ENGG1200
Project A Brief

Semester 2 2019

Engineering Modelling and Problem Solving

PROTOTYPE FIXED-WING UAV FOR REMOTE SENSING AND MONITORING

The Brief

This document is your Project A Brief. Supplementary information will be communicated through the Project Sessions and announced via Blackboard. If your team requires further information or details, please contact your project leader.

Roles

Work submitted as part of this course must be designed and built entirely by students enrolled in ENGG1200 Semester 2 2019. Project Leaders, tutors and university technicians can be used as consultants for specific information. Your team is required to engage with this project brief, understand it and clarify any specifications necessary to deliver the project on Demo Day.

Safety

This course requires you to manufacture and assemble components yourselves. Since this is a university project, the university has a duty of care for your safety. You are therefore required to complete this work in the UQ Innovate Centre where you will undertake safety inductions, and university staff will supervise your work.

Project A asks you to design a UAV aircraft prototype suitable to be launched ballistically from a high-energy rail, that then glides for maximum range. The UAV must be able to broadcast its state of position, acceleration and landing, and maximise both distance travelled and flight time, in several flight tests. You must also provide an accurate prediction of your flight trajectory using wind tunnels, industry-standard modelling and simulation software packages (CAD, Computation Fluid Dynamics, etc.). The project is suitable for all first-year students, but will specifically develop mechanical, electrical, and software engineering knowledge.

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Abbreviations

BOM	Bill Of Materials
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CFD	Computational Fluid Dynamics
CG	Centre of Gravity
CNC	Computer Numeric Control
FDR	Flight Data Recorder
IMU	Inertial Measurement Unit
QRP	Quick Release Plate
UAV	Unmanned Aerial Vehicle

CAVEAT

The design scope and specifications may change during semester as more detailed project information becomes available. Changes to design briefs are common in industry, so this adds to the authenticity of the project and allows you to develop skills to deal with ambiguity and uncertainty.

1. Introduction

An entrepreneurial friend, Tony Stark, has returned from exchange at Stanford University (right next to Silicon Valley) with a burning idea. The business opportunity is to provide an aerial platform for near-term sensors for remote sensing and monitoring. These sensors operate as a network, or array of many independent sensors, which allows their operational altitude to be relatively low, for adequate ground coverage. Remote sensing of this sort is usually accomplished with a more expensive asset, such as a satellite or high-altitude aircraft. Furthermore, continuous and responsive monitoring is frequently prohibitively expensive or even impossible.

Tony's vision is of a robust fleet of fixed-wing UAVs for flexible, low altitude remote sensing. A combination of inexpensive, easy to manufacture, fixed-wing UAVs with good aerodynamic performance and a portable launch rig, is thought to be a novel solution. To capitalise on the current boom in the UAV and remote sensing industry, this project is time critical.

You have been assembled as a six-person team of expert, graduate engineers. As a team, you will be required to meet the following requirements of this high-profile project:

1. Design, build and test a small, unpowered, ballistically-launched UAV prototype.
2. Demonstrate the UAV's performance in terms of flight range and endurance.
3. During the UAV's flight, the acceleration and position of the UAV must be known.
4. The UAV design must demonstrate the robustness and an ability to launch multiple times in quick succession.

To inform your design decisions, you will perform preliminary aerodynamic investigations using CFD and Wind Tunnel experimentation. The mechanical and structural design will be developed by iterating CAD models and physical prototypes. The wing structure will be developed using 3D printers for rapid prototyping and design.

Information from these models and simulations will be used as inputs to simulate the flight trajectory of the UAV. This will be used as a tool to evaluate key performance metrics of your early UAV designs (flight range and endurance) during the conceptual and preliminary design stages. Modelling and simulation will allow you to minimise the lengthy and costly process of iterating with physical models and physical flight testing. Your final product, however, must still be validated with real-world testing on Demo Day.

2. Project Goal, Objectives and Scope

The project goal is to fly a small ballistically-launched, unpowered UAV prototype with a real-time onboard positioning capability. You will use models and simulations to achieve optimum performance in a limited time frame and at a low cost. Your prototype design will be tested in a physical flight demonstration of range and endurance on Demo Day. A successful physical demonstration will help validate your preliminary models and simulations and confirm your engineering design process.

2.1 Scope

Resources provided by the university, and out of your scope, include:

- The launch rig.
- The electrical design and components required for measuring UAV acceleration and position, the Flight Data Recorder (FDR).
- The FDR wireless data receiving base station.
- The materials and manufacturing of the interface between your UAV and the launch rig, Quick Release Plate (QRP). Note the QRP design is still within your scope.
- The material, manufacture and instrumentation of a tensile member used to measure the launch force (Tensile Member).

2.2 Objectives

To develop a successful design and achieve project goals, you will need to:

1. Research UAV design principles, examples and performance parameters.
2. Research materials and their selection parameters and manufacturing techniques, suitable for a UAV.
3. Produce a CAD model of the UAV for virtual design iterations, manufacturing and mass calculations.
4. Perform CFD simulations and Wind Tunnel experiments on different airfoil shapes, to inform UAV wing design and choice.
5. Explore the structural and aerodynamic design space for maximum flight range and flight endurance.
6. Develop a three degree-of-freedom trajectory simulation to predict a given design's performance and guide your design decisions.
7. Design and submit for manufacture a 3D printed wing structure.
8. Design and submit for manufacture the QRP.
9. Assemble, program and debug the FDR.
10. Size and submit for manufacture a tensile member and attach and calibrating a strain gauge.

3. Design Specifications

3.1 Overview

The major physical components that your team will design and manufacture for this project are the:

- UAV with 3D printed wing structure
- FDR
- QRP
- Tensile member

These components are shown in Figure 1 and detailed in subsequent sections. A description of the launch rig and launch sequence is given in Section 4. Before launch, your tensile member, fitted with a strain gauge, will be used to measure the launch retraction force. The UAV will be launched horizontally and glide (unpowered) until it lands on the ground. The FDR is carried onboard throughout the flight to measure acceleration, detect the time of launch and landing and to report flight endurance. This data will be transmitted, in flight to a wireless base station to determine the UAV's position throughout the flight.

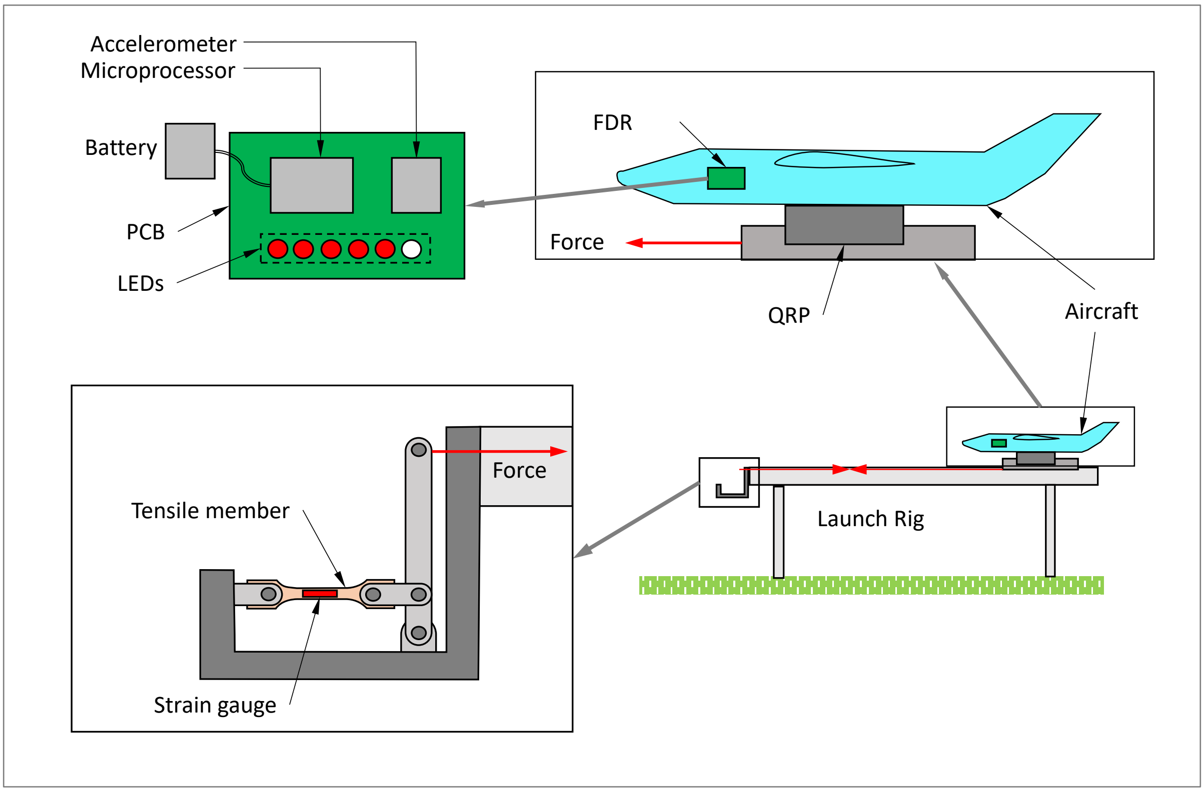

Figure 1: Major physical components of the project (Forces shown occur when sled is fully retracted)

3.2 The UAV Design

The UAV must be designed for maximum range (flight distance) and maximum endurance (flight time). Paramount to performance is the UAV's wing design, as this is the dominant aerodynamic surface and usually the largest weight of an aircraft. For rapid prototyping and to reduce costs, the wing structure must be 3D printed.

The following constraints apply to the UAV.

Dimensional Constraints

The UAV must meet the following:

- Maximum wingspan of 600 mm.
- Maximum total length of 600 mm.
- Maximum height of 300 mm.
- Maximum mass of 0.25 kg. This does not include the FDR.

Material Constraints

- Your wing may contain up to two materials in addition to the 3D printer filament (PLA) and any adhesives, films or fasteners.
- The UAV must not contain any metallic components, except small, concealed fasteners if required.

Manufacturing Constraints

- The wing structure must be 3D printed.
- The wing skin (aerodynamic surface or outer mould line) must not be 3D printed.
- The tail and fuselage must not be 3D printed.

Design Constraints

The UAV must:

- Have a fixed wing.
- Be completely unpowered, except for the FDR.
- Allow an unobstructed view of and access to the FDR.
- Interface with, and be supported entirely by your QRP during launch.
- Have a maximum cost of $150 or less (this does not include the FDR).

Any UAV prototype that does not meet the specifications and constraints given in Section 3 will not be tested on Demo Day and will receive ZERO marks for all performance criteria. Speak to your tutors or Project Leader if you are unsure whether your design satisfies these constraints.

3.3 Flight Data Recorder

Your UAV will carry an onboard FDR, as shown in Figure 2. The purpose of the FDR is to measure and transmit 6-axis acceleration data (3 linear, 3 rotational), therefore functioning as a simple Inertial Measurement Unit (IMU). This information will be transmitted to a receiving base station, which will record and process it to determine the UAV's position during the flight. The final recorded position (range) will be reviewed against your actual measured flight range. Additionally, the UAV's flight endurance will be measured and displayed using onboard LEDs. The approximate size of the FDR is 40 x 75 x 15 mm.

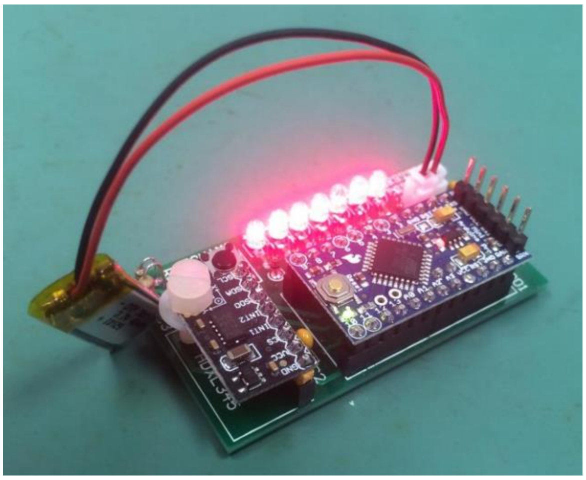

Figure 2: An example of an assembled FDR. NOTE: Your FDR may look different

To determine flight endurance and identify when to start transmitting, the FDR will need to differentiate between the acceleration measured during launch, flight and landing and measure the time between these events. Upon landing, the first five LED's will be used in a binary pattern to indicate flight endurance in seconds. The sixth LED can be used to assist with fault finding.

FDR kits will be handed out in Project Sessions and will require assembly during the FDR Labs. Full details of time, location and booking requirements of FDR Labs will be given on Blackboard.

3.4 Quick Release Plate

The QRP is the interface between your UAV and the launch rig. The lower section of the QRP must be as shown in Figure 3 (i.e. the unshaded portion) to attach to the launch rig. You will design the upper, shaded portion to support the UAV during launch. Your QRP will:

- Meet the design requirements of Figure 3, allowing secure attachment to launch rig. Note: hole dimensions shown are oversized appropriately to give clearance fit with the launch rig dowel pins.
- Support your UAV completely before and during launch, at the correct orientation.
- Allow your UAV to begin the flight at the end of the launch step.
- Remain firmly attached to the launch rig throughout the launch.

For safety reasons, the QRP is the only component the UAV will touch, while on the launch rig.

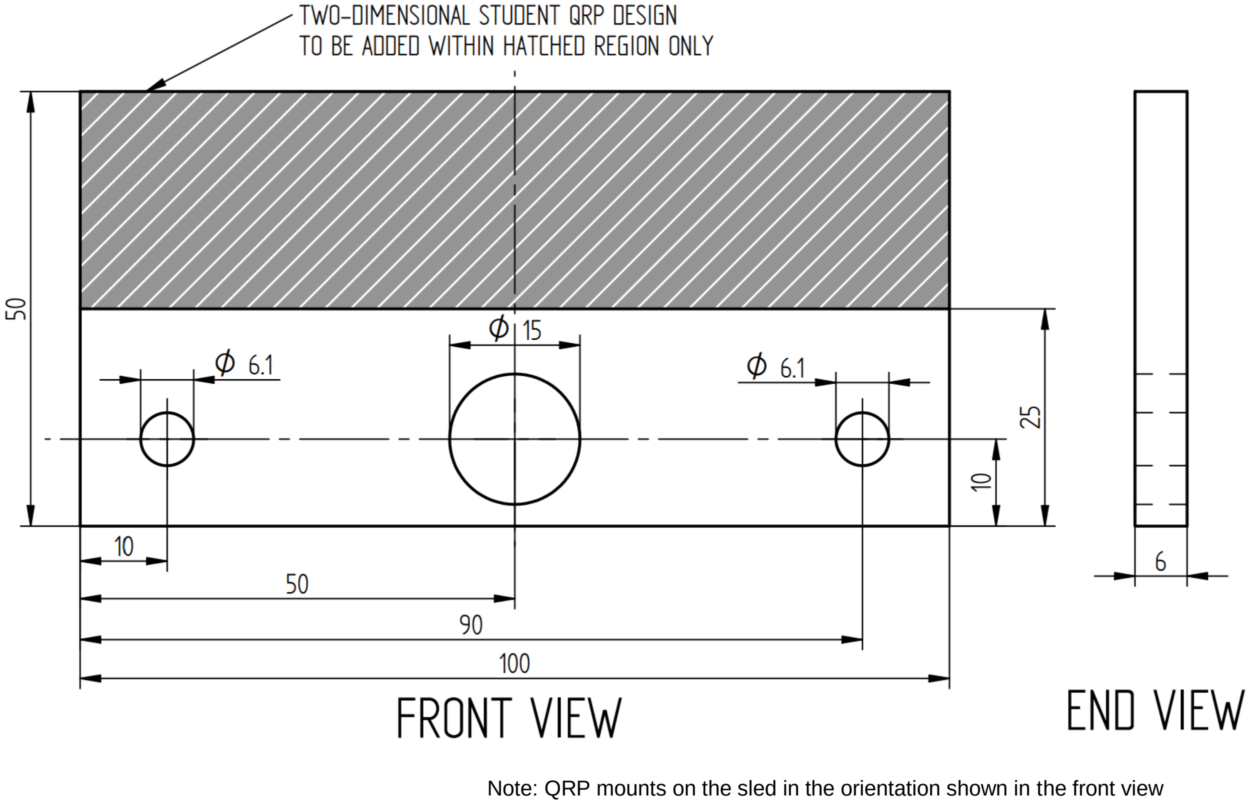

Figure 3: QRP design specification for launch rig attachment. (All dimensions mm).

3.5 Tensile Member

Each team will design and submit for manufacture one tensile member to measure the strain (and subsequently force) at launch (Figure 4). You must predict the strain, and you will receive marks depending on the accuracy of your prediction. To design this "instrument" you should aim to maximise elastic deformation while remaining safely within the appropriate material limit and the strain gauges working limits. This ensures the best resolution in strain measurement.

The tensile member will be waterjet cut from sheet stock of one of the following three materials; Acetal, Aluminium and Polyvinyl Chloride (PVC). Your team is responsible for selecting the gauge width (w_1 to w_5) and material from the options given in Table 1.

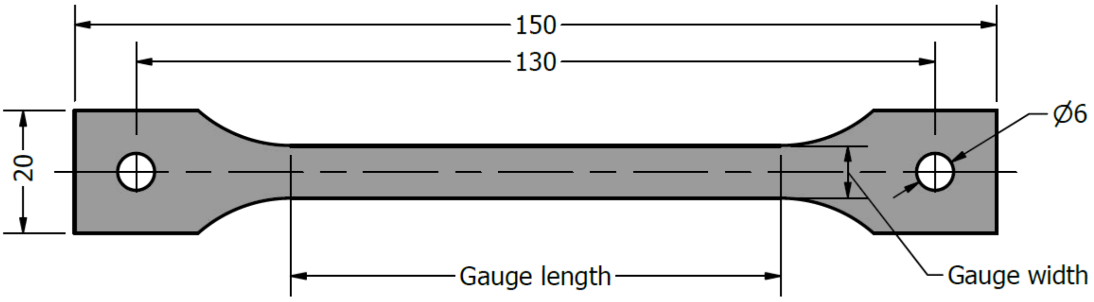

Figure 4: Tensile member dimensions. (All dimensions mm)

Following manufacture, you will attach two strain gauges to the tensile member. These will then be calibrated and tested before Demo Day. Strain gauges are delicate and sensitive, so the Instrumentation Workshop will store your tensile members until Demo Day.

Table 1: Tensile member material and geometry width options.

Material	Thickness (mm)	Gauge width (mm)				
		w_1	w_2	w_3	w_4	w_5
Acetal	5.0	10.5	11.0	11.5	12.0	12.5
Aluminium	3.0	10.5	11.0	11.5	12.0	12.5
PVC	4.5	10.5	11.0	11.5	12.0	12.5

4. Launch Rig

4.1 Set Up

Figure 5 shows the launch rig that will ballistically launch your UAV. The launch rig functions as a large, horizontal ballista and has the following characteristics:

1. The launch point is 1725 mm above ground level.
2. The maximum retraction distance is 2000 mm.
3. The rail is fixed and horizontal.
4. The sled is the part of the launch rig that supports your UAV and travels with it during launch, and has a mass of 0.1 kg. On top of the sled are two 6 mm diameter dowel pins and a central hole for a 15 mm diameter magnetic locking pin. These pins secure your QRP in place (see Figure 3).

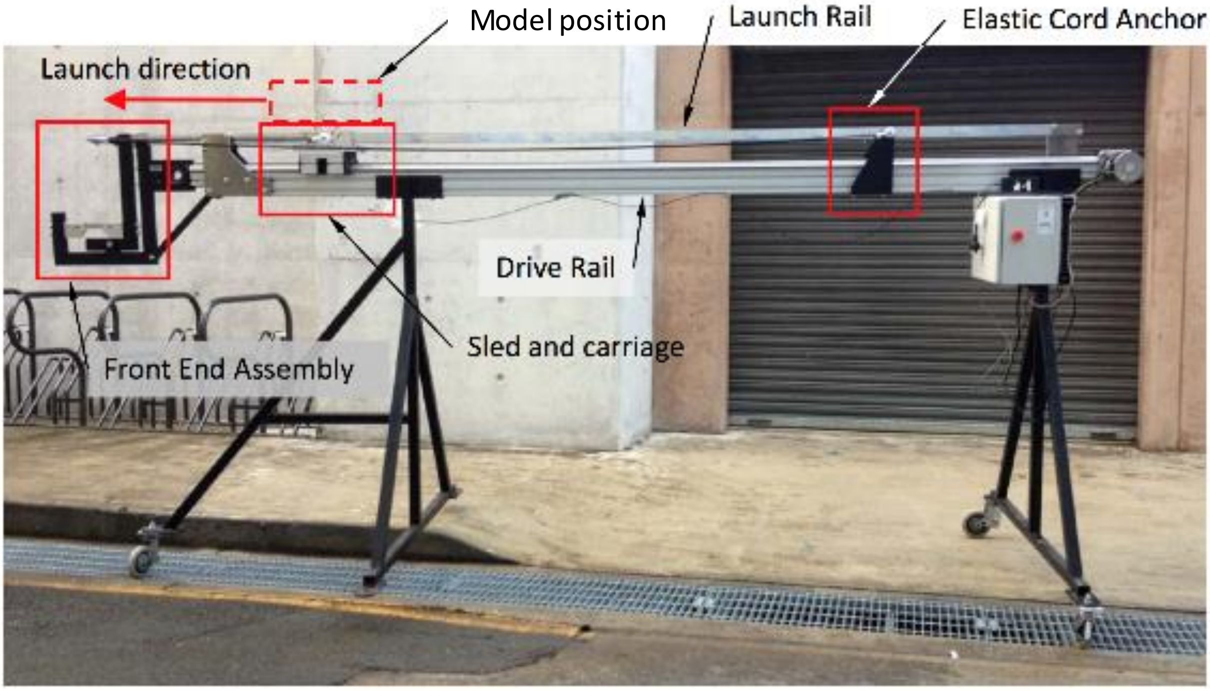

Figure 5: Launch Rig

The launch rig has two elastic cords that accelerate the sled and attached UAV during launch. Each of these cords wraps around a pulley at the front of the launch rig (Figure 6, left end in Figure 5). The force on the pulleys is, therefore, twice the force experienced by the sled.

The pulleys are mounted on a lever with a moment arm of 400 mm (Figure 6). The pin that holds one end of the tensile member is also mounted on the same lever arm 71.5 mm above the pivot point. Using the ratio of these distances gives the force in the tensile member as 5.6 times the force at the top of the lever arm and therefore 11.2 times the retraction force.

A gazebo will be positioned over the front end of the launch rig, at all times to catch any UAV's that pitch upwards and travel vertically, immediately on leaving the rig. To avoid this, the UAV's centre of gravity must be in a reasonable position (this will be discussed in Project Sessions). The edge of the gazebo will be approximately 0.62 m above and 2.0 m in front of the launch rig.

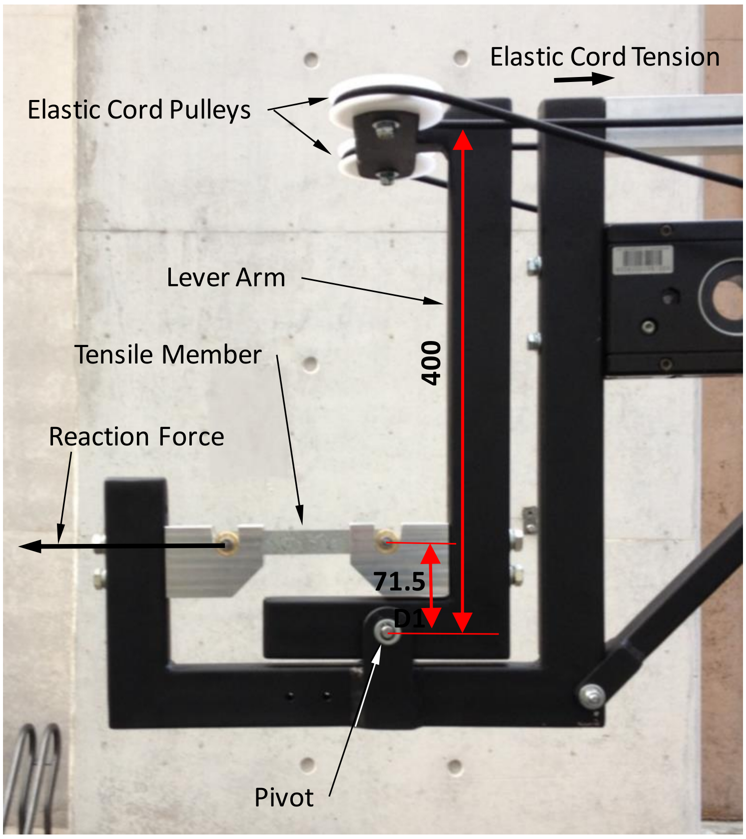

Figure 6: Front end assembly detail view. (All dimensions mm).

4.2 Retraction Force

Figure 7 shows the relationship between retraction distance and the force on the sled. Note that the relationship is not linear and that it follows a different curve during retraction and extension. Note that the maximum retraction distance for launch is 2000 mm.

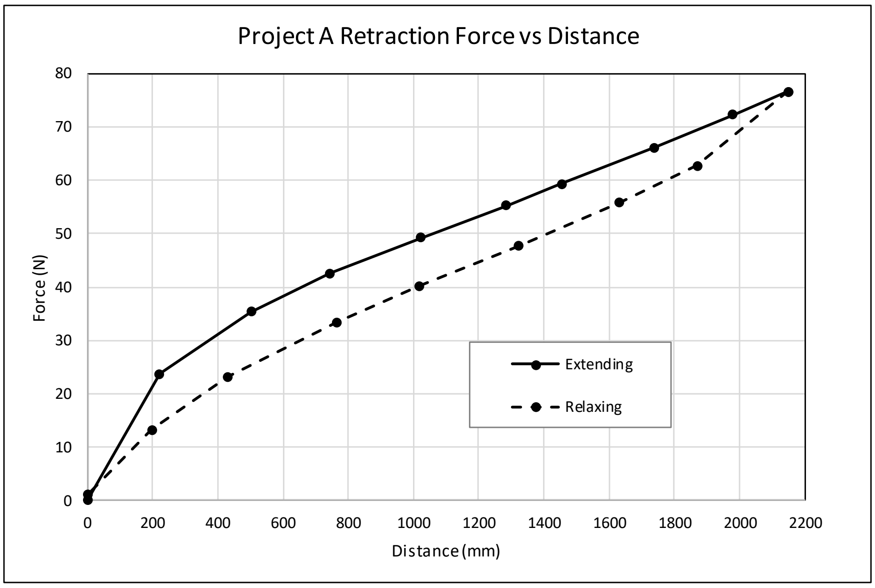

Figure 7: Retraction force to distance relationship.

4.3 Launch Standard Operating Procedure

The launch of a UAV proceeds as follows:

1. Assumed state: the system is at rest with the sled at the front of the launch rig and no tension in the elastic cords. There is no power to the retraction motor and no QRP or UAV attached.
2. QRP is mounted on the sled and magnetic locking pin secured.
3. UAV is mounted on its QRP.
4. If the UAV is not entirely supported by the QRP alone, the launch will be aborted.
5. Tensile member is inserted into the pin grips, and the strain gauge signal wires are attached.
6. A safety check is performed. UAV is secure, and only operator is in exclusion zone.
7. Power is connected to control system and operator retracts sled to the distance specified by team.
8. As the sled retracts, force on the sled increases and therefore increases the load and strain in the tensile member.
9. The sled stops at a specified distance, and operator notes the measured strain in the tensile member.
10. The operator warns of launch, checks the exclusion zone and triggers launch.
11. Sled disengages from retraction motor and accelerates to the front of the launch rig.
12. Sled impacts bump stop at the front of the launch rig and immediately stops.
13. UAV disengages from the QRP and commences flight.

Only the operator may operate the launch rig and will always enforce an exclusion zone around the launch rig and flight area.

5. Models and Simulations

5.1 Overview

The UAV CAD model will be used to perform rapid design iterations, model the mass and centre of gravity of the UAV, aid manufacture and to communicate your design through engineering drawings. CFD programs, in conjunction with Wind Tunnel experimental testing, will be used to inform your choice of wing airfoil profile and wing design. The aerodynamic coefficients describing the selected airfoil profile's performance will be used in the Simulink Trajectory Model to predict flight range and endurance. By comparing your model's predictions against measured data, you will identify differences and validate both your models and engineering design process.

Results from your models will be used to inform your design decisions and to optimise for maximum performance. A schematic of this process is shown in Figure 8 and will be discussed in Project Sessions.

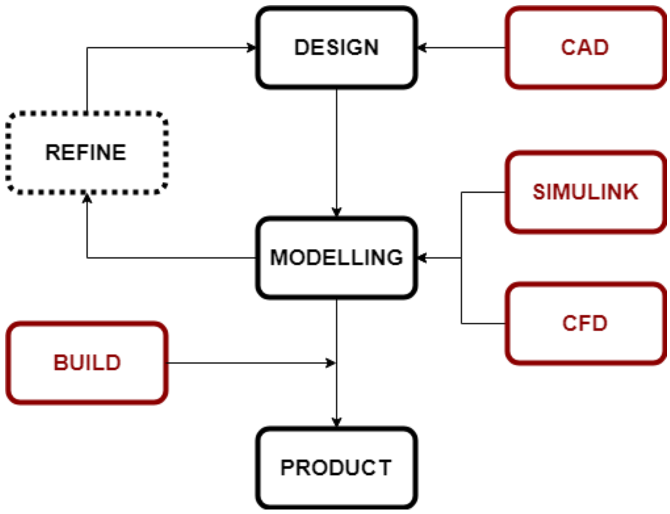

Figure 8: The ENGG1200 engineering design process

5.2 CAD Model

You will create a 3D CAD model of the UAV and progressively refine the design over the semester. This model will help guide your physical design and manufacturing. It is expected that you continuously iterate your CAD model as your design matures.

All CAD tutorials and support material will use PTC CREO. You are, however free to use any CAD package you wish, but depending on the package, tutors may not be able to provide support. For the QRP, CREO is REQUIRED to generate the CNC toolpath because it interfaces with our CNC machines (see Section 6.3).

5.3 Trajectory Model

Trajectory modelling will use Simulink to model the UAV's flight behaviour. You will explore its performance by accounting for lift and drag in a 2D, three Degrees of Freedom trajectory analysis. Throughout the semester, you will continuously refine the Simulink model to better understand the UAV's performance, identify desirable design changes and to evaluate these changes.

Output from the Simulink model will also be used to aid the design of the FDR code and to determine a desirable UAV centre of gravity location.

5.4 Aerodynamic Model

You will explore the aerodynamics (lift and drag) of fundamental airfoil profiles in CFD software. Physical experiments on the same airfoil profiles in a Wind Tunnel will complement this investigation. The goal of this exercise is to “inform” your wing design and learn about the process of collecting aerodynamic data for airfoils. Note that you are not required to simulate or test your specific profile and will select an airfoil from published data.

6. Manufacturing

6.1 UQ Innovate

UQ Innovate is a student workshop available to EAIT students. To access this space, you must complete the required inductions and training. UQ Innovate has machinery, hand tools, expertise and basic materials available for purchase. More information may be found at https://makerspace.uq.edu.au/

6.2 3D Printing

All wing structures will be printed using PLA filament on the Flashforge Guider II 3D printers in UQ Innovate. In Week 7, you will submit a prototype wing structure for printing and in Week 10, your final wing design.

The print jobs must meet the following constraints:

- Maximum print time of 4 hours per submission.
- Maximum print height of 200 mm. Wing structures will be printed vertically, so this limits the span of any individual section.
- Maximum number of individual parts is 12.
- Minimum thickness of any feature in any direction of 1.8 mm.

The wing structure will be printed with the following specifications:

- PLA with a layer height of 0.2 mm.
- Minimum of two external perimeters (top, bottom and sides).
- Maximum overhang without supports is 45 degrees.
- Print orientation will be determined at our discretion.
- Supports, brims and rafts will be used at our discretion; may need post-print cleanup.

6.3 QRP Toolpath

Your QRP will be manufactured using the HAAS CNC mill in UQ Innovate. The instructions for the mill (the toolpath) will be produced by your team from the CAD model of your QRP. To generate this file, you must use the CAM tools included in the software package PTC CREO. You may however, import a solid generated in a different CAD package.

The QRP manufacture must meet the following constraints:

- Only 2D profile milling will be used (that is, your QRP is 2D and a constant 6 mm thick plate).
- The maximum allowed machining time is two hours.

The toolpath must be submitted in Week 6. Your QRP will be manufactured during Week 7 and be available for collection in Week 8.

7. Testing and Demonstration

Continuous testing of individual components and the entire UAV will ensure the success of your project. There are two formal testing sessions scheduled to provide you with the opportunity for valuable feedback, from tutors and project leaders. These sessions are voluntary, and no marks are attached.

You are encouraged to test your UAV and subsystems in different ways, as much as possible outside of these sessions. **Test early and test often**. A YouTube video that shows a previous year's Demo Day is available at https://goo.gl/q4FBCn.

7.1 Fit Test – Week 9

The purpose of this test is to perform preliminary checks on individual components and gain formative feedback from the course staff. The launch rig will be available to test the QRP fit and for mounting a prototype, but it will not be powered and no launches will be performed. The testing schedule will focus on the following areas, launch rig interface check, aerodynamics and wing structural design, FDR check and airframe materials and manufacture.

You are encouraged to think of this as a design check and an opportunity to gain formative feedback on your preliminary design.

7.2 Flight Test – Week 11

The testing schedule will conclude with test launches of your UAV from the launch rig in Week 11. The purpose of this test is to evaluate the whole UAV system. Flight tests will run twice, allowing each team to test at least once per day. Note that tensile members will not be tested – these will be calibrated, tested and then remain in the Instrumentation Workshop.

7.3 Demo Day – Week 13

Your project will culminate in three flights held on Demo Day in the UQ Centre. Your UAV's performance will be formally judged on the following:

1. Flight endurance.
2. Flight range.
3. Robustness of the UAV, in terms of any damage, sustained during flight.
4. The accuracy of the FDR reported flight endurance and range.
5. Repeatability of the FDR reported flight endurance and range.

6. The accuracy of predicted compared to actual strain.

You may demonstrate only one UAV on Demo Day. Minor modifications and repairs between flights are allowed, but may a incur penalty to your robustness score.

8. Frequently Asked Questions

Question	Answer
Can I get multiple parts manufactured using the university's CNC machines?	No. We only have the capacity to manufacture one QRP part per team. Please purchase materials and use the tools available in UQ Innovate.
Are we allowed to make absolutely any shape/design we want as long as we satisfy the design specifications and believe it will work the best?	Sort of. Your design must reflect the *design intent* of the project. We encourage creativity, but will not accept designs such as hot air balloons or arrows. If you intend to design something not easily recognisable as a fixed-wing UAV, consult your project leader.
Are we just aiming to launch a projectile as far as possible?	No. You receive marks for both flight endurance and range. Your UAV will need to fly to get a good mark.
Can we purchase a model UAV and modify it to suit our purposes?	No. You are required to design and manufacture the UAV. Small, incidental components may be scavenged, but these <u>must</u> be signed off by your project leader,
If every team finds that one airfoil which provides the best C_L and C_D will we all get the same score on Demo Day?	No. Although important, UAV design has far more variables than wing profile. You will also have to consider wing placement, fuselage design, tail sizing and design, centre of gravity position, mounting point for launching, wing incidence, dihedral and taper, surface finish…

Notes

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA
CREATE CHANGE

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