AENG21100
AVDASI 2
Department of Aerospace Engineering
University of Bristol

UAV Fuselage Design

Team 6

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2. Executive Summary

This report presents a detailed analysis of the design, manufacturing and testing of Team's 6 UAV fuselage prototype. The UAV design was driven by a range of predefined requirements and constraints on the different disciplines of expertise. Aerodynamically, the main design focus was optimising the UAV's flight characteristics across four distinct phases of flight (take-off, maximum endurance, dash and landing). The prototype's spars, ribs and joints were structurally designed for $6g$ manoeuvres at ultimate and limit loads, with the empennage being analysed at a $45m/s$ speed limit case with maximum fin deflection. Dynamically, the UAV was analysed to understand its modes of oscillation, natural frequencies and flutter characteristics and determine if the damping was adequate. The MAC design was focused on producing a PID controller that was 'better than without' it. It needed to stabilise the UAV when an impulse was applied in the wind tunnel and move the UAV to different pitch demands.

In terms of dimensions, the prototype had an overall length of 1.40m, with a 1.25m long tapered carbon fibre main spar with an average diameter of 34mm and a thickness of 0.6mm. Layers of reinforcement were added at the most critical joint areas (two layers at the wing root joint and one on the empennage area). A six rib configuration was chosen for the fuselage body, with 10mm thick plywood ribs reinforced with 0.5m long carbon stringers. To maintain a stable CG position, improve the overall aerodynamics and introduce shear stability, a 3D printed fuselage skin shell was chosen. The nosecone and boat tail were 3D printed, with bolt holes allowing easy access to the payload compartment.

A conventional empennage layout was chosen using a NACA 0009 aerofoil for both the VTP and HTP, which consisted of ribs with a full foam insert between them. These structures used the same carbon fibre spars with a diameter of 12mm, thickness of 0.5mm and lengths of 0.44m and 0.63m, respectively. The HTP was designed with no sweep, an aspect ratio of 3 and a taper ratio of 1. It had a total span of 0.63m, a root chord of 0.21m and the distance between the aerodynamic centres of the HTP and the main wing was 0.86m. The aspect ratio of the HTP had to be altered multiple times during the design and manufacturing phases due to structural concerns. The VTP had a sweep angle of 5^o, an aspect ratio of 1.64 and a taper ratio of 0.9. It had a span of 0.39m and a root chord of 0.25m.

So that only one pushrod was required, the elevator was designed to be one continuous component, comprised of small ribs and foam inserts pivoted about a singular spar. The mechanism consisted of a non-continuous servo connected directly to the elevator spar via control horns and a pushrod made of hardened piano wire. This actuated a single flap across the whole horizontal tailplane. The onboard hardware included a Teensy 4.1, an Adafruit MPU-6050 IMU and a 433MHz RFM69HCW transceiver with a Teensy 4.0 powering the ground station. A digital low-pass filter was placed on the IMU to filter out high-frequency noise.

The results from testing were overall satisfactory and in line with the predicted performance. There are, however, specific areas of future improvement described throughout this report and highlighted in its conclusion. The wind tunnel test found the pitching moment coefficient to be negative with an increase in the angle of attack, an average C_L at $20m/s$ with 0^o elevator deflection to be 0.000487, and the average C_D for 0^o elevator deflection and angle of attack were 0.443. The maximum achieved applied load was $1748N$ with a deflection of the aft fuselage at a limit load of $16.1mm$ and a deflection of the HTP at a limit load of $5.4mm$. The vibrations testing found the key frequencies located at around 10Hz and 45Hz. The control system analysis found that, for an impulse response, an increase in the proportional gain reduced the rise time. However, this did not correlate with an increase in the overshoot of the system. When the derivative gain was set to 3.5, there was a reduction in the rise time but an increase in the overshoot.

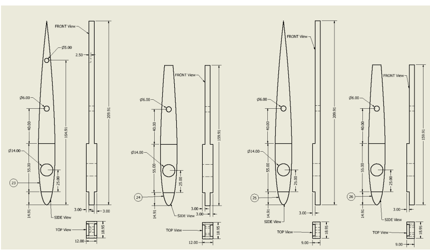
The main factors that affected the design and manufacturing processes were sudden task re-allocations and balanced compromises between disciplines. The structural design suffered from over-designing, and the MAC discipline struggled from testing time constraints reducing their ability to fine-tune the gains.

3. Illustrations

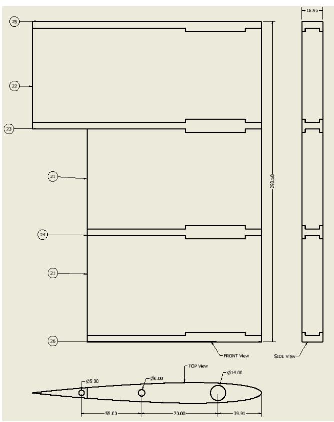
This report section includes some design illustrations and considerations. The components list with the full mass budget breakdown and CG calculation is in figure 1. The prototype's total mass was around 5.8kg, and its CG was calculated to be positioned at around 295mm from the nosecone. Detailed CAD illustrations and rendering of the fuselage design, as well as Control Circuit diagrams, can be seen in the figures below. Other CAD illustrations (such as the nose cone, fuselage skin design, spars and bulkheads) can be found in appendix 7-Further Illustrations.

Component	Number	Distance from nose (mm)	Invididual Mass (g)	Total Mass	Moment
Batteries and Motors	1	73.4	700	700	504037.8
Electronic Shelf Floor	1	73.4	10	10	7200.54
Nose Cone	1	82.5	68.7	68.7	55600.6275
Fus Bulkhead F (forward most)	1	110	36.6	36.6	39495.06
Fus Bulkhead E	1	200	36.6	36.6	71809.2
Payload	1	205	3500	3500	7038675
Fus Bulkhead D	1	283	36.6	36.6	101610.018
Fus Bulkhead C	1	335	36.6	36.6	120280.41
Fuselage Bed	1	360	140	140	494424
CFRP False Spar (Fus) 5mm dia	2	360	9.05	18.1	63921.96
Fuselage Stringers (4 units)	1	360	54.9	54.9	193884.84
Fuselage Skin	1	360	279.4	279.4	986729.04
Main Wing Root Joint	1	410	113.6	113.6	456910.56
Fus Bulkhead B	1	505	36.6	36.6	181318.23
Fus Bulkhead A (rearmost)	1	610	36.6	36.6	219018.06
Fuselage Rear 3DP Piece	1	676.667	113.9	113.9	756079.962
Main Spar	1	735	379.6	379.6	2737048.86
VTP Main Spar	1	1215	23.9	23.9	284867.685
HTP NACA 0009 Elevator	1	1229.8	2.89998	2.89998	34986.3389
HTP Main Spar	1	1240	36.5	36.5	444000.6
VTP NACA 0009	1	1255	32.4	32.4	398894.22
HTP NACA 0009 w/o elevator	1	1272.5	56.2	56.2	701557.245
Servo casing	1	1275	47.2	47.2	590365.8
VTP False Spar	1	1295	7.3	7.3	92738.835
HTP False Spar	1	1305	14.7	14.7	188190.135
Elevator Spar	1	1376	8.6	8.6	116087.616
Final Mass (g)	**5827.49998**				
Centre of Mass (mm from nose):	**295.266568**				

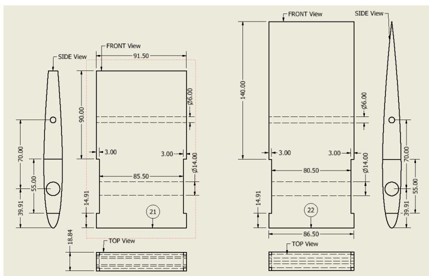
Figure 1: Components list and CG calculation



(a) HTP Ribs

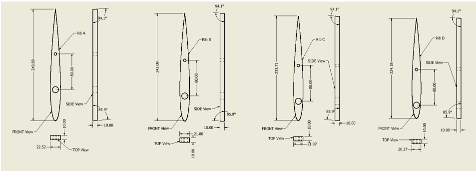


(b) HTP Assembly

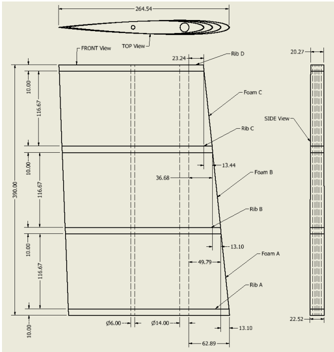


(c) HTP Foam

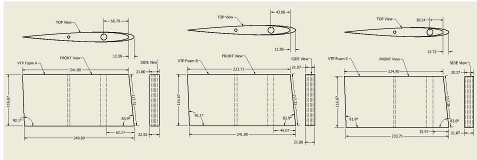
Figure 2: Orthographic drawings of the HTP



(a) VTP Ribs

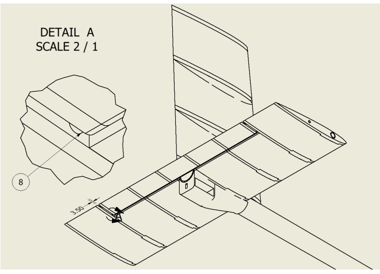


(b) VTP Assembly

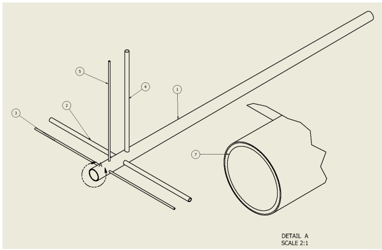


(c) VTP Foam

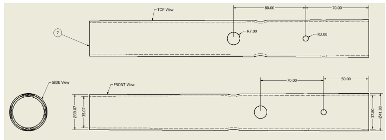
Figure 3: Orthographic drawings of the VTP



(a) Elevator Assembly

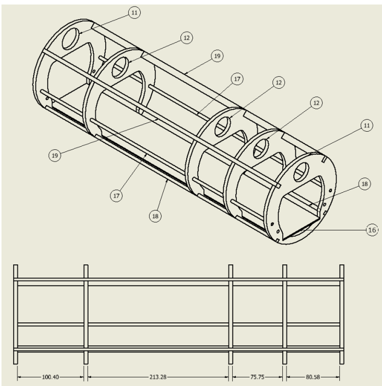


(b) Spar Assembly

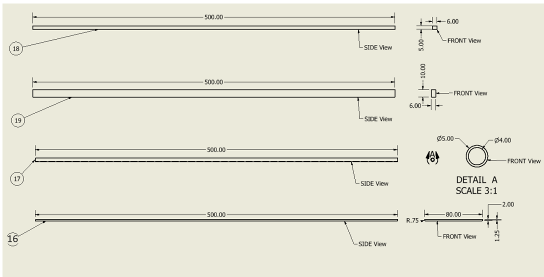


(c) Spar Joint

Figure 4: Orthographic drawings of the Elevator, Spar Joint and Spar Assembly

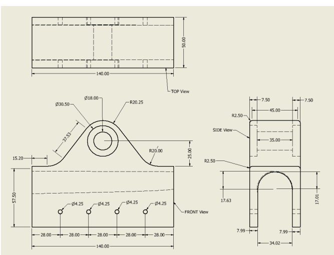


(a) Fuselage Assembly)

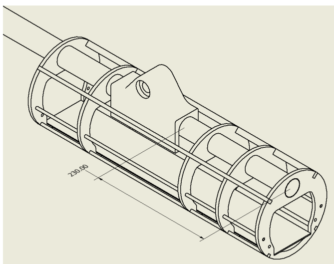


(b) Fuselage Stringers

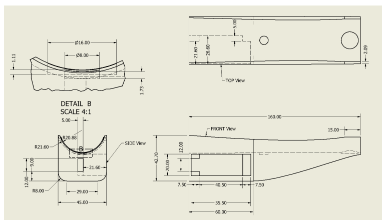
Figure 5: Orthographic drawings of the Fuselage assembly and Fuselage stringers



(a) Wing Root Joint

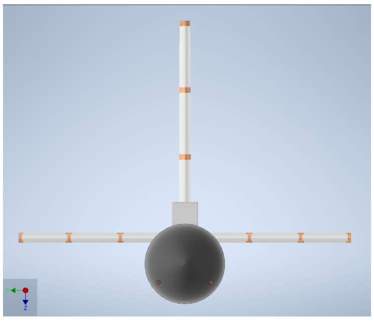


(b) Wing Root Joint Position

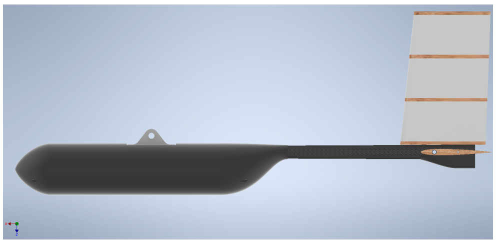


(c) Empennage

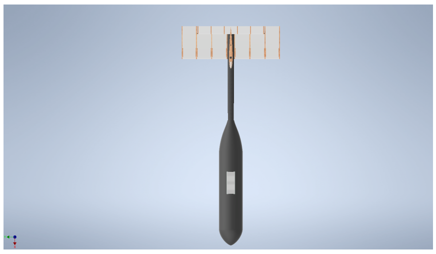
Figure 6: Orthographic drawings of the Wing Root Joint and position as well as the Empennage



(a) CAD Render (Front View)



(b) CAD Render (Side View)



(c) CAD Render (Top View)

Figure 7: Orthographic projections of the UAV Cad Render

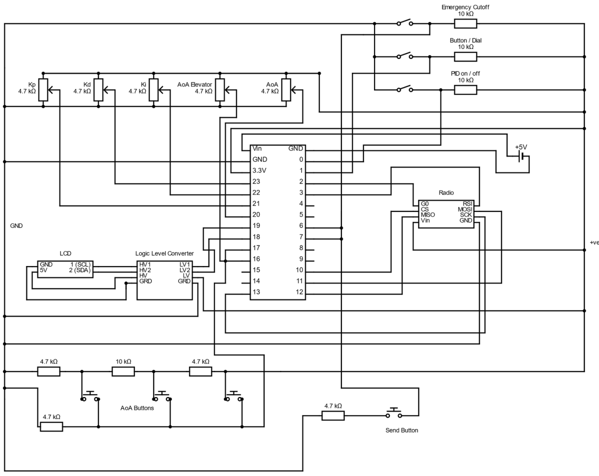


Figure 8: Backside of the control box lid

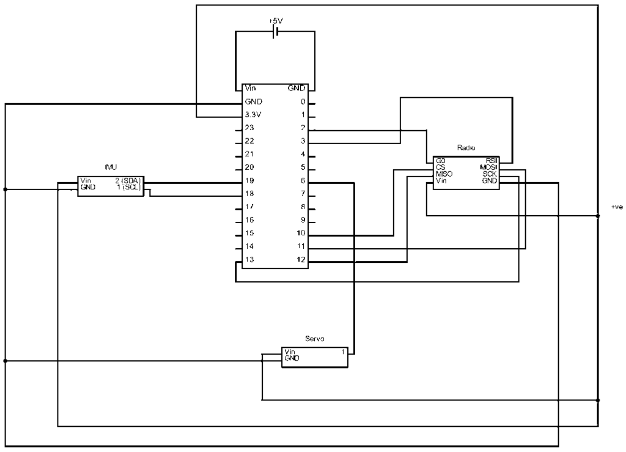


Figure 9: Control box circuit on strip-board

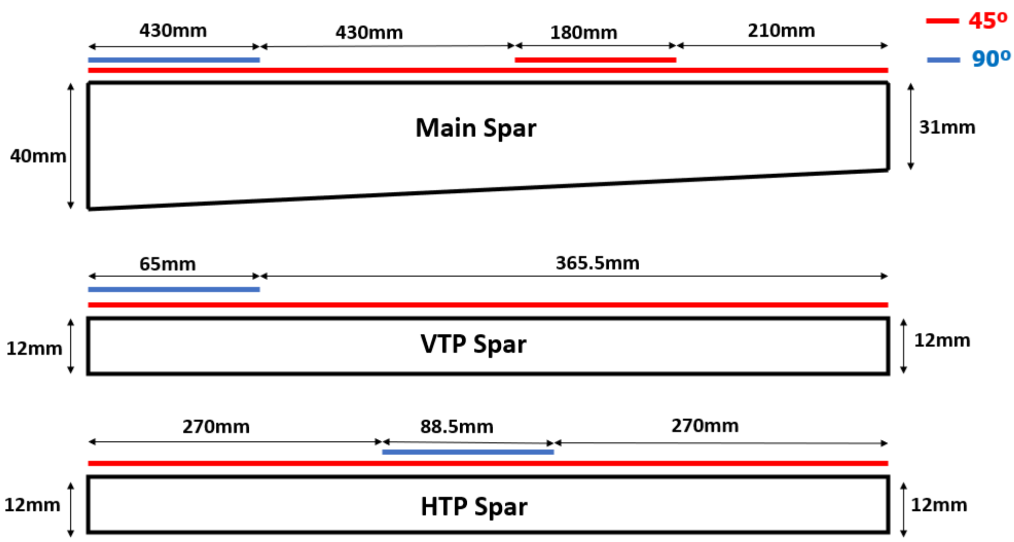


Figure 10: Lay-Up Configuration