APPENDIX II

HEM 1-X Concept Evaluation Details

Wing location

High wing

Mid wing

Low wing

Parasol wing

To the designer's experience, a configuration with inherent lateral stability is highly desirable when designing a cargo aircraft. In this case however, there is an unfamiliarity regarding the design and flight dynamics behavior of rotor VTOL aircraft. 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 phase. Therefore, and since the rotors cannot fit inside the wing, a configuration with rotors above the C.G. was selected. By design definition, the C.G. was set to be in the geometric center of the cargo so that the drone's flight behavior is not 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 lead to a low mounted wing which also results to further beneficial changes regarding the cargo accessibility and structural integrity which will be later discussed.

Wing type

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, as it will be later discussed in more detail, it is of critical importance to also include structural and manufacturing costs into these considerations. This Multi-Disciplinary approach will lead to an overall superior design compared to a design based only in aerodynamic efficiency.

Rectangular

Tapered

Delta

Swept back

Swept forward

Elliptical

The concept outlined here does not require any sweep angle. This would be useful for a flying wing configuration or to involve directional stability with the use of hybrid winglets/vertical stabilizers (especially in a case of a canard configuration). The tapered planform was preferred over the elliptic one, 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 –as shown in later calculations- and as such the induced drag is not the dominant source of drag in this case. Furthermore, 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 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, improves the aerodynamic efficiency compared to an orthogonal wing while it does not pose structural difficulties as a higher one.

High lift device

The design of the high lift device is determined by considerations regarding the robustness and safety of the aircraft. In an unfortunate event of a rotor failure, the aircraft will have to land –or glide to land- as a conventional aircraft. 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. For that, we have to ensure that the high lift device can provide the appropriate lift coefficient increments to allow for this desired landing velocity. A significant consideration in this design is the influence of the Reynolds number on the aerodynamic behavior of the high lifting system. Each of the potential configuration's efficiency is dependent on the Reynolds number in a different 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. 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 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.

Plain flap

Split flap

Slotted flap

Kruger flap

Leading edge slot -1

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. The operational velocity range was not high enough to justify the addition of the complex system required by a variable sweep wing.

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.

Cruising conditions: Lift=225.6N, Drag=9.22N, L/D=24.46

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 1mx1mx1m transport box. Adding struts result to extra connectors, extra structural considerations and more work on transfer and the assembly/disassembly process.

Structural Integrity analysis

Tail Configuration

Aft of forward

Aft conventional tail

The design of the longitudinal stability control configuration is based a lot in 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. We take advantage of the structured required for mounting the rotors by mounting the tail configuration near the rotors. This leads to an efficient inverted U wing. Thus, the empennage structure does not interact with the pusher motor. *This allows us to keep the fuselage as single part with a length under 1m.*

Canard (foreplane)

Three surfaces

Horizontal and vertical tail

Conventional

V-tail

T-tail

H-tail

Inverted U

Attachment

Fixed tail

Moving tail

Adjustable tail

Structural Integrity analysis

A fixed tail with a conventional elevator/rudder was preferred over a more complex, heavier and difficult to predict moving tail. A moving tail can also lead to less smooth pitch changes due to the high associated lift slopes per angle of attack change.

Lift/Drag estimation: Lift_h=, Drag_h=0.54, Lift_v=, Drag_v=1.88

Engine and the aircraft cg

Pusher

Tractor

An analysis was conducted to determine the required power requirements for the VTOL and thrust providing motors. At this early stage the mass of the batteries and the motors are not exactly known. Therefore, an extensive survey was conducted in batteries and motors available in the market. This allowed the development of a weight-power relationship for the motors as well as a weight-capacity relationship for the batteries. This allowed the determination of the optimum number of throttle and VTOL motors. For the forward flight this number was 2. This also makes the aircraft more robust and safe as it can continue forward flight even if one engine fails. 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 (lifting) fuselage body.

Number of engines and rotors

Single-engine

Twin-engine

Tri-engine

Four engine

Multi-engine

Rotors

Four engine

Multi-engine

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

Landing gear mechanism

Fixed (**a.** faired, **b.** un-faired)

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.

Partially retractable

2. Landing gear type

Tricycle (or nose gear)

Tail gear (tail dragger or skid)

Bicycle (tandem) 0

Multi-wheel -1

Bicycle (side-by-side) 0

Float-equipped 0

Removable landing gear -1

Since the configuration uses a spacious fuselage with an inverted U empennage, it makes sense to add no more complexity by using a typical tricycle landing gear set up. This also dictated by the CG position which is in the center of the cargo bay. A taildragger configuration would require the 2 gears to be in front the cargo bay which would cause changes in the fuselages fore shape as well as demand extra structural bracings within the fore part of the fuselage.

Fuselage configuration

The main consideration in this providing enough space for all the systems and the cargo bay while ensuring easy access by the UAV user and sufficient cooling of the heated parts. 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.

Shape

Circular, rectangular etc

Lifting body, bullet shaped 2

Lf/df ratio

Openings, cargo payload

Manufacturing-Related Items Configuration

Materials for structure

Metal (often aerospace aluminum)

Wood and fabric 1

Composite materials 2

Significant weight reduction

Metal and composite materials 1

Assembly technique

Kit-form 0

Semi-kit form 0

Modular 2

Primary control surfaces

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

The aircraft uses 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 had a major impact in this decision.

Elevon-rudder

Aileron-ruddervator

Flapron-rudder-aileron