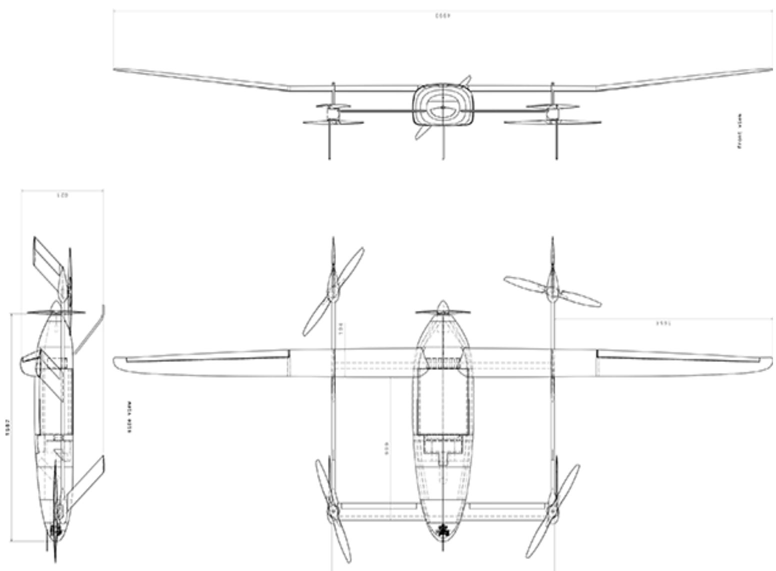
Design Description

General inspiration for design

The idea for this concept came from a payload centered approach. While the requirements state that the payload shall be accessible from the bottom, which is easier to automate, automatic loading will not be available when you want to the use the airplane for example in remote rural areas and have higher flexibility operating it. This leads to the fact that you will have an inexperienced user loading or unloading the airplane. When looking at existing configurations the hover propellers are most of the time in the same plane as the fuselage. So if an inexperienced user is unloading the aircraft, as a designer I do not want him or her to crouch next to the fuselage with the propeller close to his or her face and trying to get the payload out from the bottom. Unloading the airplane from the top is therefore the safer option. As you also want the payload in the center of gravity of the plane the configuration most suitable for this is a canard configuration (this rationale inspired Rutan to design the Solitaire). While in a normal wing/tail configuration static pitch stability dictates that your wing's neutral point is close to the center of gravity and therefore over the payload when you require accessibility from the bottom, a canard configuration makes it possible to shift the wing back while having still static pitch stability, accessibility from the top and all surface generating lift. The additional benefit is that the canard will stall first on this configuration which makes the aircraft harder to stall. The design was inspired by the Rutan Solaire and VariEze / Long-EZ.

Rutan Solaire

Next to the payload centered approach archiving the range is key in this challenge, meaning to maximize Lift over Drag, which means in cruise condition to minimize drag, which leads to a high wing aspect ratio and wing loading.



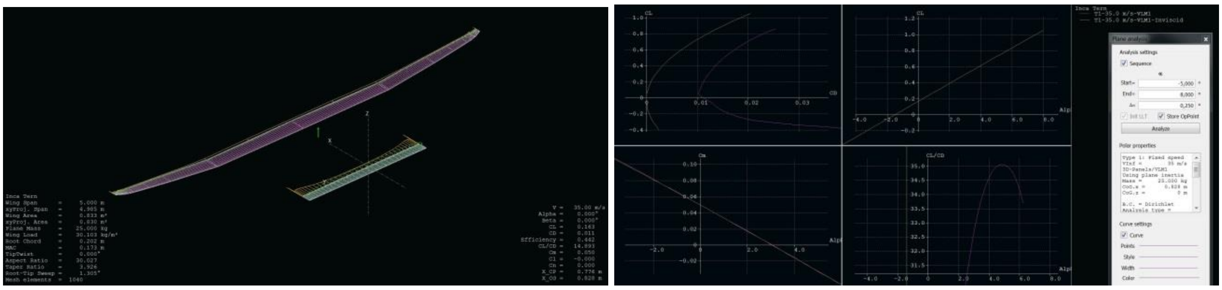
Three side view of Inca Tern

Mission – Payload / Range

The cruise speed was fixed at 35m/s. It cannot be too close to the stall speed (~23m/s) and not too high since it would require more battery power, although the overall drag (especially parasite drag) would decrease. The payload is for the longer mission (100km) is 3kg and for the shorter mission (60km) 5kg. Currently the aircraft could make 114km / 74km, meaning some parts of the mission can be flown sustained with 10m/s head wind, but not the whole mission (132km / 81km)

Aerodynamics / Stability & Control

The configuration is designed with a canard layout with a high aspect ratio main wing (~30) and a wing loading of 30kg/m². Both mean aerodynamic chord lengths are quite short, which makes low Reynolds number profiles (MH-31 on both wings) necessary. The L/D is around 15 depending on the parasite drag that still has to be determined (efforts with friction coefficients acc. to Mason and CFD did not deliver realistic values). The current guestimate is 0,034. The configuration is statically stable with a margin of 10%-20% depending on the mission and the battery setup. The canard includes the elevator; the outer wing the ailerons and the vertical plane the rudder. The canard accounts for 15% of the overall lift and has a slightly higher incident angle than the main wing, which makes it stall first. The configuration was checked for lateral stability (spiral stability) in AVL and it fulfilled the respective criteria.



Configuration in XFLR (see attached files for higher resolution)

Weight

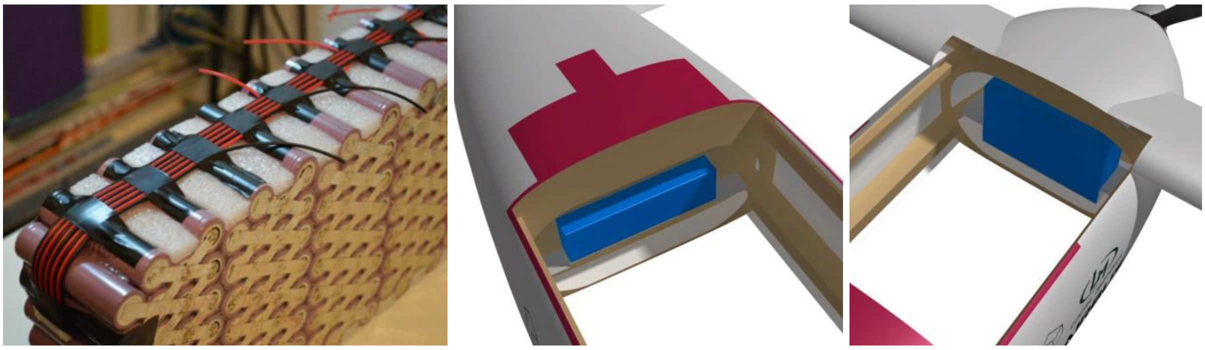
The overall weight of the aircraft is maximum 25kg due to certification rules. The mass empty is ~15kg (60%) of which ~7kg is airframe (~27%), 4kg propulsion system without batteries (~17%) and ~3kg avionics & equipment (~15%). Depending on the mission batteries are (20%-30%) and payload (12%-20%). The payload/cargo container is directly centered in the center of gravity.

Motors / Batteries

For hovering a thrust of 245,3N is required. This leaves 61,3N for every of the 4 vertical propellers. A KDE7215XF-135 motor with 27,5*8,9 propeller blades at ~55% throttle would fulfill this task. After evaluating the different charts of the KDE and the U10+ motors, the U10+ was chosen instead since the KDE seemed a little bit too big. The U10+ leaves a margin of ~30N per engine/propeller combination for ascending at 100% throttle. In cruise a thrust of 18,2N is required, for which I'm also using a U10+ KV100 motor with 26x8,5 propeller blades at under 50% throttle setting.

KDE7215XF and U10+

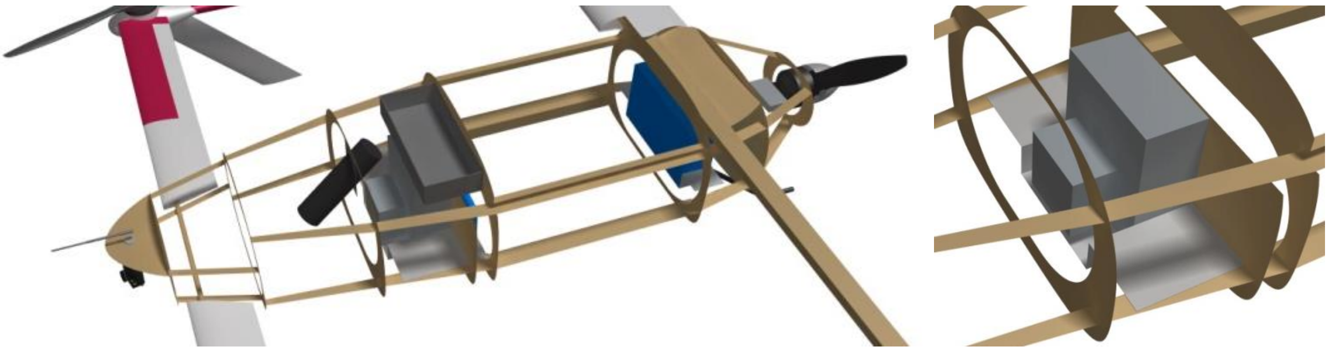
For the batteries a 12s11p setup of Panasonic NCR18650GA cells (cell energy density: 224-255Wh/kg) is used. The overall pack energy density is reduced to ~200Wh/kg. They are located in front and in the back of the payload container and can easily be plugged in and out. Wiring around the payload bay goes through the C profile longerons (see structural concept).



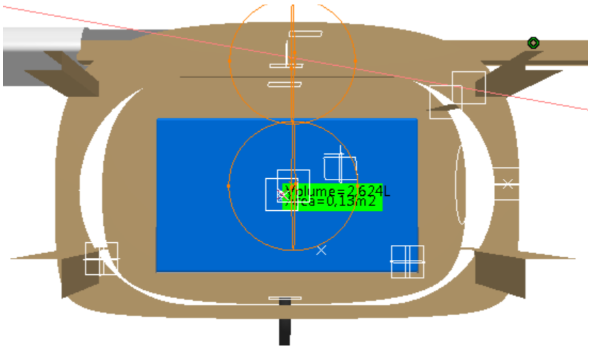
Battery pack and location in the fuselage

Structural Concept

The internal structure of the fuselage is build up with frames and four longerons, which are shaped like C and L profiles. The C profiles give the possibility to put cabling for example for the batteries through there. The L profiles give the possibility to directly mount equipment with a plate on top of them. The fuselage is made out of carbon fiber. The wings that have a bending beam through the fuselage have ribs, an outer layer and a honeycomb filling. For the rest of the structure also carbon fiber is used.



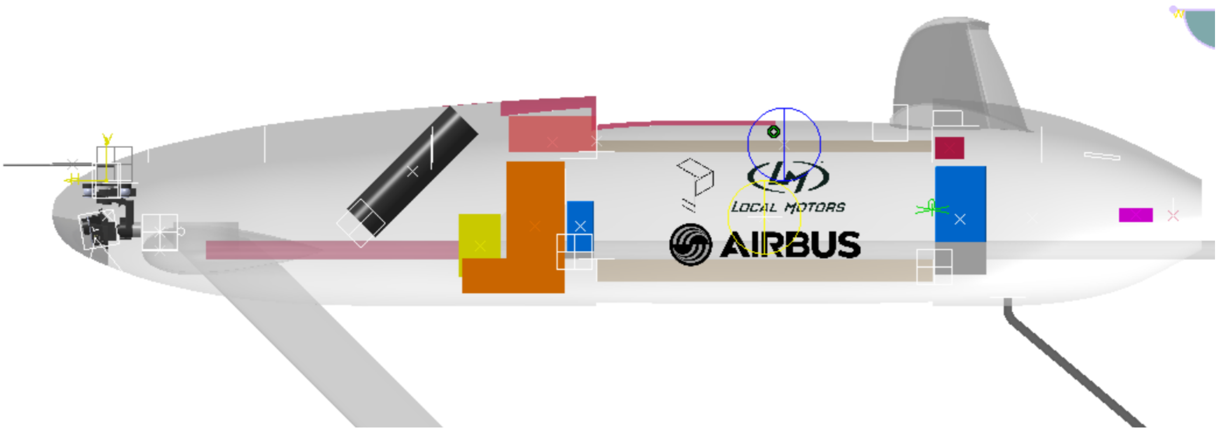
Overall structure, mounting of equipment on the longerons



C and L profile longerons for cabling and mounting

Equipment

The required equipment is positioned in the fuselage.



From left to right: air data probe, gimbal, parachute launcher, comms (yellow), flight control computer (orange), parachute box (pink), batteries (blue), IMU (red) and ADS-B transponder (violet)

Explanation of design details

Landing gear

As a landing gear a combination of winglets/fins and skid was used, which orientates itself very closely on the original Quadcruiser concept. It is however possible to change to a conventional gear replacing the fins and the skid with wheels for flight testing.

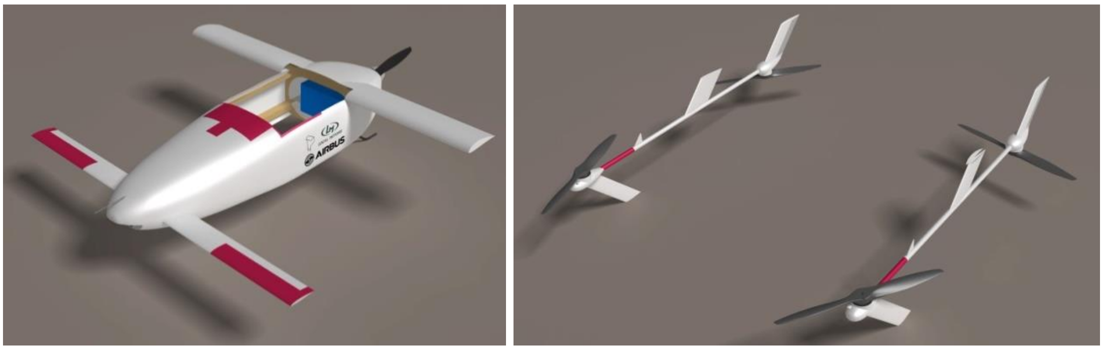
Landing gear concept

“Waterproofness”

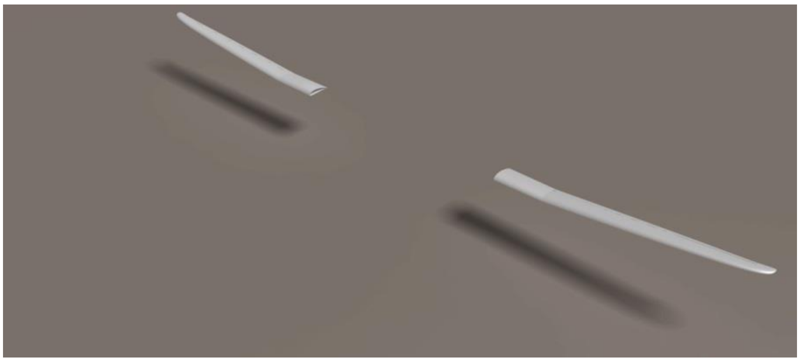
For the connection of the cargo box and the structure rubber parts are used that water cannot get into the fuselage.

Modularity/Ship-ability

The aircraft can be disassembled into 6 parts: the fuselage with center wing and canard, two frames with the lift motors and vertical tail planes, two outer wing parts that can be plugged in and the cargo container. The parts that are have all a maximum length of 2m (required) can be put in a cargo box and transported with a regular Mercedes Sprinter.



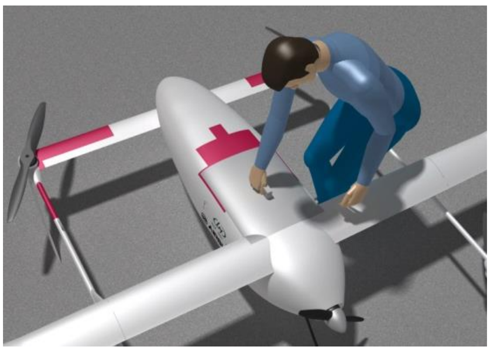
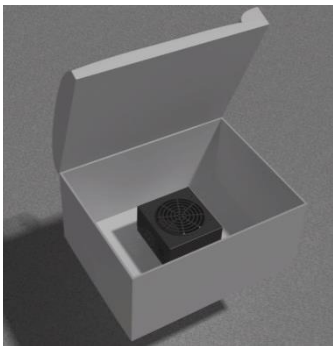
De-assembled parts: fuselage, frames



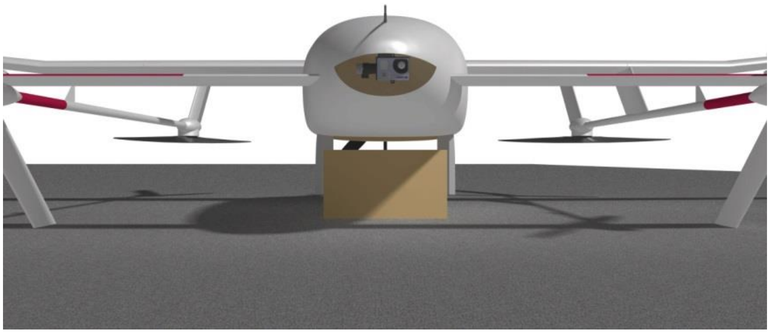
De-assembled parts: outer wings

Ease of handling

The aircraft can either be unloaded with taking out the cargo box completely and then opening the top cover or leaving the cargo box in and opening the bottom of the bay through automatic folding. The cargo in the cargo box is centered by flat plates connected to springs on the vertical walls (only ideas for concept in the current state). The cargo box has a handle on top that completely vanishes in the top cover during flight (similar to an extendable suitcase handle).


Unloading from the top, idea for a centering the cargo in the cargo box



Unloading from the bottom

Exchangeable payloads

It is possible to re-configure the cargo container with additional equipment. There would be for example enough space below the aircraft to add an additional gimbal. When the lower doors of the cargo container have to be changed for the sensor, they cannot be opened for additional cargo anymore, but the container can still be taken out from the top, opened and depending on space and weight, additional payload added. The cargo container is always connected via plug with the airplane power systems, if power is needed for the sensors.

Additional gimbal in re-configured cargo container

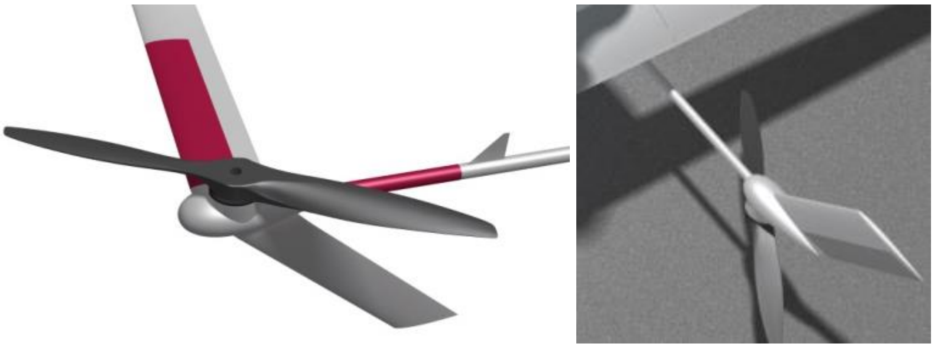
Fail Safe components to prevent catastrophic failure

In case of loss of cruise motor power there are two possibilities: if control actuators and data link are still working, it is possible to glide down since the airplane is designed as pitch stable configuration. If control is totally lost a parachute is provided to land the airplane safely. The parachute launcher and main parachute are located in front of the center of gravity and when launched the cover of the fuselage is blown off that the parachute can unfold. The main parachute is connected to the main structure close to the center of gravity.

Fuselage without cover after parachute launch, plane on parachute

Safety provisions: Limit time on ground with rotors spinning

For safety and visual indication the areas that the upward facing forward lift propellers cover are marked on the frame and canard with bright colors. There is also a triangular plate on the frame that avoids that your hand slips down the frame into the propeller. The aft lift propellers that are downward facing behind the main wing are partly covered by the frame and the vertical tail plane.



Dangerous areas that a colored / triangular plate, aft lift propeller covered by vertical tail plane and frame

Data sheet:

Wing span = 5m

Wing area = 0,833m²

Canard area = 0,19m²

Wing loading = 30,1 kg/m²

Root chord = 0,2m

Canard chord = 0,12m

MAC = 0,173 m

Aspect ratio = 30

Taper ratio = 3,9

x cg (from canard LE) = 0,828

x np (from canard LE) = 0,855

Vertical propeller area = 4* 0,385 = 1,54m²

Thrust / weight, cruise engine, max = 0,27

Thrust / weight, lift engines, max = 1,08

See frame sheet for further reference data.