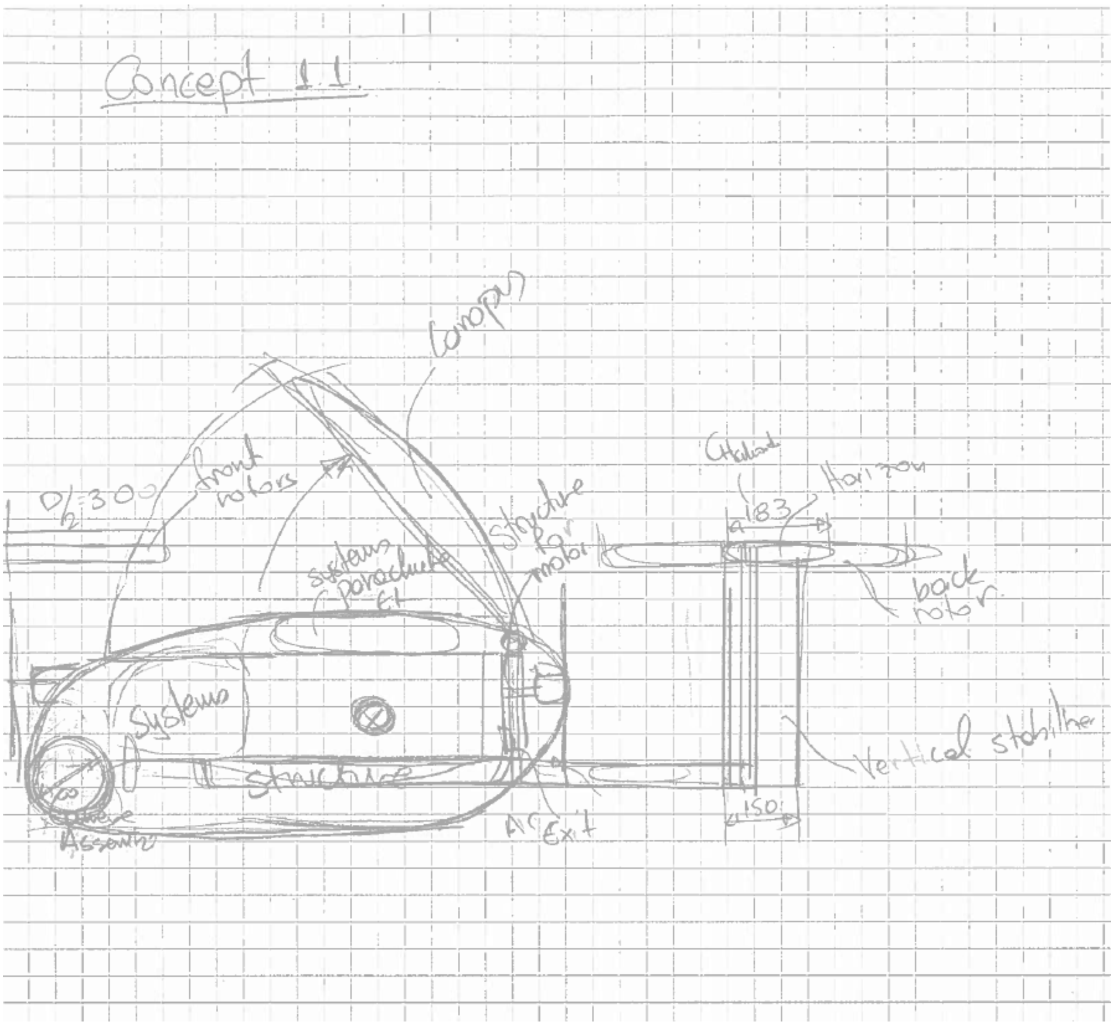
- Conventional (i.e. elevator, aileron, rudder)
- Elevon-rudder

- Aileron-ruddervator
- Flapron-rudder-aileron

The aircraft is based in a conventional configuration featuring a horizontal and a vertical stabilizer. Therefore, there is no need for mixing the control surfaces' roles, for the radio controlled set up of which the team has not prior experience. A conventional control surfaces approach is used. The safety and robustness of the aircraft had a major impact in this decision.




Concept 1.1
Rotor
Horizontal Stab
Pusher
Vertical Stab


Concept 11
Canopy
front rotors
structure for motor
systems
structure
Air Exit
back rotor
Vertical stabilizer
183
150