Airbus Design Proposal

Design philosophy

Many highly efficient gliders have the following characteristics; high wing, t-tail glider and tadpole fuselage. Quadcopters are also among the most manoeuvrable aircraft. Therefore, it would seem that the most logical hybrid would be a combination of these two. However, it was found that given the nature of this competition that another configuration, the wide-body, canard with retractable quad arms, may be more suitable.

The first thing that was noted from the rules is that 25 kg is the target mass. Even though this is the maximum there is no need to aim for anything less. Additionally, a quick analysis of motors shows that four motors are likely to be the most efficient form of lift, since the rules stipulate you have at least four lifting motors. Rotors could be put within the wing, but this would make them less efficient and weaken the structural integrity of the component they are within (by necessitating giant 29” holes). Even prop guards significantly reduce the performance of rotors, so we decided it would be preferable to mount the motors external to the aircraft in clean air.

Given that a forward camera is also required, a tractor motor is unlikely to be a possible configuration. Multiple forward motors could be utilised, but this is likely to cause unnecessary additional mass. This called for an unconventional layout. The inspiration for this aircraft is drawn from Burt Rutan, known for his peculiar designs, and in particular his home-built, ‘Long-EZ’. This was a very high performance canard aircraft and was cause for much research into canard aircraft. The research found that the pusher configuration and shorter fuselage enabled significant drag savings.

Image of a Long-EZ from http://www.wingermodels.com/long.htm

A wide-body was chosen for ease of use. Given the dimensions of the payload, it was likely that an elliptical cross-section would be required. The decision was made to have the major axis lie horizontally so that only a single fuselage deck would be required (instead of stacking items vertically, we can stack horizontally). A removable top-hatch then enables easy access to all components. This was very important for this design as it is intended to be as modular as possible. Being able to access all areas of the aircraft with the removal of a few covers makes life much more convenient for the user. This prevents the need to remove multiple components to gain access for maintenance. This design allows for a very open-plan layout, that can be customised for various operations. The single deck also means that a complex truss structure is not required internally, saving weight.

Another key design feature of this aircraft is an attempt to have as ‘clean’ a body as possible. On this basis we decided to retract all external components into the fuselage. Obviously retraction mechanism adds weight and complexity to the design, but we felt that the drag savings and safety of this design provides the costs. This will be discussed in greater detail in a later section, but a preliminary result from wind tunnel testing that we carried out at our university showed that the drag cost of the quad-rotor system could be over **6N**. To put this in perspective, the wing in this design produces 6.6N of drag. The rotors are in effect doubling the drag of the aircraft, making the kind of mission described in this challenge very difficult. We felt that although the 60 km mission may be possible with this drag, the 100km mission would not be. By removing external components we were able to achieve significant performance gains.

It is noted that adding extra moving parts the risk of failure is increased, so we implemented one of the simplest designs we could find. The retraction system is similar to the servo landing gear systems of many heavy-lift quads. It encompasses a tension spring to aid the motor against drag when retracting and extending during flight and is rated to hold over 20kg. As such we feel any failure in this component is well mitigated and the risk is of comparable order to many other structural elements in the aircraft.

The last major consideration was the design speed of the vehicle. This vehicle is competing in an industry that has many transport options such as ‘traditional’ drones, cars, motorbikes and the like. We, therefore, felt that unless the vehicle could travel at a reasonably fast speed, there would be little uptake of the technology. This vehicle is also intended to be an emergency response vehicle, so it should be capable of travelling fast. As such we optimised for a cruise speed of 35m/s. However, the aircraft was designed to operate efficiently over a range of velocities for different mission profiles.

In order to land, usually, you would like to approach at a speed less than 15m/s. If this wasn’t the case you would find it hard to find runways long enough for you to land. This is less than half of our cruise speed, which would mean that we would need to increase our lift coefficient by more than four times. Given that this would require complex high-lift devices on the wing, this idea was abandoned. Furthermore, greater performance can be gained from the wing if landings are not a concern. For a canard, especially (where the canard limits Cl max), incorporating a stable landing into the design would result in significant performance losses. Given that the wing and tail configuration cannot support a fixed wing landing, wheels were not incorporated in the landing system. This enabled a slender landing gear design that retracts neatly into the fuselage.

For these reasons we would like to canvass our design the FD-7 (‘fat duck’). Further justification is provided in the ensuing documentation to complement the summary provided above. Please feel free to view all the relevant, drawings, figures and data to feel confident that our design is both viable and fully capable of surpassing the requirements of this challenge.

COTS items

- Lift motors: U11 from tiger motors
-Lift Propeller: T-motor 29x9.5”
-Lift ESC: T-80 Flame 80A
-Cruise motor: Terminator 30 from plettenberg
-Cruise Propeller: APC 20x15” folding propeller
-Cruise ESC: PowerJive 120+ ESC
- Retracts: see DJI spreading wings series
- Lipo: Tattu 30Ah 22.2V (30km) or Tattu 22Ah 22.2V (60km)

Design

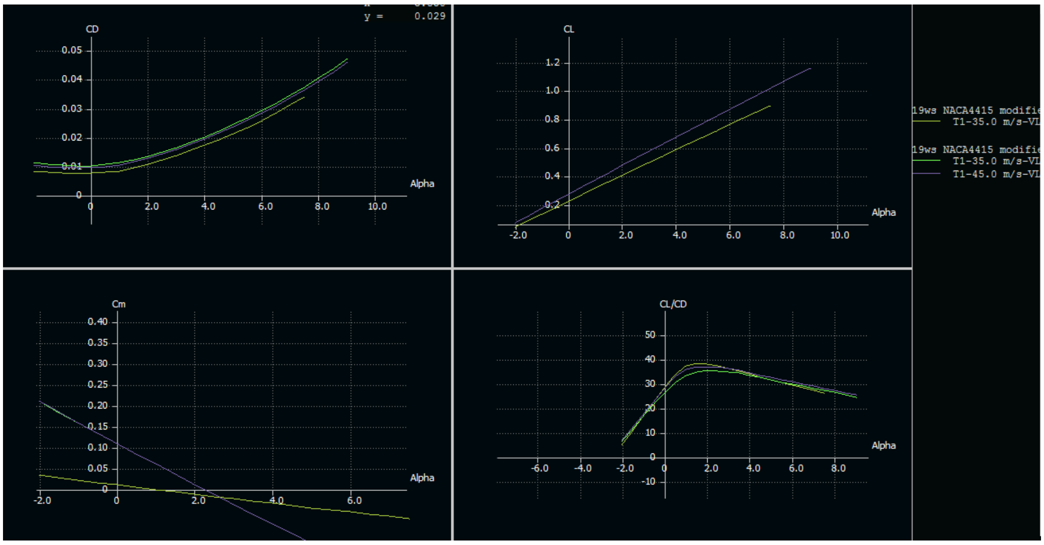
Aerodynamics

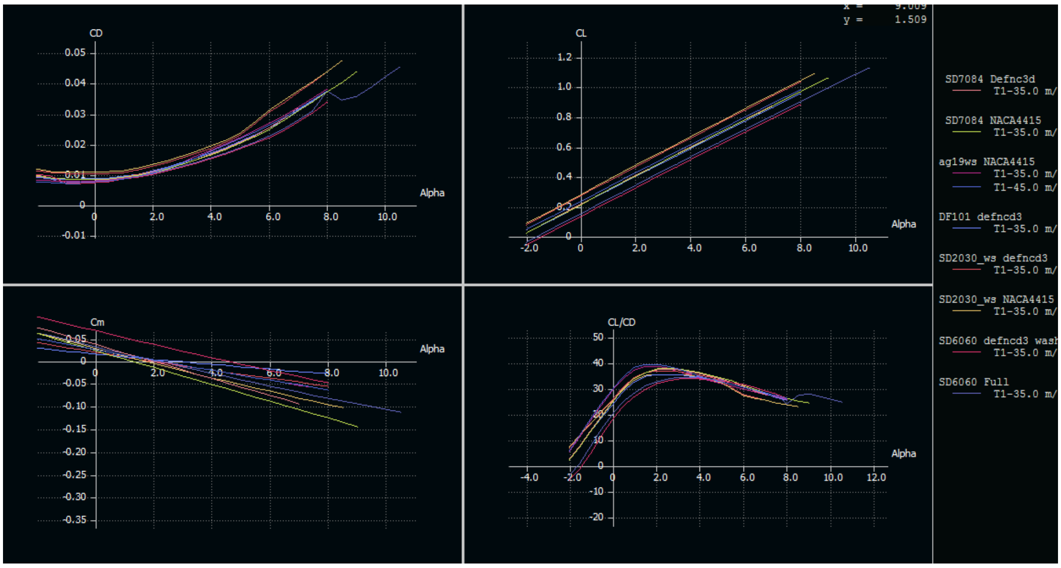
An appropriate place to start the design process was with the wing. The main aim was to design the most efficient wing possible (highest L/D for max range). We used a drag build-up using principles from “Fluid-dynamic Drag” by Hoerner. Knowing that we would be retracting most components, this left only three components exposed to the air, the fuselage, tail and wing (antennas and pitot tube were disregarded as little information was provided about them). For the multitude of aerofoils available we wrote a script to parse for profiles that achieved certain criteria that best optimised our flight conditions (canard at 35m/s). Data was extracted using X-Foil. We also wanted the tail to be as lightly loaded as possible as this would give the highest efficiency. This is because the main wing produces lift more efficiently than the canard tail. A few aerofoils were then used to make various configurations in XFLR5 to see which performed the best and also would provide a safe aircraft to operate. This resulted in an ‘AG-19’ profile for the main wing and a ‘DEFIANT CANARD BL145’ for the canard.

The key criteria that these met were that they achieved static and dynamic stability and were highly efficient. They also provided gentle stall characteristics that would mitigate aircraft instability. However, there were some performance losses from this configuration. In order to always be stable the canard must stall first, which is why we chose the BL145. This limits the maximum lift coefficient that the aircraft can produce. Despit this we were able to ensure that the maximum lift coefficient was at least double the cruise lift coefficient without the aid of flaps.

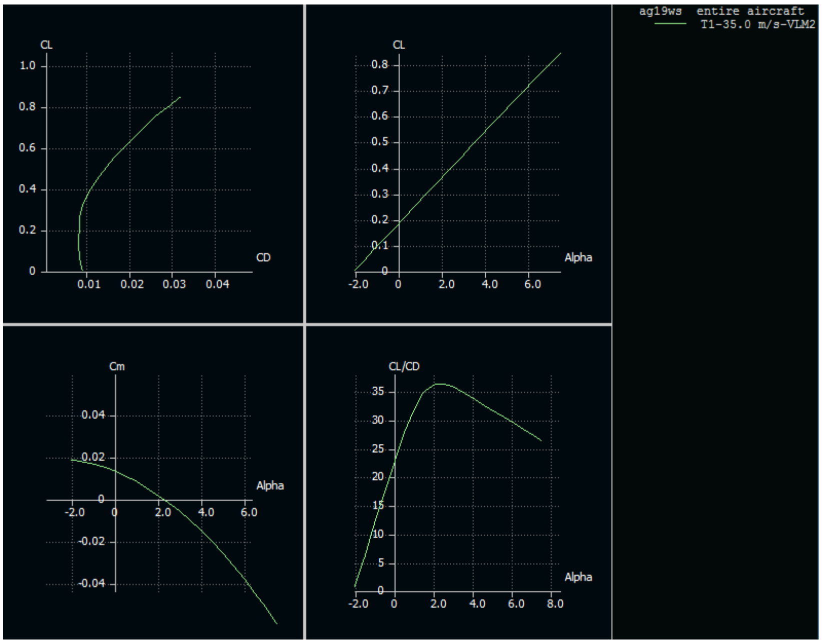
It was tempting to make the wing have a very high aspect ratio to reduce the induced drag, but for structural reasons we decided to limit the span a little.

Our efforts gave a wing and tail combination capable of reaching L/D values of almost 40 (see drag polars presented). Obviously the figure for the entire aircraft will be lower, but this was a good starting point.





Considering, this aircraft is not to be flown by a person, but rather computers, artificial stability can be achieved through good control algorithms in the autopilot. However, we still made attempts to enforce stability on the aircraft. By having an almost marginally stable, but still stable configuration we were able to produce data that suggested we could maintain an L/D ratio over 30!



However, we decided that this data would not reflect the true viscous effects that would be present. As such we applied our own boundary layer theory to the fuselage to get a better representation of the drag. This will be discussed later. However, this was sufficient evidence for us that we had a workable solution, when winglets were added for directional stability. To set the winglet/fins further back from the CG (this increases the length of the moment arm), the out-board section of the wing was swept back. This section also had some washout to ensure the ailerons were never stalled and control could be maintained, during gusts or other turbulence.

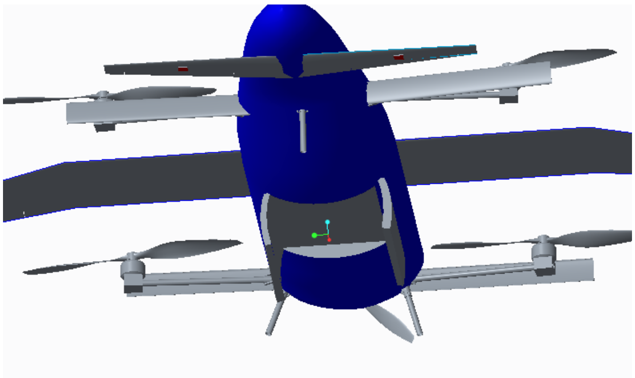
This configuration also provided good natural resistance to stall (because the tail stalls first returning the aircraft to normal angles) and spin. All the other stability regimes were also within allowable ranges. The aircraft's stall resistance also means that the aircraft's response to sudden gusts and drafts is also good.

It was decided to incorporate ailerons and elevators, but a rudder was omitted. This is because it is not expected that this aircraft will be executing very complicated manoeuvres and so it was decided that elevators and ailerons were sufficient. However, there are options for adding rudders to the winglets as in the Long EZ or using thrust vectoring (we were unsure if this was allowed by the rules) if necessary.

A high wing and low tail was utilised to minimise interference between the two lifting surfaces.This also increases airflow to the motor.

Fuselage

As was stated in the summary, a wide-body fuselage was chosen for operator convenience and modularity, by allowing for only a single-level fuselage. Top-hatches that can be removed easily (they clip into the formers) are built-in for access. Underneath these are braces in order to maintain tension across the upper surface of the fuselage. These braces can be unscrewed if large items are to be inserted into the aircraft. Underneath the payload are doors that can be unlatched. Doors were chosen as these are the simplest and lightest devices to automate. The hinges of the doors are made of a flexible Kevlar membrane. For this competition it was chosen to use tie downs to fasten the payload as these are light and simple to operate. If desired an autonomous system for opening the door and unloading the payload can be added, but that was outside the scope of this challenge.



An additional benefit of the canard layout, is that the centre of gravity is further forward relative to the wing than a conventional aircraft. A theory behind this concept is available in 'General Aviation and Aircraft Design' by S. Gundmusson. The forward position means that the payload can be accessed using the forward hatch without the need to remove the wing or have access underneath the aircraft.

A very simple geometry (series of ellipses) was chosen for the fuselage to maximise internal volume. The more curves there are in a body the harder it is to fit things inside. The fuselage is also divided into three sections. The front section is insulated from the rest of the fuselage. This allows sensitive electronics to be kept in this compartment if so desired. All connectors inside the fuselage are also water-tight and fastened to the foam core. The centre section houses the payload and lipo's. The final rear most section houses the cruise motor and flight termination equipment. This section bolts directly into the wing root supports and so is capable of supporting loads from both the motor and parachute. Keeping all the load-bearing elements relatively near to each other enabled lighter manufacturing.

The fuselage also has relatively large straight section in order to allow the props to fold in. However, based on work done by NASA scientists when studying canard aircraft, there may not be a significant advantage in tapering the fuselage of a pusher. In a paper they published, 'Wind-Tunnel Investigation of a Full-Scale Canard-Configured General Aviation Airplane' by L.P Yip (also see more generally "Aircraft Design- A conceptual approach", D.P Raymer) it was noted that the pusher propeller 'cleaned' up the wake of the wing and the other components. This makes sense as the propeller creates a favourable pressure gradient for the on-coming flow for much of the length of the fuselage. Therefore, even straight fuselages will experiences little flow separation. As such, skin friction drag is the dominant term and we needn't consider the impact of profile drag. Based on this we feel that we were justified in using a boundary layer approach to calculating the zero-lift drag for the aircraft. Specifically we used a laminar boundary formula 1.328/(Re^(1/2)) to compute the skin friction drag on the fuselage and wing. We then multiplied this by interference factors given in Hoerner, noting that there was some turbulence generated because of the propellers in the fuselage. This lowered our L/d to about 24.7, which we felt was still a very good figure.

This fuselage design also allows for scalability, since the motor is fastened very close to strong structural members. If the aircraft were to be scaled up, it would be very easy to replace the electric pusher motor with a gas one. As was stated before the motor is located in the rear section of the fudelsge, which has been made very strong.

Propulsion

For the propulsion system we found it very hard to find reliable data. Using the UIUC database we were able to find information relating to specific propellers, however, for the rest of the propulsion system we had to rely on manufacturer specifications. We chose motors and Lipo's with a wide operating temperature range to best meet the challenge conditions. Furthermore, since we weren't sure of the reliability of the data we overcompensated in this area. It is likely that it will be found that amongst the competition, we will have a very heavy propulsion system. However, having incorporated such a system we are very confident that this design will be able to perform in all weather conditions. Given more time (and funding) we could, of course, test some potential motors in a wind tunnel and using this data conclude on a lighter system.

One major difficulty for use was finding a motor and propeller combination that could operate at very high air speeds. In order to maintain positive blade angles (to get positive thrust) the propeller must have a lot of pitch and be spinning very fast. Hence, we chose a 20x15" propeller. This provides us with a lot of static thrust at transition. Given that our stall speed is very high (22m/s -refer to our wing section for reasoning), having surplus thrust is certainly a benefit. It also aids in our climb performance. These numbers show that we can easily complete a transition without losing much altitude or control of the aircraft, despite the high stall speed. The excess power available also allows for high flying altitudes.

The vertical lift motors are equally spaced around the centre of gravity. They retract synchronously, so do not shift the centre of gravity when folding. Additionally, the centre of thrust was placed as high as possible to ensure stability during the vertical modes.

All five motors are capable of operating in the conditions stated. Additional cooling vents are provided for the cruise motor since it is internally mounted. However, lipo performance will drop significantly in the extreme conditions speculated in the challenge. As such the lipo's and other sensitive electronics can be kept in thermal insulation for cold conditions. As they operate, they will produce heat and return to normal operating conditions. For extreme heat, insulation will be used again, but to prevent heat getting to the electronics. The temperature will first be reduced with the addition if 'instant-ice packs' (chemical refrigerants). Although these are only effective for a short time, the insulation, should ensure cooler temperatures for a significant amount of time.

All the motors used are dirt and shower resistant to ensure operability in a variety of conditions. As was stated earlier, connectors will be water-resistant as well. The nose section of the fuselage is also further sealed from the environment with light gaskets.

The Lipo's chosen were from a reliable manufacturer in Tattu, who specialise in hobby aircraft. It was decided to go for a fairly safe estimate of 180Wh/kg for the energy density to ensure that the challenge could be completed. However, these numbers are likely only attainable under standard operating conditions. Two packs are used so that the mass of the lipo's can be balanced around the centre of gravity. This means that even if more energy is required for a mission, larger packs can be installed without affecting the centre of gravity position.

Retraction

As was stated in the summary there are large gains to be had by retracting components into the fuselage. In wind tunnel testing conducted at university it was found that 12” props produced approximately 0.15N of drag in 25m/s wind, even when parallel to the airflow (1.5N when perpendicular). Even more, drag was produced, if they were behind each other as the turbulence caused increased drag. The motors each produced 0.5N of drag, but were more streamlined, so there was less interference. At 33m/s the drag rose by almost double. Considering that we will be using 29” lift propellers of the drag penalty could be significant even if the propellers are kept parallel to the freestream. Furthermore, the testing showed that when the propellers were not fastened they would oscillate in the wind. Spinning of the propellers was observed if there was any flow perpendicular to the plane of the propeller (ie. because of downwash from the wing). As such, the drag for this could be anywhere from 6-15N, depending on your flight speed. Taking the lower end of the spectrum, 6N, this could significantly increase your required battery weight. This increase is dependent on the propulsive efficiency of the system, but we decided that the drag increase was too great for a long range aircraft. An esc brake could be applied to stop the propeller from rotating, but some sort of actuator and position sensor would also be needed to position the propeller correctly first.

Apart from performance, there are other benefits to having retractable quad arms. These include allowing people to safely approach the aircraft and easy storage of the vehicle. Propellers are very sensitive to mass imbalances so have to be stored carefully. This design allows for them to be stored within the vehicle itself, which makes for an enormous convenience. It also increases safety as there is less chance for operator error when assembling. The retraction system is also very light only adding about 150g per motor. This is much less than the added weight for the drag increase from externally mounted propellers and motors during cruise.

The system for retracting motor arms is also very simple. We essentially employ the same system used on quads to retract landing gear. The particular design we have locks when the arm is at full extension preventing any movement. Additionally a tension spring is employed to aid the motor against wind resistance. The system is made simpler, because we attach a cowling to the outside of the motor arm, such that when it closes, it fits perfectly with the fuselage. As such, no additional hinges or doors are required. The same applies for the landing gear. The curvature on the inside of the propeller housing stops the arm getting stuck if the propeller approaches the fuselage at a 90 degree angle.

A safety switch is also placed in the system to disengage and reengage the motor, when it folds to make the aircraft even safer for users.

Construction

Fuselage

The fuselage core is made from high density foam. This can be milled out in halves from a large block. The mill can then form cavities for all the relevant components to sit in. This construction process allows for great flexibility in the layout of the aircraft. Fibreglass is then laid on both the outer and inner surface, to form a sandwich structure with the foam. This provides significant rigidity, with little need for additional support. Formers are added to provide as mounting points for load-bearing elements, such as motors, landing gear and wing.

Sample fibreglass and foam can be found at the following sites, respectively.

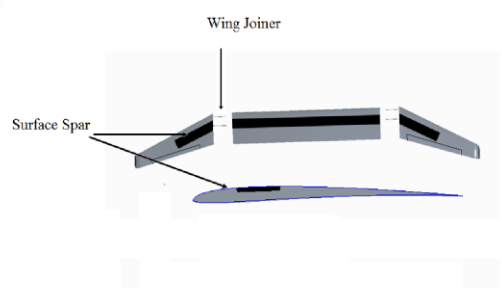
https://www.pccomposites.com/category/dry-fabrics/fiberglass-dry-fabric/
https://secure.solidsolutions.com.au/view_products.php?cat=65

The rear section of the fuselage is not covered with composite, but is instead covered with a plastic film to reduce skin friction drag. The reason for this is that the internal formers in this area are very strong, so no other reinforcement is required.

The formers are carbon fibre plates that have been routed to shape. The formers fit into slots in the foam core and are adhered to the composite skin. This provides the load transfer from the wing and motors to the fuselage. Although carbon-fibre is known to be RF opaque, the limited use of carbon fibre here should not pose an issue.

Wing/winglet and Canard

The wing is made in a similar fashion to the fuselage. There is a foam core with a composite skin. There are also cut outs for the control surface. A Kevlar hinge is used for both the ailerons and elevators to minimise the number of components required. Skin sizing is approximated using Mark Drela's stressed skin approximations. A surface spar is also employed on the wing. Adding additional carbon to the surface of the wing increases the flexural strength of the wing, preventing it from failing in compression when bending. Additional, material can be added to the lower side of the wing, but this is less likely to fail as this area is usually in tension.



A 3-part wing was chosen to maximise flexural strength at the root. The outboard sections of the wing then fit into the central section via two pipe joiners. These are then retained in place with the aid of fastening bolts.

Safety and Maintenance

The safety of personnel operating this vehicle and also that of the general public is of utmost importance. In order to prevent injury to people and damage to property it must be ensured that nothing approaches the vehicle while it is armed. This is achieved by using a lighting system on the aircraft to show when it is armed and unarmed. Furthermore, when it is on the ground and disarmed the lift rotors should be fully retracted and disengaged. This means that reduces the chance of the motors spinning suddenly and injuring people. The aircraft will also be able to enter a maintenance mode where the quad motors can be extended, without arming the motors. The top hatches ae easily removed to swap batteries and conduct general maintenance on the vehicle.

A flight termination parachute and launcher is incorporated in this design to mitigate almost all kinds of failure, including total system power failure. In such a circumstance the rear hatch opens and the parachute is deployed. A parachute ensures the safety of the aircraft as well as anything below it. The rear cruise propeller also folds to ensure that cables can't get caught.

Storage and Transport

As has been stated, storage is very easy with the FD-7 as the motors are self-contained. The nose and rear-sections can also be removed making the design more compact.

Conclusion

This concludes our proposal for the FD-7. We appreciate the time you have taken to read this document and hope you find the FD-7 of outstanding quality. This has been a very enjoyable competition and there have been many high quality entrants.

Thank you very much for the opportunity to compete and we hope that you'll find that the FD-7 was a great contender.