I certify that all material in this thesis that is not my own work has been identified and that no material has been included for which a degree has previously been conferred on me.

Signed…………………………………………….

The Design and Development
of a Flying Platform

Christopher M. R. A. Poczka

2003/4

Abstract

This report covers the Flying Platforms progress in 2003/4 in terms of the structure and propulsion matters. Propulsion is covered as there was a need for further thrust identified. Research into gas turbines is covered. Testing of auxiliary ducts to improve the ducted fan unit are described. The structure is designed for this year's requirements. An outline design is conducted and reported. Manufacturing options are discussed together with further research areas.The cost of materials needed for the structure is also covered.

Acknowledgments

I would like to thank Dr. Martin Jenkins and Dr Gary Lester for their support and contributions to the group project.

I would further like to thank the Technicians of Exeter University for their support, mechanical workmanship and expertise.

Finally I would like to thank all the members of the Group for their work of 2003/4, namely: Liam Dushynsky, Alex Tombling, James Mackensie-Burrows, Kevin Lowis, Richard Forder, Richard Holbrook, Rebecca Hughes and Jody Muelaner

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Nomenclature

JM	Jody	Muelener
RCH	Bex	Hughes
CP	Chris	Poczka
RH	Rico	Holbrook
RF	Richard	Forder
LD	Liam	Dushynsky
KL	Kevin	Lowis
JMB	James	Mackensie-Burrows
AT	Alex	Tombling
ICEngine	Internal Combustion Engine	

Introduction and Background information

1.1 Project description

The objective is to design and develop a flying platform with a team of nine final year undergraduate students from various specialist engineering disciplines (Mechanical, Civil, Electrical and Management). Using the knowledge gained from previous years' of development, together with personal knowledge and skills, support from supervisors and academic staff, the aim is to work as a team towards a common goal; the design and further development of the flying platform.

1.2 History of Flight

The first flying platform was developed by American organisation, Hiller Advanced Research Division (A.R.D.)[1], which advanced research division successfully achieved this in 1955. Since then, academic institutions as well as the defence industry have been researching and developing this area of advancement in both manned and unmanned vehicles. The strong interest from the defence industry has resulted in development of numerous types of such devices over the years. Besides being utilised in the defence industry, such devices many also be applied towards other areas such as, search and rescue operations, agriculture, humanitarian aid, civil engineering and law enforcement

The flying platform can be divided into two specific groups, namely, Manned Aerial Vehicle (MAV) and Unmanned Aerial Vehicle (UAV). Details of which are listed below.

1.2.1 Manned Aerial Vehicle (MAV)

Following more than 50 years of research and development, technology advancement in this field has made it possible for private individuals to purchase a MAV commercially.

MAV devices are complex and require input from the operator. They are highly damped to enable the individual flying and controlling the vehicle to have almost total control of the vehicle. This means that these devices do not require high precision sensing devices to control the motion of the vehicle. For the purposes of the flying platform, this type of device is not useful as the sensing / control of the vehicle is the key to the flight of the platform.

1.2.2 Unmanned Aerial Vehicle (UAV)

UAVs, on the other hand, are complicated to develop as they require a complex control system. Despite the complexity involved in its development, technology advancement in this area has resulted in UAVs becoming more compact in size. The defence industry is particularly interested in this area of development and have made advancements with respect to UAVs based on aircraft designs. This means that they do not hover over the ground like helicopters.

A survey of available technology has determined that to the author's knowledge, the only systems available are based on helicopter designs (Marvin, the UAV[2] helicopter designed by TU BERLIN) or have one used ducted fan for vertical flight. In the latter case, stability is ensured with the use of vanes and horizontal flight is provided by a second fan mounted horizontally.

Rotomotion, LLC[3], produces model helicopters with an autonomous flight system. They use open-source software produced by enthusiasts, together with commercially available parts, to design the control system. The helicopter comprises of a standard large model sized helicopter. The advantage of using a “standard platform” such as a helicopter is that the mathematical model for helicopters is highly developed and proven. This makes design of the control system easier.

As Rotomotion uses open-source software, this would be a useful starting point for the development of a digital control system. Although the mathematical model will inevitably be different the control algorithms used will be similar. Once the algorithms are studied these could be amended to suit the flying platform scenario.

The software uses predictive control algorithms to predict the motion of the helicopter. The hardware required to run the software is an 8MHz chips 256kB of ROM and the same of RAM. As the software is open sourced, it is freely available. When used in conjunction with an IMU (Inertial Measurement Unit) and GPS, the helicopter is able to fly to any given point.

The problem with implementing such a course of action is that no student has enough knowledge of programming to write the algorithm onto the chips.

1.3 Previous years work at Exeter University

The flying platform project has been running for some years at the university and is advancing through the build up of knowledge and development throughout the years.

The 2002/3 group succeeded in developing and building the flying platform to a tethered flight status. Due to the lack of evaluation of the power systems, the flying platform was dependant on external power. Thus during flight, the platform was dependant on an umbilical cord to supply a control signal and power.

The group’s success lay in its strong organisational structure which lead to good progress and development. Critical Path Analysis (CPA) was conducted before commencement of the project to identify and define the areas that required focus and development. Communication within the group appeared good and strong.

1.4 This groups objective for the platform

The development of the flying platform will be centred upon providing power to the platform to enable it to take flight independently without external power supply. Further, development of the control model is to be complemented and integrated with the IMU provided by BAE systems for accurate control of the platform. The structure and thrust were to be considered and amended where necessary. A PDS is included in Appendix A.

1.5 Tasks and responsibilities

1.5.1 Group management

Before the commencement of the project, the group appointed LD as a permanent chair and a JMB as permanent administrator, who would take charge of the minutes. The agenda for meetings was handled by AT and the treasurer was KL. These appointments were kept throughout the year.

The early stages of the project were spent investigating the developments and progress made by the 2002/3 group. Individual reports written by the 2002/3 group were distributed to be analysed and read. Depending on the specialist engineering field each student came from, tasks were allocated accordingly. Distribution of workload was constantly evolving throughout the project.

1.5.2 Personal tasks

The project was subjected to ongoing changes and the full extent of the tasks was highlighted towards the end of the project. The following is a list of areas the author investigated into throughout the year.

- Design and rebuilding of the pulse width modulated speed controller unit
- Research into gas turbines
- Research into predictive control
- Design of Ducts to be built around the flying platform
- Design of the structure
- Redesign of snake engine attachment

2 Electronic speed regulator and revolutions counter

2.1 Electronic speed regulator

2.1.1 Requirements

The characteristics of the control fans were required for control system development. The available thrust had to be evaluated to determine the size of the central fan unit. The evaluation of the thrust available required a reading of revolutions per minute (rpm). For this purpose, a frequency to voltage converter was required. The 2002/3 group designed an electronic circuit to record the rpm. Unfortunately, this circuit[4] was not included in the material handed over from the group and had to be redesigned. Using information from their material[4], the author constructed and developed the circuit further as the literature showed that the circuit diagram would not be capable of measuring the frequency band required.

Constructing the circuit was the first step towards gaining further data on the control fan characteristics.

2.1.2 Design

The design of the frequency to voltage converter produced by the 2002/3 group was incorporated, subject to modifications done to fine-tune the resistor and capacitor values to reach the right band of frequencies, as the components from the group was inadequate. A circuit diagram is shown in Appendix B.

The design of the electronic revolutions counter utilised a light gate provided by photo diodes. As the photo diode appeared too weak over the distance required, the author considered replacing the light emitting diode (LED) with a laser pointer, which has higher energy in the light beam and a longer range. A laser pen was sourced, as laser beam is high in intensity and easy to direct. This was used to provide a strong signal into the circuit, together with a photo transistor as the recording device.

2.1.3 Testing

The circuit was tested with an oscilloscope and a digital signal generator. The signal generator simulated the frequency light beam being cut and the oscilloscope was used to show the resulting voltage. The data was correlated to determine the accuracy of the speed controller and the sensing circuitry.

2.1.4 Conclusion

The circuit was tested and in full working condition. This was used to successfully test the power characteristics of the control fans as well as the ducted fan experiments.

3 Propulsion Research

3.1 Background

The engine purchased was an OS max 0.91 two stroke engine with a rating of 4.5 HP. The ducted fan made by RAMTEC, was 5.25” in diameter and specified to provide 60N of thrust when combined with the engine specified above. The control fans were to provide 20N of thrust, allowing for a total thrust of 80N. This thrust was required to leave enough thrust margin to lift all the other components of the flying platform. Initial tests of the output thrust indicated that the maximum achievable thrust from the central ducted fan unit was about 35- 40N, 33% less than what was expected. This fact seriously affected the flight ability of the platform. With the outer control fans contributing 10N each to the thrust, a minimum of 40 N of thrust was required from the central fan unit to allow the platform to take off. In light of this defect, alternatives, as listed below, were considered.

3.2 Considered solutions:

3.2.1 Design of a custom made purpose built fan

Design of a custom made purpose built fan was researched into and concluded to be beyond the scope for the group as a thorough design process will have to be conducted, and time constraints would not enable it to be built and tested[i].

3.2.2 Gas turbines

The author researched model sized gas turbines to be used as a generator to generate electricity or used directly to provide thrust. A survey of such manufacturers was conducted and found, as indicated under section 3.3 Gas turbines. The gas turbine combined with a gearbox and a propeller (turbo propeller version) was found to be very capable of providing the thrust required for application to the flying platform. Otherwise, the gas turbine could be driving an electric motor providing 3 phase generation to the platform.

3.2.3 Ducts to improve the current duct

The RAMTEC 5.25" duct does not include any auxiliary ducts (upstream or downstream). Further to the background research conducted[ii], the author commenced upon developing the design of lower and upper duct extensions. The upstream duct is of highest importance in increasing the thrust of a ducted fan unit. Thus, the author researched into the possibility of utilising both upstream and downstream ducts to optimise the airflow into and out of the ducted fan. This will be further discussed in 0section 04 4to greater detail.

3.3 Gas turbine

3.3.1 Background

Gas turbines are widely used in helicopters and aircraft to provide power to the rotors and electrical systems. There are model helicopters that have been successfully implemented with gas turbines as their means of propulsion. These models use the gas turbine only to provide the power to the rotor as they use batteries to power the electrical systems.

3.3.2 Gas turbine Theory

Gas turbines are a very powerful propulsion method as they have a high power to weight ratio. They are usually fuelled by natural gas or liquid kerosene and comprise of three stages, namely, the compressor, combustion area and turbine[5].

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[i] See JM report for details on the custom made fan

[ii] RCH individual research topic "Optimisation of Fan and Propeller Design"

The compressor pulls the air into the combustion area, causing pressure to rise by up to a factor of 30. The compressor consists of turbine blades in a conical shaped chamber. The airflow compresses increasingly as it progresses deeper into the compressor.

The combustion area has a fuel injector lined around the inlet. The high pressured air from the compressor enters the chamber and flows through the "flame holder" which is a perforated metal sheet. The flame holder is necessary, as without it the flame will blow out as high speed air enters the combustion chamber. This problem is the main design issue when designing gas turbines.

Thereafter follows the turbine, which is on the same shaft as the compressor, i.e. the turbine drive the compressor. The hot gasses flow through turbine and out of the exhaust. There is a power take off at the end of the turbine that connects to a shaft supplying power to the application, i.e. a generator for example.

Included below is a list of four main propulsive versions of gas turbines[6]:

<u>Gas turbine jet:</u> The turbo jet is the most basic gas turbine variant. The only main difference is that the gas turbine jet has an optimised air inlet nozzle. The nozzle is curling inwards rather than outwards as these are designed for high speed flight and not to induce high drag at high speeds.

<u>Turbo fan</u>: The turbo fan includes a large turbine in front of the compressor. This brings about a lot more thrust and is the common installation on commercial jet planes.

<u>Turbo propeller</u>: This design is similar to the turbo fan design, but instead of the fan in front to the compressor, there is a reduction gearbox and a normal propeller. This version is very fuel efficient though slower than the turbo fan. It has a higher static thrust and is better suited for heavy power demanding applications such as a C-130 transport plane.

<u>Afterburner</u>: This system is based on a normal gas turbine. I is used to increase the thrust during takeoff, climb or in military application during combat. Fuel is induced into the hot air after the turbine, but before the air leaves the jet nozzle. The reaction utilizes the unburnt oxygen with in the exhaust air. The increase in temperature due to the reaction makes the velocity increase and thus the thrust.

The advantage of a gas turbine is that it has high power to weight ratio compared to other means of energy production, like a reciprocating engine. It is also usually smaller than the equivalent size reciprocating engine. However, the disadvantage is that it is more costly in comparison to similar installations. To highlight key feature a comparison has been conducted between the RAMTEC engine and the Wren turbo propeller gas turbine (see Table 1). These installations also use relatively much fuel when they are idling and operate far better at a constant load rather than a fluctuating one. This is the reason why gas turbines are not used for car engines for instance, as they would not be able to cope well with the fluctuating power demand. For transatlantic flight though were a cruising velocity is kept for most of the journey the gas turbines are very efficient.

3.3.3 Application to the Flying Platform

For the flying platform, the application could be implemented in two ways:

1. The gas turbine could provide the total power for the flying platform. The current central fan could be replaced for a larger electric fan (or a number of small ones), using the power supplied by the gas turbines.
   Gas turbines have a band of rpm (revolutions per minute) in which they work very efficiently. This quality makes them very suitable as a power generation unit, where the turbine can run at a constant speed.
2. The second option is to use the gas turbine with a turbo propeller configuration. There is a unit produced by WREN Turbines[7] that can currently provide approximately 15kg of static thrust, which for the current size of the platform is ample. Turbo propellers are by design the coolest available gas turbine installation The gas turbine will provide in any case an automated starting sequence. The main advantage is that the gas turbine has far more power available than required at this stage. Gas turbines have another problem that as they are so highly sensitive shock loading.

   A comparative table of the characteristics is given below:

Characteristic	RAMTEC Fan with OS engine	Wren turbo-propeller
Thrust (max)	60N	300N
Engine power	4.3 HP	7.1 HP
Weight	1270g	1600g (excluding prop)
Fuel consumption	28g/min	38g/min
Fan / Rotor size	5.25 "(duct diameter)	21" X10"
Price (£)	500	3500

Table 1 -Ducted Fan vs. Turbo-propeller characteristics

3.3.4 Conclusions

The initial research into gas turbine looks promising, although the cost is high. With prices around £3500 pounds this was not viable for this year's platform, but should be considered when subsequent work is done. With such a high thrust the propulsion section would leave ample opportunity to develop other areas of the platform further, with out having to redesign propulsion continuously to meet new demands in subsequent years. This would allow propulsion to be left at a stage and the attention for focus on other aspects of the project, such as lateral flight.

4 Duct Design

4.1 Back ground

A preliminary analysis and design of a duct was conducted. A full investigation including a complete CFD (computational fluid dynamics) investigation would not be possible due to the detailed scope of analysis required and the time constraints of the project.

The author used research [8,9] and the Model Ducted fan design book[10] to design ducted fans. It was decided to only proceed with a preliminary analysis and design of a duct, as Duct Theory

The shape of the duct will have to be adjusted according to the conditions upon which the propulsion system is active. It has been found that the shape of the duct affects primarily the thrust characteristics as well as the rotor design[8]. Thrust is created by a propulsion system by adding velocity to the stream of air flowing through it. This is based on the momentum theory Figures 1, 2, and 3 below illustrate the effects of a duct on the airflow.

The flow around a rotor based propulsion system can be divided into three regions: the inflow, the slip stream and the free stream.
This can be seen in Figure 1.
The rotor aspirates air all around the tips of the rotor.
The next scenario to consider is the scenario of having a duct enclosing just the tips of the rotor.

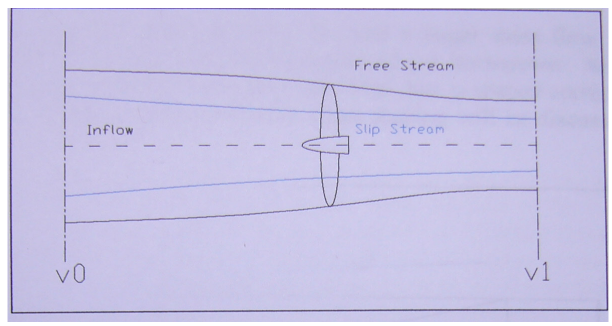

Figure 1 - Flow around a rotor with out duct

In Figure 2, air is not aspirated as the duct locks the passage. Thus the air has to move up stream bend around and flow though the rotor and duct within the slip stream. Note that there is no free stream in this scenario as the air flow is all confined to the slip stream. Losses due to the open propeller tips are known as tip losses and reduce the effective area of the rotor by creating reversed flow regions near the tips. This can be seen in Figure 2.

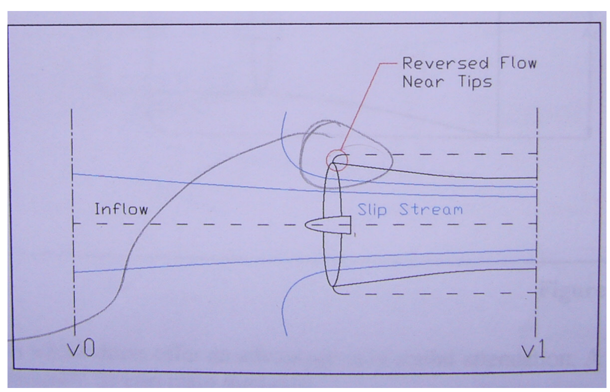

Figure 2 - airflow around an open Lower stream duct

Figure 3 shows a duct included with an up stream duct. Airflow can move more freely around the lip of the new duct.
The lip is made of a certain radius determined by analysis and is designed to reduce losses around that area.

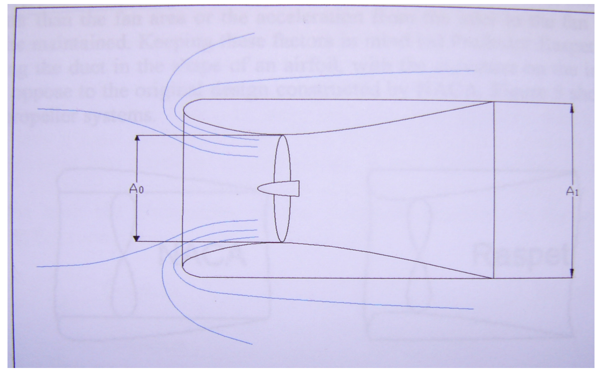

Figure 3 - airflow around a complete duct

Engineering models of duct involve certain assumptions and constraints:

Density of air: Air is a compressible fluid, The changes are small and thus it can be modelled that density is constant, but only changes with light altitude.

Uniform flow velocity: The duct is assumed to be at least one fan diameter in length, It is assumed that the inlet velocity does not change with distance from the hub.

Actuator disk representation: The fan and stators or flow strengtheners are modelled as a disk that increases the energy within the system, by producing a static pressure rise. This means the duct is modelled as an inlet are with an inlet velocity ratio, a disk (the fan/ stators / flow straighteners) providing a static pressure rise and the nozzle with an air jet having a certain exit velocity.

Atmospheric pressure at the outlet: It is possible to design a duct with a contracting or expanding exit nozzle. This will higher or lower the exit pressure respectively. The design process outlined will use the assumption that the fans outlet static pressure is equal to the atmospheric pressure, i.e. the fan is running at the designed speed/ conditions.

The design of a duct is an iterative process. The following steps are to be considered:

- Estimation of duct efficiency
- Engine Rating
- Fan sizing
- Mass flow
- Exit area
- Fan swirl / Horse power swirl
- Capture Area
- Fan entry static pressure
- Fan Flow speed
- Duct exit velocity

This calculation only calculates the area and velocities at inlet before and after the fan and at exit. For the purposes of testing or validating the test procedure, this calculation is not useful. However, it provides an insight into what mechanisms and assumptions are involved when calculating those parameters.

4.2 Concerns with the current duct

The duct bought by the group has not got any fitting to the top of the duct , i.e. the duct finishes on the same level as the rotor blades, as seen in Figure 4. As discussed above this is not a favourable situation. Thus an upper duct was decided to be implemented. The ducted fan bought by the group has no front duct as this type is to be fitted within a model aircraft that would already posses such an inlet and out let.

Figure 4 - Duct inlet picture

Form Figure 5 - Duct outlet picture can be seen how the engine clearly intrudes into the airflow of the fan. There are high losses achieved round the cylinder head and tuned pipe/ exhaust.

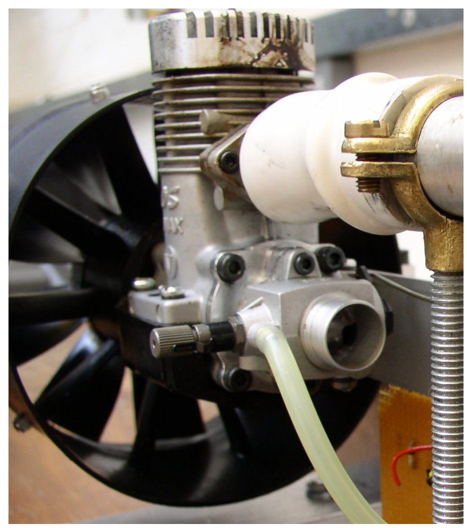

Figure 5 - Duct outlet picture

4.3 Other improved Model Ducts

Figure 6 –VIOJETT sold by BVM

Figure 7 - BVM attachment

BVM engines, a model engine manufacturer, promote a special duct (VIOJETT) that has a variable cross-section but allowing the cross-sectional area to remain the constant throughout the duct, especially near the engine. This is done by reducing the stators and widening one of the stators to cover most of the cylinder head. This allows for greater air flow efficiency (up to 85%). There is also the possibility of purchasing a special attachment that attaches behind the cylinder head and extends out to the tuned pipe (Figure 7) yellow attachment in Figure 6.
This sort of attachment streamlines the flow of the cylinder and allows the boundary layer remains reattached, reducing energy losses in the air flow and thus gaining thrust of about 0.5kg.

Future groups should consider the manufacture of such an adaptor should a ducted fan system be used in subsequent work.. One method would involve wrapping the engine in plastic, creating a mould by plastering the engine and from that mould[11] producing a casing such as the yellow one seen in Figure 7.

4.4 Design of the test ducts

Separate lower and upper ducts were designed with the use of cardboard. These were tested together with the ducted fan. The use involving fluid dynamic analysis together with fluid dynamic software to predict the flow was thought to be too complicated and time consuming. It would also provide for idealised assumptions that would not reflect the real scenario well, resulting in larger thrust gains. The bottom duct did not provide a significant improvement to the thrust characteristics of the IC engine.
After the first lower duct failed to result in further thrust, an upper duct was considered and constructed, which performed significantly better. The range of duct sizes were improved (5cm, 9cm, 14 cm, 19 cm and 22 cm) and tested to allow for a more complete picture of the thrust. Pictures of the ducts can be seen in Appendix C.

4.5 Construction

A bottom duct was designed previously and was destructed by the airflow. Improvements were made to include stronger cardboard and a better shape.

The subsequent construction of the cardboard ducts used A1 sized 1400micrograms mounting cardboard. The cardboard was held in place by staples and duck tape. The cardboard was folded and rolled up to retain the shape naturally.

4.6 Testing and results

The ducts were thrust tested in the same way as the ducted fan was tested. The mechanism utilised a counter balance and scales, measuring the force, which was then converted to thrust. The bottom duct was design and tested first. After the first duct failed to result in any significant added thrust, the upper duct was considered and 5 sizes (5cm, 9cm, 14cm, 17cm and 20cm) were tested; the results can be seen in the graph below. It can be seen that there is a clear advantage to having a duct present and thus it was decided that the manufacture of a 17cm duct to aid the thrust produced optimum performance. For more design information of the test ducts refer to Appendix D.

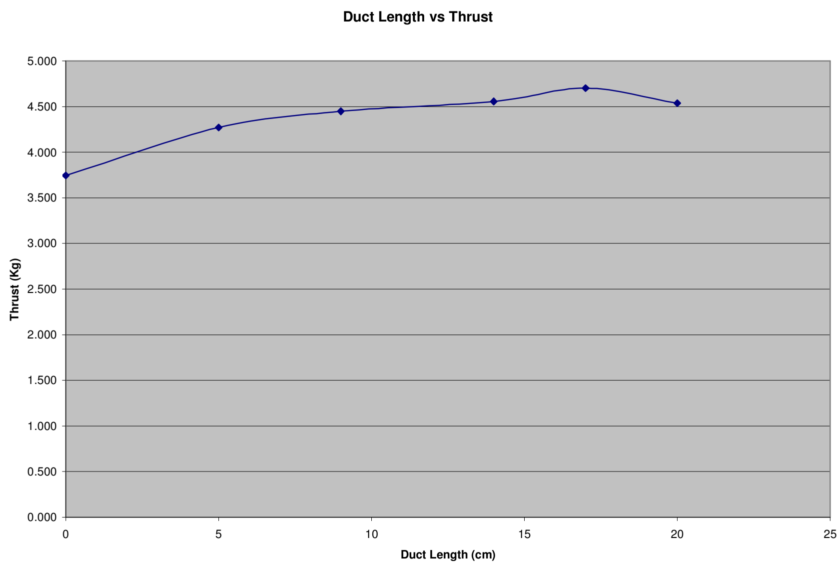

Figure 8 - Graph of Duct Length vs Thrust

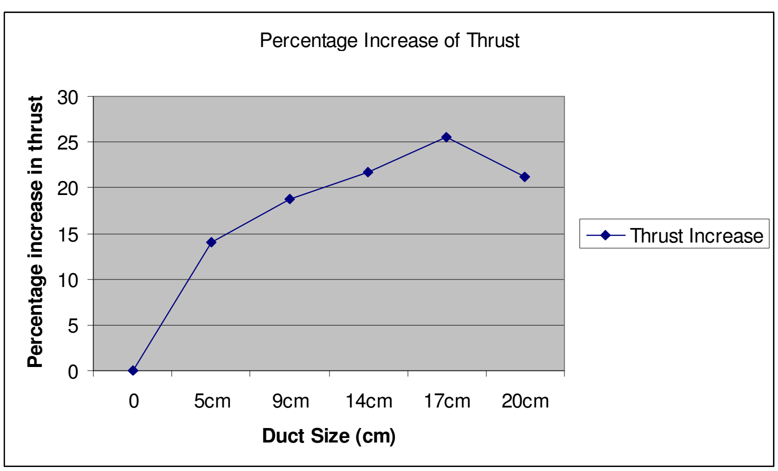

Figure 9 -Percentage increase in thrust

4.7 Design for the structure

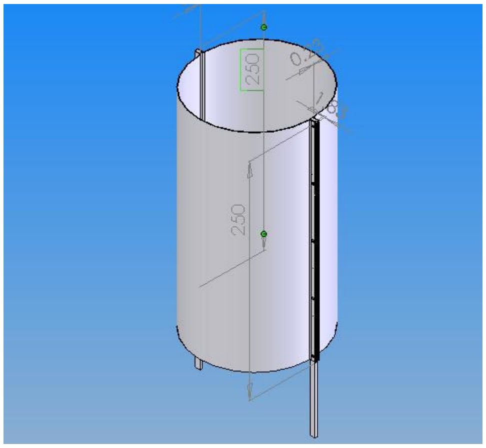

Figure 10 - Duct design

An upper and lower duct were considered. The upper duct yielded sufficient thrust increase.
The duct consists of 0.5 mm sheet aluminium bent into ½ cylinders and riveted together. The bottom inner lip has a thin layer of rubber to reduce vibrational noise from the ducted fan.
The duct is to attach to the engine mounts with some plate attached to the riveted lines. For more information, refer to Appendix E for engineering drawings of the duct.

4.8 Discussion

Model ducted fans have major flaws that the engine sits within the airflow. This is necessary for cooling purposes, but will affect the airflow away form the duct and induce boundary layer separation behind the cylinder head. For the purpose of regaining some of the lost thrust the bottom duct was constructed. The duct increased the thrust by 300g when coupled with the 14cm duct. As the duct did not improve the thrust enough to warrant construction or further investigation.
The upper duct was further investigated as it showed potential. The engine is too temperamental in terms of the output thrust and thus consistent results were unobtainable. This can be seen in the duct results in Appendix D. The duct was only varied in length, which is not at all conclusive. The angle of slope of the duct should have been varied to determine the effect of cross sectional area and the air flow more clearly. Another aspect is the design of a chamber that sits on the top duct edge to allow the air's momentum to be carried though and into the duct. This may allow for a shorter duct length by allowing the air to be move around the duct edge slowly rather than abruptly. Unfortunately no data or previous work could be found to validate this experiment could be found.

4.9 Conclusion

The upper duct of 17cm proved to result in the highest thrust increase from the preliminary investigation. It is uncertain if a shorter 5cm duct will improve the thrust if it is improved with a chamber on the inlet rim to "bend "the air flow in towards the duct. Another consideration would be to introduce a thin grating, like it is used in wind tunnels to straighten the flow. There is a need for more investigation, but the preliminary results look very promising.

5 Snake Arm Redesign

5.1 Background

The snake arm is the bracket the holds the shake in line with the throttle on the engine for both the Genset and the thrust rig. The first snake failed due a crack created in a corner and propagated resulting in failure of the bracket. This needed to be built and the author redesigned it in the process.

5.2 Design considerations

The snake arm was poorly designed. As the snake arm is connected to the engine directly, there is a lot of vibration going through the part. There were sharp edges left in key structural areas, which then allowed stress propagation to occur. This as can be seen in the figures listed under Appendix F.

Another design fault is that the snake does not lie in line with the throttle. The snake has to bend to reach from the snake arm attachment to the throttle. This meant that the throttle could be fully opened, but not completely closed. To close the throttle the fuel line has to be closed. Figure 11 and Figure 12show version 1 and 2 of the snake arm respectively.

5.3 Design of the snake arm

The new design considered all considerations above. The design was based on the same material and same dimensions, but a different shape. Any sharp corners were filleted to reduce crack creation and propagation (see the yellow circles in the figures below). The orientation of the snake arm attachment has also changes from vertical to horizontal to bring the snake inline with the throttle (see the red circles in the figure below). The engineering drawing is included in Appendix G. Shown below are two SolidWorks drawings of the two versions of design. The author had only influence on version 2.

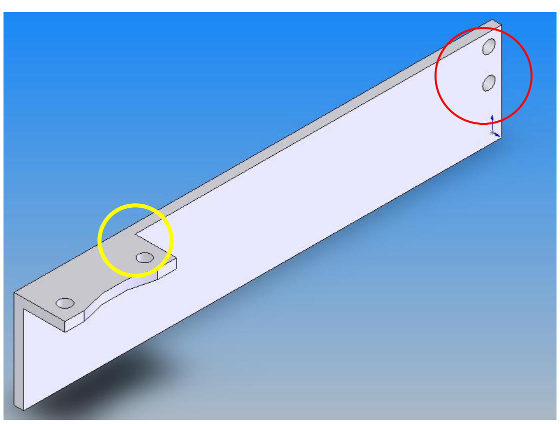

Figure 11 - Snake arm version 1

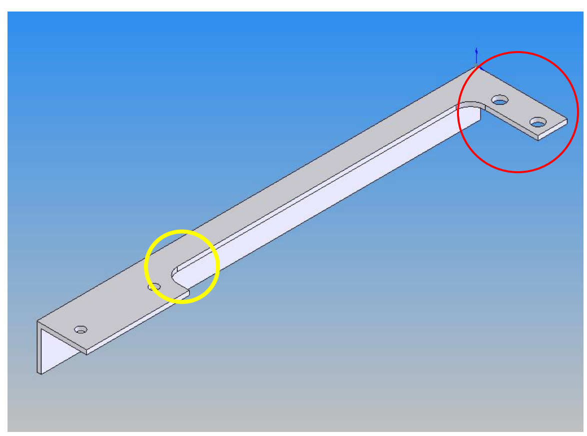

Figure 12 - Snake arm Version 2

5.4 Manufacture

The snake arm was manufactured from an aluminium angle extruded section. The holes were drilled with a pillar drill using a 3 or 4 mm drill piece where applicable. The recess was removed using a mill with a 5mm willing piece. A file was used to file the recess for the cylinder head near the engine mount. Finally the section was bead blasted to improve the aesthetics and appearance of the part, as well as the fatigue life. The blasting is non uniform and consequently leaves small compressive residual stresses in the surface which improve the fatigue life[12].

5.5 Conclusion

This design of version 2 should supersede version1 and the failure The failure of the previous version and optimise the throttle adjustment were successfully highlighted and incorporated into the new design.

6 Structural design

The structure designed by the 2002/3 group was successfully implemented last year. This year's structural design was to use last years design and adapt it for the IC engines. The structure was one of the most dependant areas, i.e. much information and validation had to be carried out by other sectors to allow the structure to proceed, for instance the Genset had to be proven to work and positioning of several components had to be determined before the structural design could be committed into the finals development stage.
Most of the delays for the structure were due delays in predecessors, i.e. duct testing, engine testing, Genset testing, etc.. These delays were mainly caused by restrictions placed onto testing due to noise complaints within the department of computer Science.

6.1 Background

6.1.1 Analysis of 2002/3 flying platform structure

<u>Analysis</u>

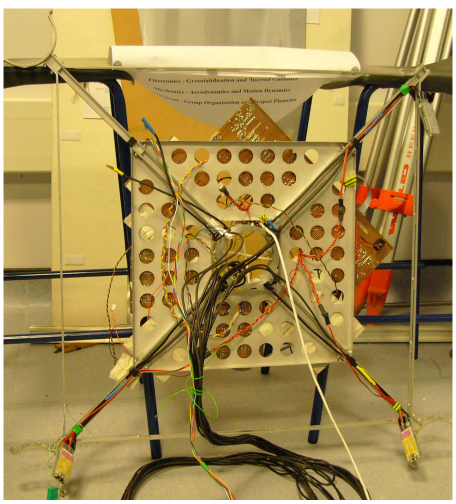

Figure 13 - Underside of flying platform of 2003

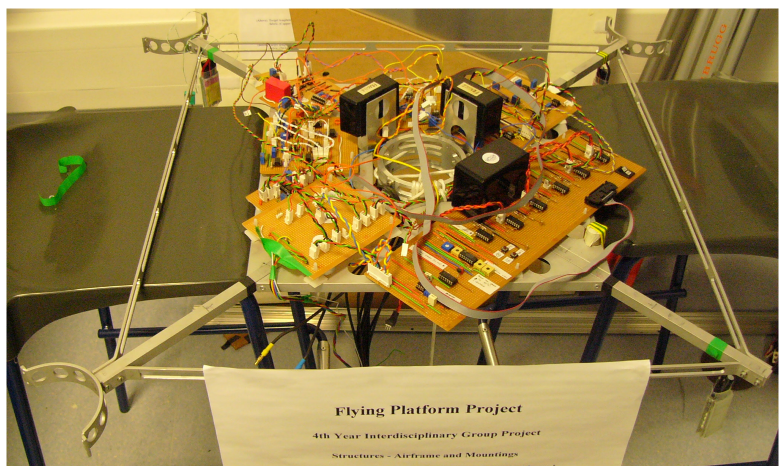

Figure 14 - Topside of Flying Platform 2003

The previous flying platform's structure was designed for a smaller central fan and included an aluminium hub enclosing the central fan. Last year's platform utilised three gyros that were mounted separately, each needing a separate mounting bracket. Aluminium was used throughout except for the bolts and nuts which were made from galvanised steel. The arms were made with aluminium extrusion. The central hub encasing the central fan was made from rolling stock and turned on the lathe. The control fan holders were made from flat bar welded to square bar. The tensioning bars were made of flat bar as well. The plate was manufactured using 0.5mm aluminium sheeting.

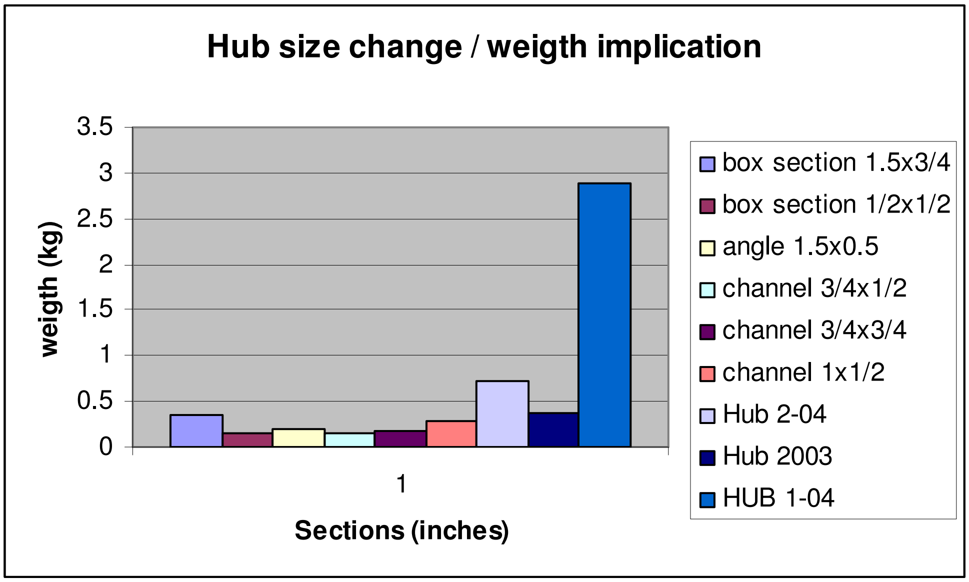

Figure 15 - Weight of different materials

The tallest bar in the graph is a scaled version of the hub from last year. It can be clearly seen that this is not a viable option as this component alone would weight in excess of 2.75 kg, if it was scaled and implemented on this year's structure.

The control fan mounts could be taken from the last year's structure to be fitted onto the new structure. These mounts were well designed and optimization of these was deemed not to yield any significant results.

Conclusion

Last year's design was suitable for last year's purposes. The weight for last year's platform was 0.970kg and costs £45. The analysis focused on the structural rigidity, lightness, safety factors and strength, but did not consider vibrations. As only electric motors were implemented, the vibrations were not that important and pronounced.

The main difference between the last year's structure and this year's scenario is the use of an IC engine as a power source. This will induce a lot of vibrations into the structure and possibly cause interference with some of the sensitive electronic components on board. As highlighted in Figure 15, an advantage of eliminating the hub is that it has a high weight even with weight reducing slots included. It also involves high machining time cost.

6.1.2 New Requirements for the structure

For the adaptation of the new structure, the following considerations were taken into account.

- Provide for the new IC ducted fan unit
- Reduce machining cost and simplify current design
- Reduce vibration induced by the two IC engines
- Adaptation for the Power Generation Unit
- Low centre of mass relative to the centre of lift
- Possibility of the structure be adapted to the new fan design by JM

For a full PDS of the structure, see Appendix H.

It was found that the structure would be more stable in terms of the control if the centre of mass lay below the centre of lift[iii]. This would though also influence the platforms manoeuvrability, as such a low platform will provide an extra moment reaction if tilted. This moment reaction is what stabilises the platform when it is stationary, but should it move laterally then the moment would result in and acceleration towards the direction the platform is moving. This can very difficult to control and thus a compromise was met allowing the platform base to extend 0.2m below the" flight deck". This meant that the Power generation set (GENSET) was to be place as low as possible to aid the stability of the system as a whole. The main change between last year and this year's platform is the change into the onboard power generation, rather than storage. This including an internal combustion engine meant a higher lifting weight and thus a larger central fan to generate enough thrust. This was to be compensated by a larger ducted fan powered by an internal combustion engine.

The two IC engines have shown during their test runs that they incur considerable vibrations onto the structure. This will have to be looked at in some detail. The change from the 2002/3 group's 2D structure to this proposed 3D structure, in addition to the increase in weight of around 3-4 kg due to the Genset and fuel would result in this structure being far heavier compared to previous structures. The Genset Testing setup required and alignment between the IC engine and the electric motor shaft of 0.05mm. The alignment needs to be kept to such a small detail or else the flexible coupling will fail. To ensure this alignment is possible the Genset will have to be mounted on aluminum flat of a thickness greater than 5mm. The Genset is to be carried as low as possible to lower the platforms centre of mass. The weight of the platform is going to increase as the Genset moves lower. The Genset has been decided to be mounted at 0.2 m below the flight deck.

Following the design of ducted fan units certain user groups warn of the implications these fans can have in terms of catastrophic failure due to vibrations and the resonant

[iii] Reference to RCH Report on stability control

frequency. The manufacturer of the ducted fan suggests the use of vibration engine mounts.

6.2 Design Considerations

The PDS for the structure is included in the Appendix H. Key areas have been highlighted that need special attention for consideration.

6.2.1 Material selection

The 2002/3 group manufactured their structure from light weight aluminium following a thorough analysis of the material properties needed[13].

For the purposes of this structure, the author decided to retain the use of aluminium as the basis of the structure. Aluminium was found to be the lightest material with considerable strength and workability. Further aluminium extrusions are widely available from the stores within engineering. The material for the structure had to have a high ratio of aluminium. Aluminium 6061-T6 should be used as it has excellent joining characteristics and is easily available. Further, it is of high strength, high resistance to corrosion and has good workability. Its strong properties is the reason why it is commonly used for aircraft fittings, bike frames, marine fittings and camera lenses. Full details of the materials can be found in Appendix I.

6.2.2 Weight addition and distribution

The control system was designed with the overall centroid of the platform in the centre. This is necessary to ensure that the control fans do not over exert in counter balancing weight, increasing power consumption and reduce stability control.

Another problem posed by the positioning of the fuel tanks is that the weight of these tanks will decrease throughout the flight. In order to maintain and ensure stability, the position of the tanks have to be evenly be distributed around the platform structure. Another factor was that the containers had to reduce the amount of fuel movement during flight as vigorous movement of fuel within the tanks would also affect the centre of mass and allow for bad momentum.

6.2.3 Manufacture

The 2002/3 structure was simple to construct although the central hub involved heavy machining and thus took up the bulk of construction time. For this structure, the simplicity of the design has to be considered to enable the manufacturing process to be kept simple and be easily constructed within a short period of time.

6.2.4 Vibrations / Engine mounts

To mount the ducted fan and the Genset onto the platform, anti-vibration mounts are to be used. The problem that could occur with mounting the Genset would be that it relies

on the alignment between the shaft of the IC engine and the electric motor. Any slight variations could cause the flexible coupling to fail.
As the Genset setup was not finalised at the time of this report, it was not possible to conduct tests to determine the exact mounting position of the Genset on the platform.

6.3 Harmonic Simulation

A harmonic / natural frequency study was considered, but due to time constraints this could not be completed to a satisfactory and conclusive outcome. It is though advised for subsequent years to carry out a harmonic study if the IC engines are kept on the platform.

7 The possible structural designs

Looking at the design, mainly 3D systems were analysed. The basic layout of the control fans incorporated the 2002/3 group's design. The logbook submitted includes a range of sketched drawings, but the selected few as shown below will be considered in detail.

7.1 Wire frame

A wire frame design was considered. This would utilise members in tension and compression to reduce the overall weight by preloading the system. Using this ties or even wires the frame would be constructed much like older aircraft. It was felt that this design although it had potential was too difficult to fine tune or repair in case of damage. The IC engines were also considered to be causing too much vibration which might allow the tension and compression members to lose their state of compression or tension due to the high frequency induced vibration resulting in the structure not remaining in its state of equilibrium. There were to many unknowns involved in this design, resulting in this design being dropped.

7.2 Box section design

The design is based around the idea of using sheet aluminium as a basis and designing the individual sections separately. The sections can be designed to the size, strength specification that is required for the specific part. This would allow the sections to remain stiff and can be custom made to fit the purpose. Below is a basic design utilising a squre box section.
Although the design appears basic, the sections have been significantly enlarged in term of width and depth in comparison to the 2002/3 group's design. The proposed material is aluminium sheeting of thickness of 0.5mm -1mm. In Figure 16, the cross-section of the arms is unclear. The shape is a C-section, with the bottom edges crimped inwards to give the section more strength, whilst keeping weight low. To further reduce the weight, holes were introduced to the side flanges of the section, as seen in Figure 16.
The structural components, especially in flight have to have a high second moment of area resulting in keeping the mass as low as possible. The second moment of area is the measure that a structure is a measure of ability to resist bending or torsion[14].

One of the problems faced with the manufacture of this design is that the technicians were of the opinion that it would not be possible to bend the aluminium sheeting to an accuracy high enough to produce these sections.

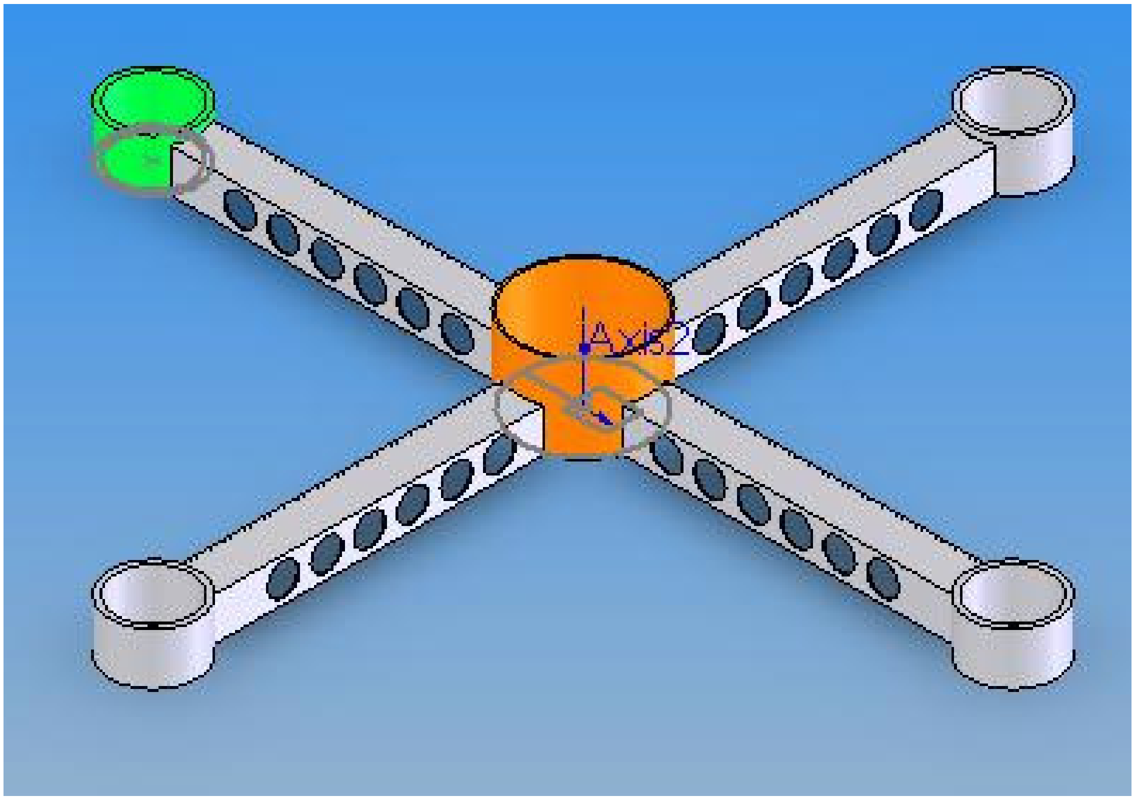

Figure 16 - Box section design

7.3 Modular based on last years design parameters

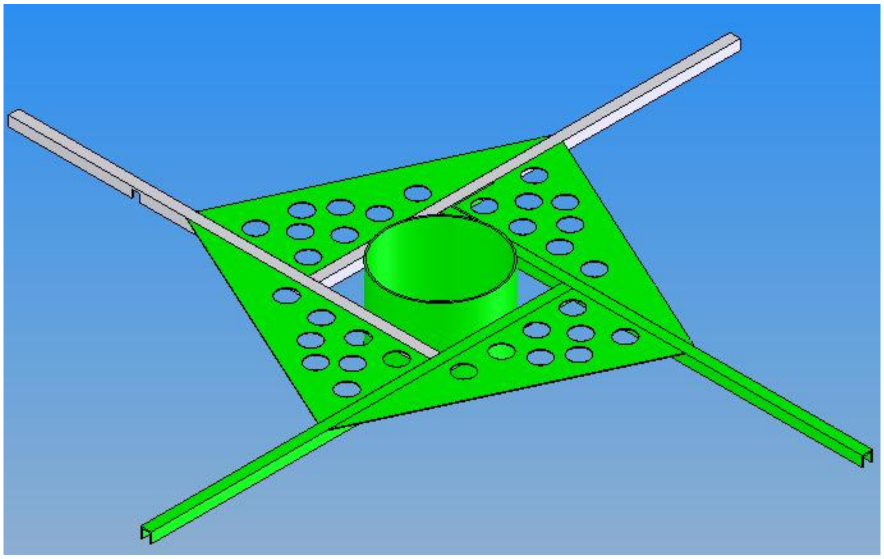

Figure 17 – Modular design

The modular design is based on last year's platform in terms of size and dimensions. It can be see from Figure 17 that the arms are not straight inline with the centre of the central fan but offset to the side. This design allows for the central fan unit to be separated from the remaining structure. The distance between the end of the arms and the centre axis of the platform is still 500mm. The materials are all standard aluminium extrusions or bar sections.

The plate acts as stiffening mechanism for the platform whilst providing support for the electronic components. This plate has weight saving holes included, reducing the weight of the component.

8 Final Design

8.1 Mock up model of proposed design

A mock up model was used to aid visualisation of the structural design. This allowed easier discussion with team members on structural matters Styrofoam and constructed on a scale of 1:2.
The ducts were made of cardboard tubing; the arms were made of cut Styrofoam. The Styrofoam needed support and were covered with parcel tape to provide extra stability and reduce the break up of the cut Styrofoam. The outer control fans were attached with pins and clued together.

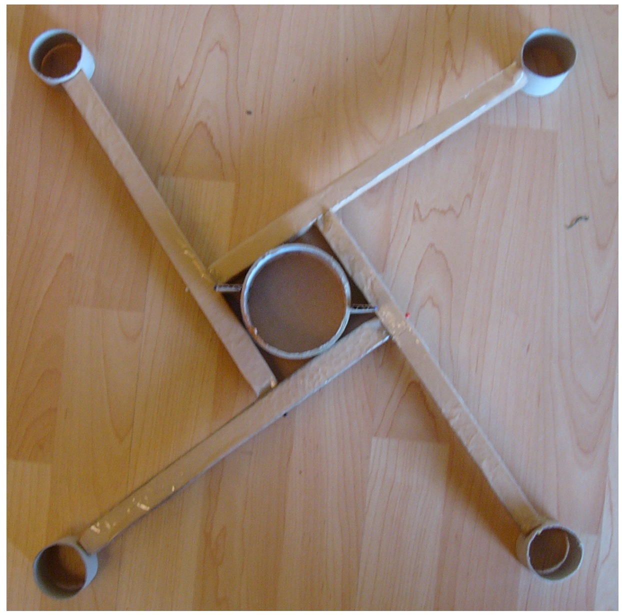

Figure 18 - Model Structure

8.2 Design

The design is based on the modular design from last year. As can be seen from Figure 19 the structure is not complete. The bottom platform is not fully designed yet as the Genset specification and mounting has not been fully defined.

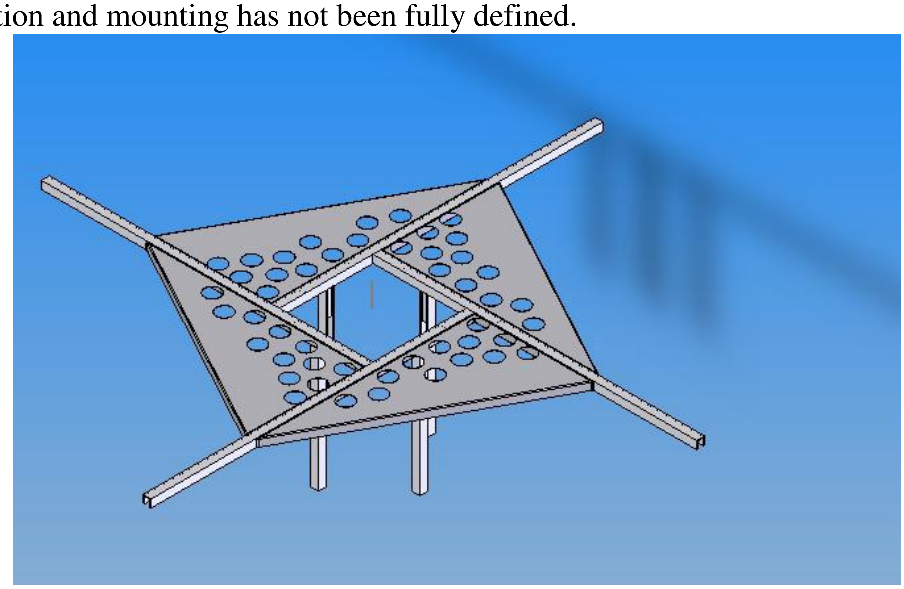

Figure 19 - Final 3D Design

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8.3 Materials

The materials for the platform are aluminium extrusions and sheeting that were easily available from the university's engineering store. See Appendix I.

8.4 Weight

8.4.1 Background

The weight of the structure is crucial, as the central ducted fan would not be produce the estimated 60N of thrust. A list of all the expected components required during flight (IMU, fuel, Genset, etc.) was made. The balance shows that assuming there are 4kg of lift available from the control fans and 4kg's from the central fan, the there will be no payload. This scenario does not include the duct providing extra lift.

8.4.2 Weight distribution

The balance of the platform at initial conditions is key to having a successful control system. A major factor with the weight distribution is that the centre of mass has to be on the central axis, running vertically along the shaft of the central fan..
The Genset is the heaviest combined item. Unfortunately tests with the Genset have concluded that the Genset has to be mounted together in the same place (motor, flywheel, engine). This is a complete weight of 1400 g. Fuel tanks have to lie in the same plane as the needle valve at the fuel inlet, so this will be adding 1kg to the same level..

The fuel tanks need to be considered as these can be flat or high. A flat fuel tank though will cause instability by allowing the fuel to gain momentum. This could be prevented by including baffles in the tank to stop the fuel gaining momentum as it is pushed around the platform, when it is in motion.

The procedure to accurately develop a balanced platform is by collating all masses in an excel data sheet, together with their relative positions near the centroid. This would be evaluated using the parallel axis theorem. This method is also used in aircraft design[15].

8.5 Vibration / Engine mounts

RH conducted research was conducted into vibration mounts and found Du-Bro engine mounts to be the only the only suitable ones available.. These are designed for mounting an engine directly into an aircraft model and were not meant for use with a ducted fan as it does not have adequate mounting surfaces. However, the mounts can be modified to fit the scenario. The mounts were purchased as the holder could be modified to suit the purposes within the flying platform. Appendix J includes information on the Du-Bro engine mounts.

8.6 Manufacture

The control fan mountings from last year were implemented into the new structure. One of the key advantages of this structure is that it is simple to manufacture and key components and materials are readily available.

A list of requisite component parts and a brief description of the machining work involved is listed in the sub headings below.

8.6.1 Arms

The arms required to be cut into length. A slot is machined through one flange and four holes need to be drilled two onto either side of the slot.

8.6.2 Plate

Bent using the bending machine, weight reducing holes were pressed out with the butterfly press. The edges were pop riveted to give the plate more rigidity.

8.6.3 T-pieces

Milled out of a block of Aluminium to join the arms; 6 holes are drilled to fix there to the arms. The component is also used to hand the subsection from the main platform.

8.6.4 Engine mounts

A Du-Bro engine mount is used for the ducted fan. A connecting bracket needs to be designed to fit the engine mounts to the structure.

8.6.5 Mounting brackets

Various mounts to hold fuel tanks, IMU, etc. will be made of sheet aluminium an bolted to the structure. The light weight electronics ciruits can be mounted on the plating with self adhesive plastic fish bone clips.

8.6.6 Fixings

The structures methods of construction are riveting and bolts and nuts. The bolts will be fixed with NYLOC nuts to ensure these hold even with residual vibrations. Fixings close to the IC engines are treated with a penetrating Loc-tite.

8.7 Costing of the structure

The costing of the structure has been based on the components that require to be purchased. The cost of producing 10 structures will cost less than the first one designed right now. The design margins can be taken out and it may be possible to purchase the materials in bulk, to save cost. Component parts such as the connector can be CNC milled, with low machining cost if 40 of these parts are needed for the structure.

The cost for the component were received from stores and are given in the accounting sheet in Appendix K.

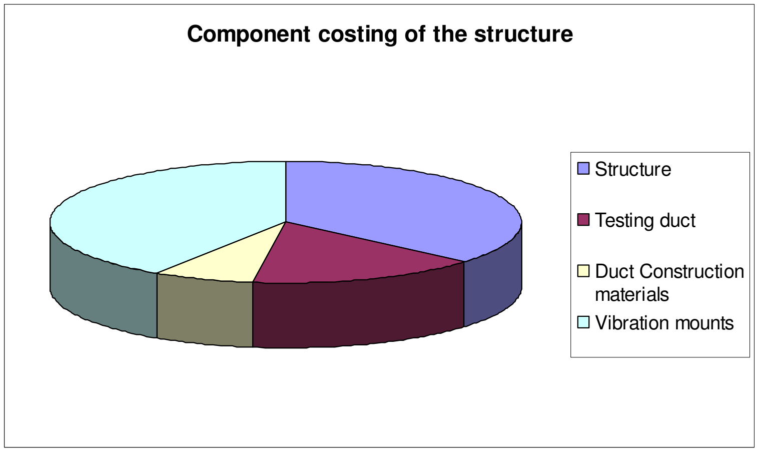


Figure 20 - Component cost of Manufacture

From Figure 20 can be seen that a lot of the cost is due to the duct testing as well as the vibration mounts. The vibration mounts require a bracket be made to adapt these for the structure. It is very possible that the cost could be reduced if the mounts were purpose built rather than bought of the shelf for batch production purposes.

8.8 Conclusion

The new design is lighter compared to last years, structurally rigid. It can be seen that the design has been greatly simplified in terms of machining cost.

A further factor is that this design is scalable to a larger size if the central fan unit is replaced by another configuration in subsequent years. Small electrical fans or JM's proposed large ducted fan would be easily adaptable to this design without many changes.

9 Conclusion

9.1 Conclusions and Discussion

Gas turbines have shown to be a viable possibility if producing power for the flying platform, providing the cost can be met. The turbo propeller gas turbine also has potential for providing thrust. Although the thrust would currently be twice the minimum demand required this could be an advantage, as it would leave redundancy in the system allowing follow up research and development to focus on other aspect of the platform, like a full evaluation of the structure.

The preliminary duct testing went well. The duct results showed that a 19cm duct would give an extra lift, Further investigation should include

The structure has been redesigned and taken from a 2D plane structure to a 3D structure. The weight of the plane structure has been reduced slightly. Vibration mounts were considered. The structure still requires a lot of understanding. At the time of writing the report no structural analysis had been conducted. The vibration characteristics have also not been fully evaluated.

These developments can be used a starting point for next year's group to fully evaluate the dynamic and static effect on the platform. There needs to be a fully evaluation of the structural characteristics when the platform is in flight

The misjudgement of the CPA meant that time constraints would not enable the structure to be fully investigated and built for testing and for the purposes of this report. However, the work progress on the structure, conducted by the author, can be adopted and taken further. A full investigation of the effect of the vibrations on the structure was impossible to be measured.
Gas

9.2 Recommendations for Further work

In terms of group organisation and management, it is recommended, based on this year's experience that the CPA should not only be conducted before the commencement of the project, group members should dedicate a substantial amount of the beginning few weeks towards allocating specified tasks in the specialist engineering fields, and maintaining the responsibility of such tasks throughout the project. CPA should be conducted by the group as a whole, and all members should provide critical analysis input.

The structure is the heart of the flying platform and brings together the propulsion, control, etc. in order for the platform to take flight. Investigation into the full extent of the structure should be defined before the commencement of the project as time constraints would require the structure to be given full attention from the beginning of the project, instead of towards completion.

It is recommended that work from this current investigation to be continued by future groups. Based on the gas turbine investigation from this author, further research and analysis can be conducted to examine the full extent of gas turbine application to the flying platform. As the gas turbine has the advantage the in turbo propeller version it would provide far more than adequate thrust for the platform.

The objective for future groups designing the flying platform would be to enable it to take flight without reliance on an external power source.

This means that there would be a lot of room for development. The platform has move out of the barley possible range into the slightly excessive range, or else the project is going to lag every year.

10 Appendices

10.1 Appendix A – Flying Platform PDS

	This design
Performance	1. Must hover approximately 1 m above the ground. 2. Flight duration to be approximately 20 minutes. 3. Must remain Stable. 4. Must provide viable operating platform. 5. Must be able to carry a payload of up to 5 kg. 6. Must have the capability to have the On/Off controlled by remote.
Environment	1. Must be capable of operating in the temperature range of -10°C to 50°C. 2. Must be capable of operating in humid conditions and to be water resistant when operating in light rain. 3. Must be operated in minimal air flow disturbances i.e. minimal wind speeds.
Maintenance	1. Onboard battery must be easily attainable for possible replacement, and recharging. 2. Fuel tank for internal combustion engine must also be easily accessible for refueling. 3. Oil checks on the IC engine will also have to be regularly carried out, as well as checks on the coolant levels.
Life in Service	1. Product's life in service is to be approximately 5 years.
Target Production Cost	1. A budget of £1000 has been assigned to this project.
Size	1. The flying platform's dimensions are to remain the same as the dimensions specified in the previous group's report.
Weight	1. Yet to be determined but should be designed with the least possible weight. Estimated weight including payload is approx 10 kg.
Materials	1. Materials used must have a high mechanical tolerance, and must have a low a density as possible.
Standards and Specifications	1. Investigate safety standards for flying objects
Quality and Reliability	1. Product must be extremely reliable as failure of product may lead to a catastrophic outcome.
Time Scales	1. 6 months to implement the improvements on the previous platform so that it operates with an onboard IC engine and is fully stable in flight.

10.2 Appendix B – Frequency to voltage converter

The circuit diagram is given below for the frequency to voltage converter. The components were soldered to a strip of strip board.

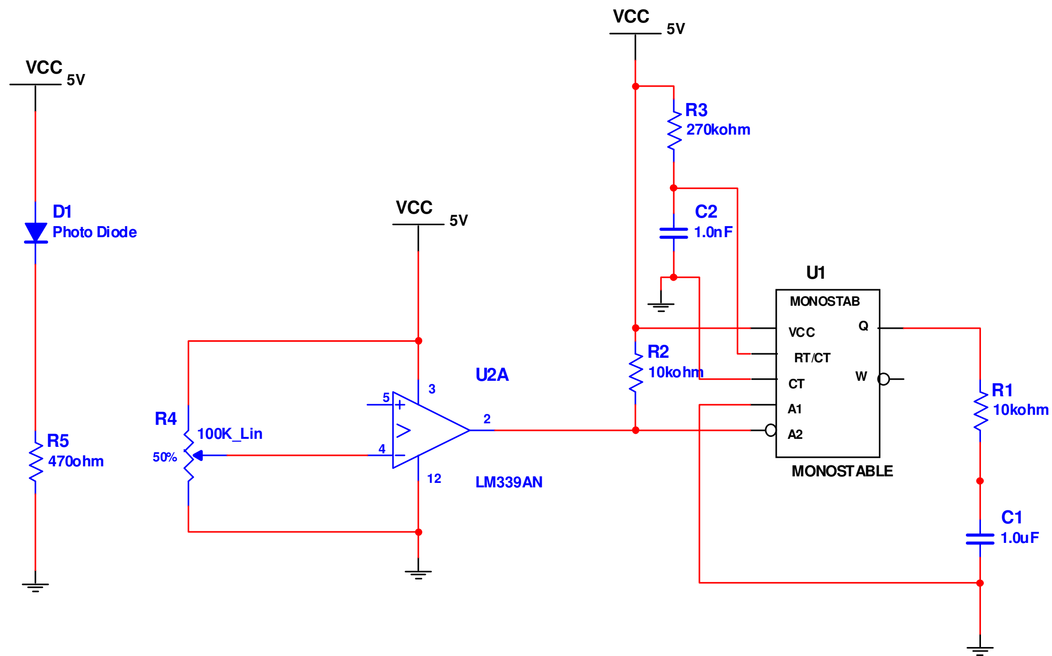


Figure 21 - Frequency to voltage converter circuit diagram

10.3 Appendix C – Testing duct pictures

In the figure below are shown the five upper ducts fro testing purposes. From this can be seen that the diameter and slope of the ducts was approximately equal through out the range. The only difference between all the ducts sizes is height.

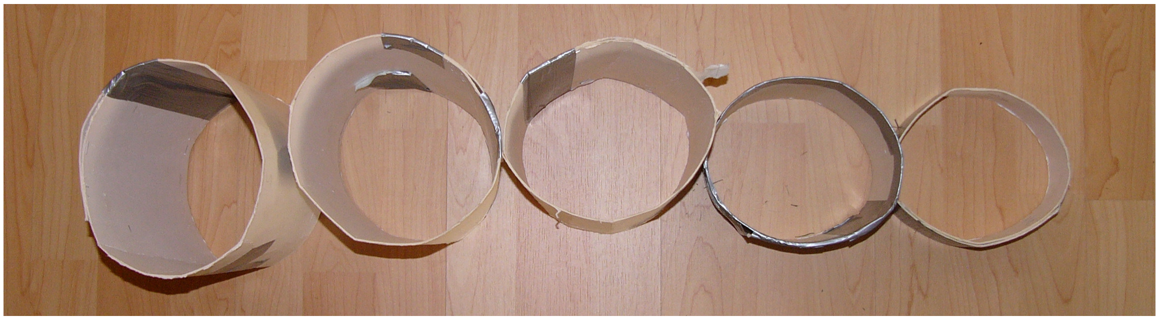


Figure 22 - testing ducts from the top

Going from the right to the left the height change can see very well. The largest duct is 22cm, 19cm, 14cm, 9cm, and 5cm (the smallest).

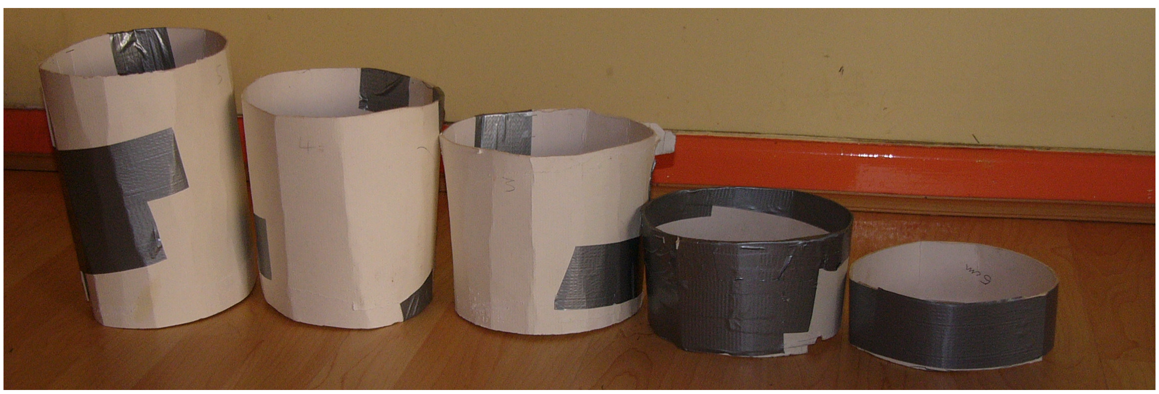


Figure 23 - testing ducts from the side

Of the lower duct two versions were made.. the first one did not withstand the forces achievable and the imploded during one of the test. The new thicker cardboard version was working, but it did not develop a significant amount of he gain overall was 300g additional thrust with an upper duct attached, i.e the lower duct was hindering the development of the air flow. Thus the lower duct was removed.

The aim for this duct was to design it on the basis of the Viojett, by keeping the cross sectional area approximately equal, when the engine is taken into account for. There had to be a slot cut into the side of a the ducted fan unit to aid cooling. Energy losses in that area were possible. The red circle denoted the area that binds around the cylinder head. The principle is good though the design lacked the advanced techniques in creating complex shapes.

10.4 Appendix D – Duct Test Results

Given below is the recorded thrust data on. Different days are colour coded. It can be seen that these test results are variable

Duct	Thrust (kg)	RPM	Average thrust (kG)	Average RPM
NO Duct	4.000	100		
	3.900	99		
	3.345	100		
	3.740	100	3.74625	99.75
5cm	4.800	100		
	4.400	98		
	4.550	97		
	3.335	99	4.27125	98.5
9cm	4.600	98		
	4.350	97		
	4.550	100		
	4.600	103		
	4.400	101		
	4.200	100	4.450	99.833
14cm	4.645	97		
	4.745	100		
	4.445	99		
	4.560	97		
	4.400	99		
	4.550	98	4.558	98.333
19cm	5.100	100		
	4.545	96		
	4.600	98		
	4.720	100		
	4.550	101	4.703	99.000
22cm	4.745	102		
	4.600	100		
	4.500	99		
	4.400	100		
	4.450	102	4.539	100.600

23/03/2004
27/03/2004
04/05/2004
06/05/2004

Table 2 - Duct test results table

10.5 Appendix E – Engineering Duct Drawing

10.6 Appendix F – Failed Snake arm version 1

The pictures below show where the crack originated and how it propagated. The new design with the incorporated fillets should resolve the failure of this component.

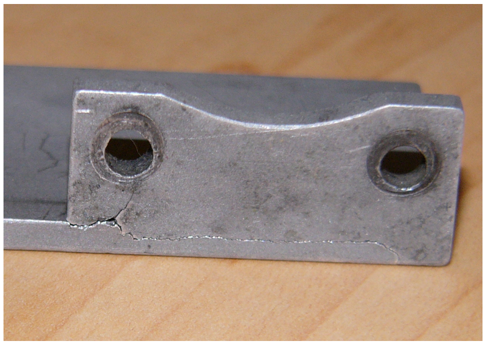


Figure 24 - Crack propagation win the snake arm

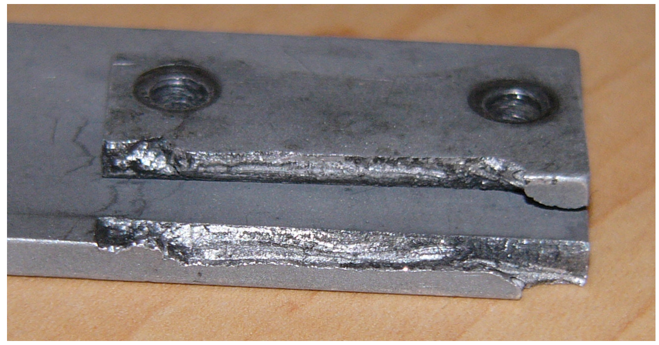


Figure 25 – two separate snake arm parts next to each other

These lower pictures show the arm attached (on the right) and removed (on the left).

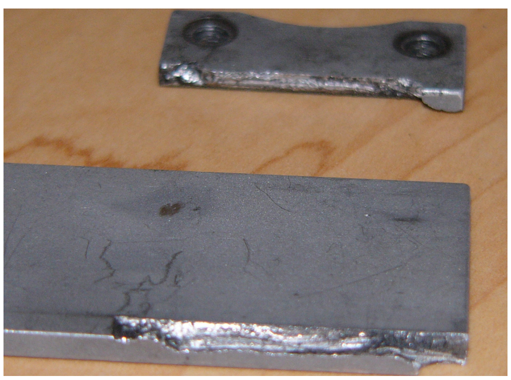


Figure 26 - Snake arm broken parts

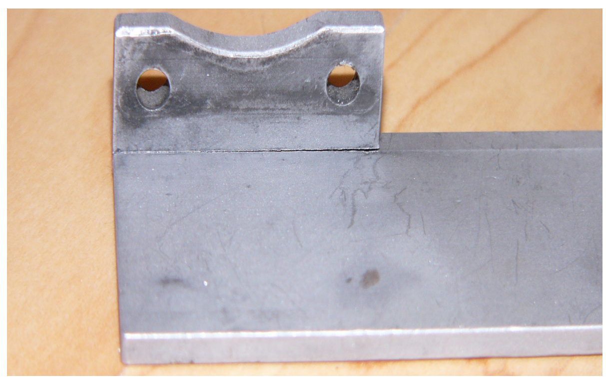


Figure 27 - Complete snake arm version 1

10.7 Appendix G – Snake arm Engineering Drawing

10.8 Appendix H - The PDS for the structure of the Flying Platform

The PDS for the structure of the Flying Platform

25/02/04 *Version 1.1*
by Christopher Poczka

Performance
The structure of the flying platform must be based on the previous year's system. Further the system must be based on the following criteria:

- symmetrical and well balanced with the centre of mass in the centre if at all possible.
- stiff and strong enough to resist the thrust exerted and carry the loads of the platform as well as fans and all the components needed for flight.
- provide and are to mount all the systems (control, power generation, etc.)
- provide mounts to enable tethered flight
- position the outer ducted fans securely and accurately.
- be as light weight as possible and easy to repair.
- facilitate the upgrade to the newly designed fan.

Environment
The structure:
- must be able to resist the chemical exposure due to the manufacturing as well as running of on board systems
- must be able to cope with the vibrations of the systems mounted onto the structure (two IC engines, 4 electrical fans).
- must be able to resist shock loading caused by the constraining forces when in tethered flight.

Safety
The highest priority will have to be give during the development process as a whole to the safety of the operator as well as spectators, whilst the platform is active.

Aesthetics, appearance and finish
The structure at this stage has the only role in being functional, thus the aesthetics are considered more in terms of safety of handling. This means that the components have a food surface finish and that the following is monitored:
- Avoidance of sharp vulnerable components or corners
- For machined surfaces, the removal of sharp edges and burs
- For turned components and drilled holes that edges are chamfered.

Ergonomics
The structure has to be designed with the functional use by human operators. Thus it is of importance to design the structure, interfaces mounting points with consideration for the ease of use by the operators. This is necessary for the design and manufacturing process as a whole.

Size
The size has been set to be the same as in the previous structure, constructed by a 0.5m pitch circle centred in the central fan, the control fans are placed on the pitch circle. There will be a deck are provided for the systems.

Weight
The structure is changing from a 2D structure to a 3D structure, thus it is expected that there will be an increase in weight for this year structure. The weight will be limited though to 1kg.

Materials
Materials must only be decided after the structure has been designed and a correct materials selection procedure has been carried out. The main materials considered will be: aluminium alloys, steel alloys, modelling ply composites, such as carbon / glass-fibre reinforced plastic, high strength foams and balsa wood.

Production Cost
The cost has been set at £75 based on last year's group. This figure includes the total manufacturing cost, specialist services and materials.

Manufacture
The design of the manufacturing processes required to manufacture the structure should be limited to the engineering workshop. Specialist processes and procedures should be avoided unless absolutely necessary.

Installation
It is imperative that all components systems and unit specification and interfaces are known prior to designing the structure, so that adequate positioning of the system components as well as the correct interfacing can be provided.

Service life
The structure must be designed for long term use, as the structure will be used by next year students. As the new fan design will be accommodated the structure, there will be no need to adapt the platform beyond this year. Thus the platform has to be built to provide long term service.

Maintenance
The flying platform should be designed with little or no maintenance in mind. There should be provisions in place to enable it to remove parts that can wear as well as remove the ancillary components for service or repair.

Standards and Specifications
This project is in the research and development stage. It must be ensured that all standards are adhered to. At the moment the project is not in practically functional state. The standards will have to be checked when as the project develops.

Quality and reliability
The quality should be maintained to a standard as high as possible, to reduce the likelihood of component failure. The mean repair time should be kept to a minimum to ensure that the platform can be brought back into service in the shortest amount of time, in case of accident or failure.

Manufacturing Processes
There may be a need for using manufacturing processes which alter the material properties, such as welding. In that case, special consideration must be taken, to ensure that the material is still able to meet specifications.

Time scale
The platform should be completed by mid march. Testing and component fitting has to be completed too.

Testing
Testing of the structure should be completed at various stages:

- Material testing, to ensure that the materials selected will be able to perform to the specification
- Component testing: The platform is to be constructed with out the auxiliary components to ensure that all components have been manufactured properly and are all able to be assembled.
- The platform should then be fully assembled with all systems and tethered flight test be executed, before the full flight test is to be considered.

Documentation
This platform is to serve many years as base, detailed documentation is need, in case future groups have to change or repair any part of the structure.

10.9 Appendix I – Material Properties

All Properties are at room temperature unless otherwise stated

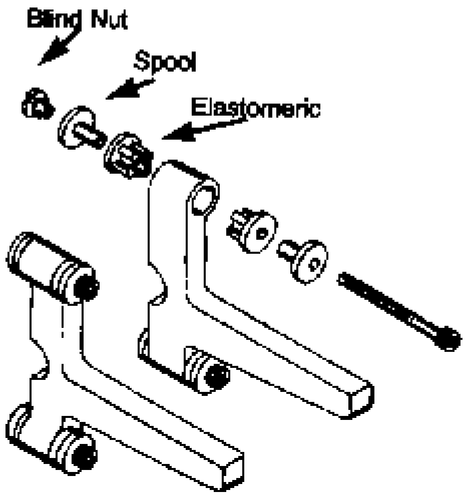
Property	Value
Density (g/cm^3)	2.7
Modulus of Elasticity (GPa)	69
Poisson's Ratio	0.33
Yield Strength (MPA)	276
Tensile Strength (MPA)	310
Percent Elongation	17
Linear coefficient of thermal expansion ($x\ 10^{-6}$) ($degree\ C)^{-1}$	23.6
Electrical Resistivity (Ω m)	3.7×10^{-8}

The Composition of the metal is 95.85 AL (min), 1.0MG, 0.6 Si, 0.30 Cu, 0.20 Cr

All values are taken from Callister, W. D., *Material Science and Engineering – an Introduction*, Fifth Edition, 2000,pp 792 -816

10.10 Appendix J – Du-Bro Anti vibration Engine Mounts information

The figures below show the engine mount and its constituting parts. The spool acts as an insert to keep the bolt away from contact with remainder of the mount. Both spools from both sides are covered by an elastomeric damper, which fully isolates contact and dampens the vibrations going through it.



10.11 Appendix K – Accounting Sheet

Item	Quantity	Price (£)
Structure		
12.7mm*1.6mmm aluminium channel	3m	£8.80
0.5mm sheet aluminium	1500*500	£16.00
50.4mm*75.8mm aluminium block	0.050m	£4.00
M3*20mm Pan head bolts,nuts washers	20	£1.00
M4*20mm allen bolts,nuts	24	£3.60
Rivets M3	8	£0.40
Subtotal		**£33.80**
Testing duct		
Mounting Card board A1	3	£9.60
Duck tape roll	1	£5.00
Subtotal		**£14.60**
Duct Construction materials		
sheet aluminium 3mm	0.5*0.5	£5.30
Rivets M3	10	£0.50
flat aluminium 15mm*3mm	0.25	£0.50
Subtotal		**£6.30**
Vibration mounts		
Du-bro anti-vibration mounts	1	£35.90
Aluminium flat 50.4mm*5mm	50	£2.00
Subtotal		**£37.90**
Grand total		£92.60

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10.12 Appendix L – Engineering Drawings of the Structure in parts

11 References

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[11] Discussion with Dr. Michael Bellmont, School of Engineering, University of Exeter, 06/05/04
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[14] Stinton, Darrol, *the Design of the Aeroplane,* second edition, Blackwell Science Edition 2001,pp 495-96
[15] Stinton, Darrol, *the Design of the Aeroplane,* second edition, Blackwell Science Edition 2001,pp 488-523