Inspiring the Next Generation of Aerospace Engineers with Crowd-Built Aircraft

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High impact aerospace build and fly projects provide inspiration to student engineers at all stages of learning, however it is often hard to provide opportunities for meaningful engagement for those with relatively little experience. The crowd-built aircraft concept was developed at Manchester to inspire creativity in aerospace structural design by undergraduate engineers and to engage high-school children with STEM careers in aerospace. The guiding principle is that a work force of 100 volunteers should be able to build an extraordinary aircraft in a single day with no previous experience using only craft tools and materials. Impact is achieved by the design goal of maximising vehicle size within a 25 kg all-up weight limit. New understanding of the engineering properties of craft materials and rapid manufacturing processes have been developed, particularly around the use of foamboard as a material for primary structure. The engineering process of taking a case study aircraft through a complete design, build and test cycle is documented with key lessons learnt on the importance of design for manufacture and assembly at crowd-build events. The project has spawned a new student society at Manchester with key values of inclusivity, creativity and sharing of knowledge that are distinct from societies set up around engineering competitions. The crowd-build process is illustrated through documentation of a series of events with undergraduate and high school student volunteers. It was found that younger participants were often faster at building due to less concern about making irreversible mistakes which unnecessarily slowed down those with more experience.

I. Introduction

In this paper we introduce the concept of aerospace crowd-building in which disparate groups of individuals are brought together for a day to intensively build extraordinary and inspirational flight vehicles from craft materials, Figure 1. It is well recognised that high impact educational aerospace design projects, can be used to inspire and consolidate learning in students already in an engineering discipline, e.g. [1–3] or engage those thinking about furthering STEM studies, however it is hard to provide meaningful engagement for those with little previous experience. Furthermore, many design projects and student societies are set up around engineering competitions that do not necessarily engage a fully inclusive range of learning styles. The crowd-building concept is based on the premise that a 100 people should be able to build a complete aircraft in a single day with no previous experience using only craft tools and materials. Impact is achieved by maximising the dimensional size of the aircraft whilst staying within a 25 kg all-up weight limit defined by the UK CAA Open Class for Uncrewed Aerial Vehicles (UAVs).

The use of craft materials and tools as a constraint is important in that it is relatively easy to make the build activity safe for participants from a wide range of backgrounds and it reduces production costs. Furthermore, it provides an unexplored region of design space in which innovation and creativity can flourish. The primary structural material used for building is foamboard, which is a polystyrene foam and paper composite material. This material is widely used in hobby aircraft building, however until now its full potential has not been exploited through lack of reliable material properties data and over-reliance on use of unnecessarily high performance materials such as carbon fibre to solve or avoid structural design problems.

In the rest of the paper, section II provides a technical foundation for engineering design and manufacture using craft materials, section III provides a detailed technical case study into the first aircraft developed using the crowd-building approach, section IV introduces the Giant Foamboard Aircraft society set up by students, section V provides details of the crowd-building process and section VI conclusions.

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a) GFA Mk1 b) GFA Mk2 c) GFQ (Quadcopter) d) GFD (Delta)

Fig. 1 Example aircraft designed as part of the crowd-built aircraft project at Manchester. GFA Mk.1 flew in June 2022. GFA Mk.2 and GFQ flew in June 2023. GFD due to fly in June 2024

Material	density, kg/m^3	Stiffness, Gpa	Tensile Strength, MPa	Compressive Strength, MPa	cost, £ per kg, 2023 prices
Depron (polystyrene foam)	40	0.014	0.41	0.28	33
Paper	750	2.24	56		2.4
Brown foamboard	58	0.18	1.3	1	20
White foamboard	78	0.234	1.69	1.3	11
Plywood	680	9	30	35	20
Sellotape (polypropylene)	900				1
Hot glue (ethylene-vinyl acetate (EVA))	950	0.05	20		13
Covering film (Biaxially oriented polypropylene film (BOPP))	900	1.5	33		1.1

Table 1 Engineering properties of craft building materials

II. Engineering with craft materials

Mechanical properties of the craft materials used for the Crowd-Build Aircraft project are summarised in Figure 2, based on the data provided in Table 1. Material class groupings are provided using data from [4]. Since there are no formal type definitions of craft materials there is quite a variation encompassed within terms such as 'paper' and 'hot glue' and inasmuch the values used here should be taken as typical values. Of note is that paper is both relatively stiff, and relatively strong, with a tensile strength similar to to plywood (but less stiff) and with similar density. Thus paper falls clearly into the category of 'wood product' as would be expected. At the opposite performance end, expanded polystyrene foam (Depron), has both stiffness and strength around two orders of magnitude less than paper, with a density one order of magnitude less. Foamboard is a type of composite sandwich (see for example [5]) and considered as an aggregate material has properties in between that of paper and Depron as expected (see section below for more detailed analysis of properties). Hot glue (thermoplastic adhesive) is interesting in that it is relatively strong (similar in strength to paper), but has low stiffness, more consistent with a grouping with rubbers. Hot glue is also relatively dense (similar to paper and plywood), and in particular is around 20 times as dense as foamboard. This means that with liberal application it is possible that the weight fraction of hot glue in finished structures can be very high. For the case study vehicle airframe, glue accounted for approximately 30 percent of the structural mass (20 percent of the all-up flight mass). In terms of cost per kilogram of material, plywood is the most economical for stiffness applications, whereas paper and plywood are equally economical for strength. The main useful attribute of Depron foam is its low density when used as a filler for higher performance materials, so it is of little concern that Depron on its own is the least economical for both stiffness and strength applications.

A close-up photo of a foamboard sandwich panel and definition of the panel section layout is shown in Figure 3. Depron is a type of *closed foam* meaning that the voids within the material are unconnected with other voids. In the photograph, the edge of the foamboard shown has be cut with a sharp blade and the voids in the foam can be clearly seen. Foamboard is available in many different brands, however all tend to use a Depron core of thickness between 3 and 10mm. In stationary applications, the paper facing the Depron typically has clay additives to make a smooth white presentation surface (but also increases the density). There exists specialist foamboard manufacture for aircraft hobby applications in which the paper is treated with a wax to make it water resistant (e.g. Flite Test/Adams, referred to

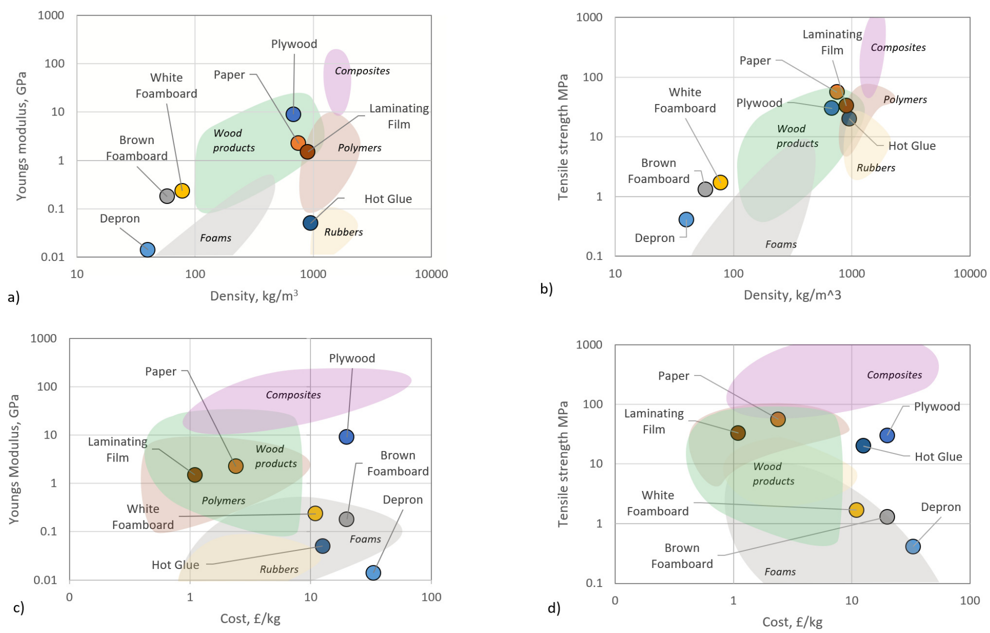

Fig. 2 Craft building material properties represented on materials selection charts [4]. Costs shown are based on estimates in 2002 inflated to prices in 2023

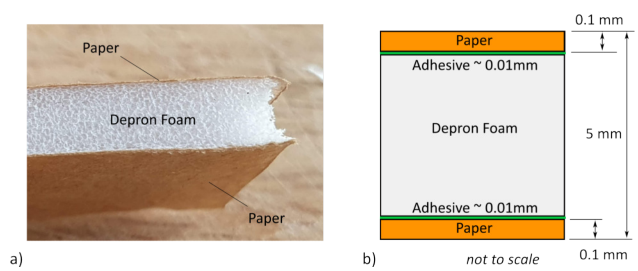

Fig. 3 Foamboard sandwich panel photograph and layer arrangement with dimensions

here as brown foamboard). The paper is bonded to the Depron using a layer of heat activated adhesive. The paper on the specialist foamboard is easy to remove cleanly from the foam which allows manufacture of efficient lap joints between panels. Comparison of the material properties of paper and Depron foam, and the aggregate properties of a 5mm foamboard sandwich are shown in Figure 4. Aggregate properties are calculated based on material volume fractions defined by the geometry in 3. There are order of magnitude differences in density, stiffness (Youngs modulus) and strength (ultimate stress) as discussed above. However, interestingly, both materials have a similar failure strain of around 3 percent, which means when used in a sandwich in plane tension the strength reserve of each is used equally, which is an efficient arrangement. From the aggregate panel properties we see that whilst paper makes up around 4 percent of the volume, it contributes to around 50 percent of the mass and provides around 85 percent of the in plane tensile load carrying capacity. In compression, the load carrying capability is more complex as it depends on local buckling of the paper, however as a pessimistic starting point, the in-plane compressive strength of foamboard may be considered as at provided by the foam alone. Using the above volume fraction model and the assumed properties for paper and Depron in Table 1, gives a predicted foamboard strength of 2.6 MPa vs an experimentally derived value of 1.3 MPa, and a predicted stiffness of 0.1 GPa vs an experimental value of 0.18 GPa. Experimental values were obtained from a simple bending test on a slender cantilevered tube and given that this experiment determines an *average* of both effects of compression and tension and it is known that the material is not symmetric in behaviour, these values should be considered as engineering estimates not absolute values [6].

To support the crowd-building philosophy, significant effort was invested in design for manufacture and in developing

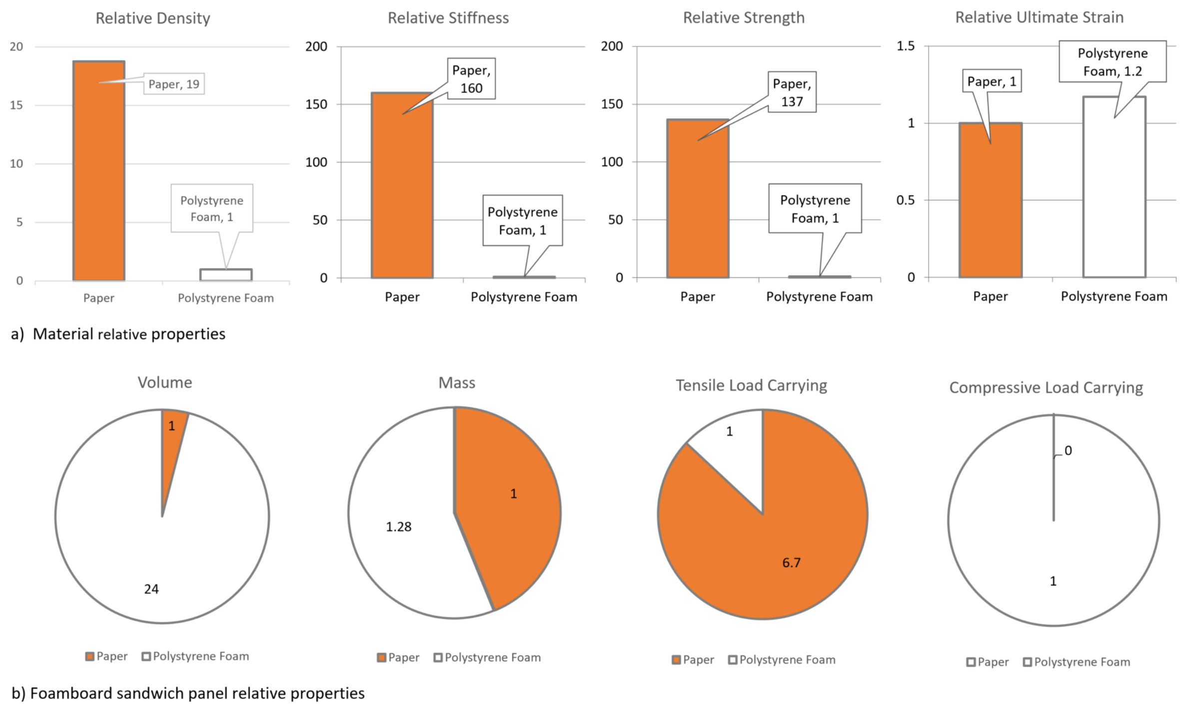

Fig. 4 Characterisation of relative material mass and mechanical properties for paper and polystyrene foam (Depron), and aggregate properties of foamboard 5mm sandwich panels

streamlined manufacturing process for component parts that are assembled on build days. Figure 5 shows a summary of process and research on laser cutting of foamboard and plywood components [7]. The most geometrically complex component for GFA Mk.1 was the tail joint (5a) and b)) which integrated loads from all three tail surfaces and the rear undercarriage. Note use of tabs and slots throughout to providing self-jigging during assembly. A wing trailing edge control surface ((5 d) and e)) provides an example of a foamboard part that is fabricated from a combination of laser cutting and folding. The required 2D net for laser cutting is obtained by a process of surface unwrapping in CAD. Note that the use of folds simplifies the assembly process by reducing the number of parts that have to aligned and guarantees that the control surface hinge attachment line is straight, hence simplifying subsequent integration with the wing trailing edge spar. The cut inventory for the Mark I Giant Foamboard Aircraft (GFA Mk.1) was for around 2000 individual parts cut from around 170 A1 foamboard sheets, taking a total time of around 6 hours (average of 10 s per part). Analysis of where the time is taken up is shown in 5g). Key to productivity was finding laser cutter power and speed settings that delivered the required cut in minimum time. Use of too high of a power setting led to excessive material ablation and in some cases fire (5f)). Optimised settings for brown foamboard are shown in 5h). Note that power has to be reduced at corners to reduce possibility of burning [7].

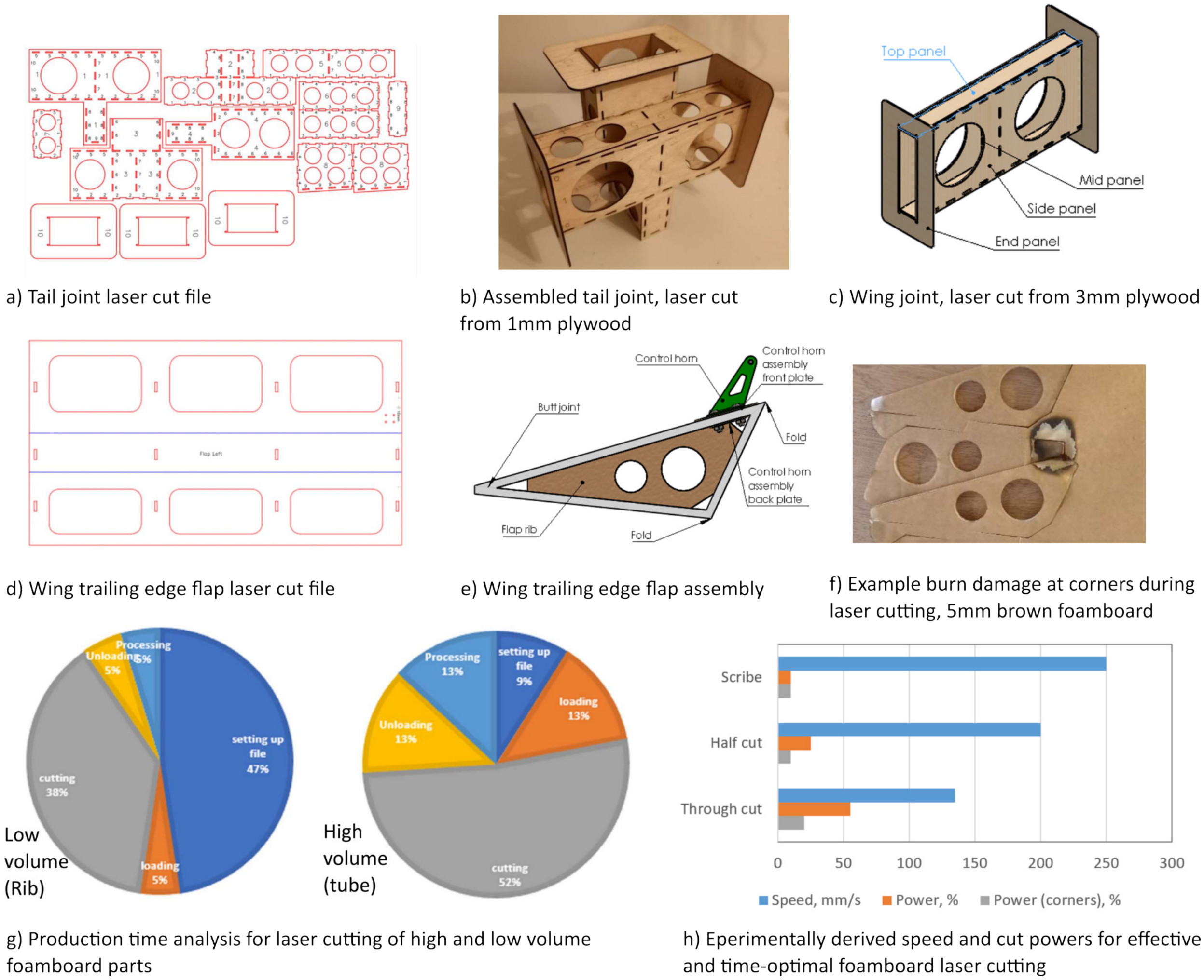

Fig. 5 Manufacturing process development and research outcomes for laser cut plywood and foamboard used for Crowd-Build Aircraft projects

Parameter	Symbol	Value		Symbol	Value
Wing			**Horizontal tail**		
Planform			*Sizing*		
Span	b	6.5 m	Volume coefficient	V_{bar}	0.5
Semi span	s	b/2 = 3.25m	Area	S_t	S/5 = 1.3 m^2
Aspect ratio	AR	6.5	Tail arm	L_t	2.5 m
Chord	c	1 m	*Planform*		
Area	S	6.5 m^2	Aspect ratio	AR_t	3
Taper ratio	-	1	Span	b_t	2 m
Sweep	-	0	chord	c_t	0.667 m
Wing lift curve slope	a	4.80	Taper	-	1
Aerofoil section			Sweep	-	0
Shape		NACA2418	Lift curve slop	a_t	3.78
Pitching moment	C_{Mo}	-0.045	*Aerofoil section*		
Alpha zero lift	-	-2.5°	Shape		NACA0012
Trailing edge devices			Pitching moment	C_{Mo}	0
Chord	-	0.2c = 0.2 m	Alpha zero lift	-	0
High lift device span	-	s/2 = 1.625 m	*Trailing edge devices*		
Aileron span	-	s/2 =1.625 m	Chord		0.3c_t
Rigging			*Rigging*		
Wing setting angle to fuselage datum	-	+2°	Setting angle to fuse datum	-	0°
			Vertical tail		
			Sizing		
			Area	S_f	S_t/2 = 0.65 m^2
			Tail arm	L_f	L_t = 2.5 m
			Volume coefficient	V_{barf}	0.038

Table 2 GFA Mk.1 aerodynamic definition

III. Giant Foamboard Aircraft Mk.1 Case Study

The objectives for the GFA Mk.1 were to design, build and fly the largest possible fixed wing remotely piloted vehicle with an all up mass of less than 20 kg*, with the constraints that the aircraft could be built by 100 people with little previous experience in a day and that the disassembled aircraft could fit within a 4x3x3m volume of a light truck for transport purposes. As a derived requirement it was decided that the primary structural material of the aircraft should be foamboard. The restriction of primary structure to foamboard was both constraining and liberating in that foamboard is not a classically strong material (constraint) but since no one had ever attempted such a project before, all options were on the table (liberating). The crowd-building aspect of the project initially arose out of necessity since the only way the project was going to succeed was with the support of an army of volunteers. However it soon became clear that the crowd-building aspect was a principal value of the project in terms of engaging engineers at all career stages. Crowd-building also raised the game in terms of design for manufacture and assembly. As a rule of thumb, it took an hour in CAD to save one minute of assembly time.

The aerodynamic design philosophy for GFA Mk.1 was to be as conservative as possible. The configuration adopted is shown in Figure 6 with key values defined in Table 2. All design choices fall within recommended guidelines for model or light GA aircraft of this configuration, e.g. as defined by standard aircraft design texts ([8][9]). Simple spreadsheet based design analysis was used to establish the neutral point, and hence centre of mass location for the required static margin, and the required tail setting angle to trim with zero elevator deflection at cruise. At a flying weight of 20 kg the aircraft has a stall speed of around 7 m/s (14 kts), which is very low for an aircraft of this size.

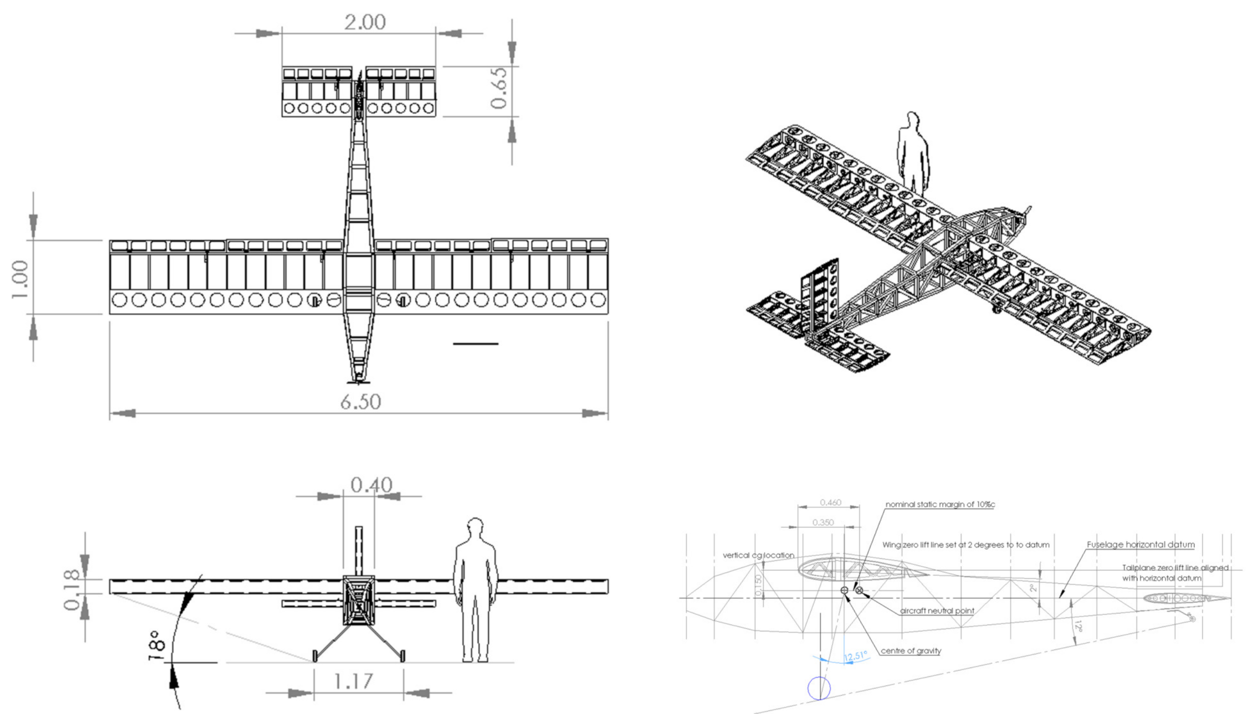

Fig. 6 GFA Mk.1 general arrangement and longitudinal rigging diagram

*At project conception the CAA 'Open Category' weight limit was 20kg, this has since increased to 25kg.

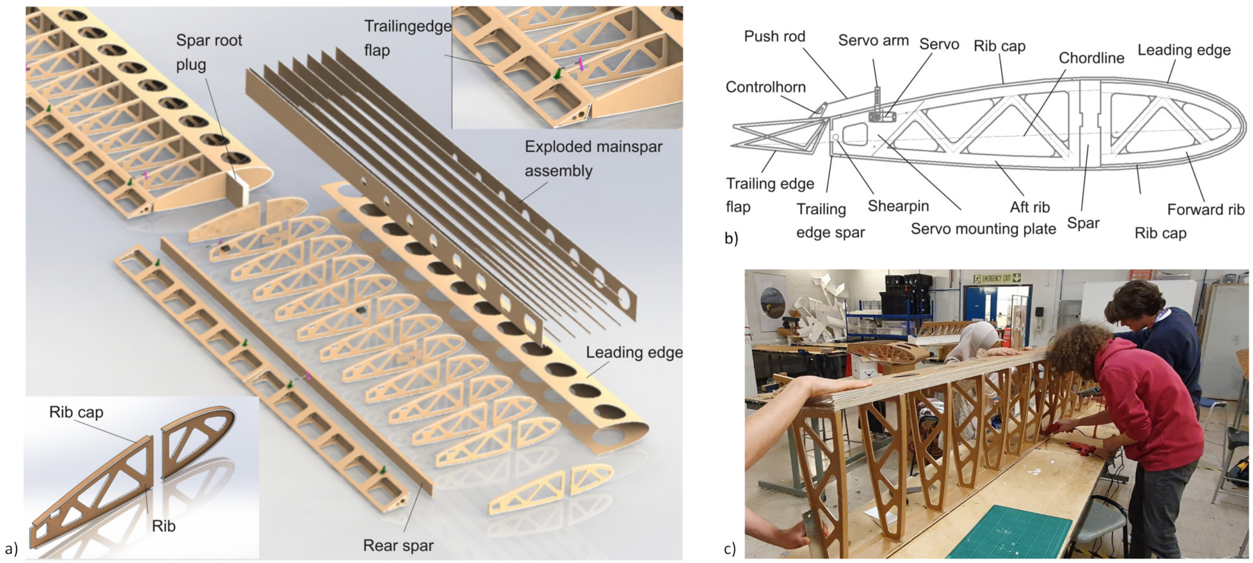

Fig. 7 GFA Mk.1 wing exploded view, section detail and manufacture

From a structures perspective, the wing spar was the most critically loaded component and drove choice of relative large wing section thickness (18 percent) and relatively low wing aspect ratio (6.5). The wing structural design concept is shown in Figure 7. The wing bending is taken by a cantilever beam comprised of eight foamboard laminations. The beam is internally tapered to reduce material towards the wing tip. Wing torsion is carried by a leading edge D box, with a shear pin at the root of the rear spar to react the torque at the fuselage join. To reduce part count and simplify assembly, the wing is unswept and untapered so that all ribs are identical. There are two identical trailing edge control surfaces on each wing attached to a trailing edge spar at 80 percent chord. All components fit together using tabs and slots (see Figure 7b)) so that wing can be assembled accurately without use of jigs by inexperienced builders (Figure 7c)). A static aeroelastic analysis of the wing was undertaken using Matlab. It was confirmed that the structural design is driven by strength requirements, rather than stiffness, i.e. the wing structure will fail due to static load rather than as a result of excessive deflection [10].

The fuselage structure is based on a truss of foamboard tubes with foamboard bulkheads at the more highly loaded sections around the wing and gear attachment, Figure 8. The choice of 40 mm box sections for the truss members was based on a creative and systematic experimental programme by a summer intern Thomas Perrin who identified that a 40 mm box provided the optimal compromise in terms of resistance to buckling, ease of manufacture and overall mass. These tubes were henceforce known as Perrin tubes. The detailed design and manufacturing process for these tubes is shown in Figure 9. The removable undercarriage sub-assembly attaches to the fuselage via a receiving box concept that as far as possible transmits only direct stresses into the foamboard structure. The motor was attached to the front of the aircraft originally via a plywood plate, however despite reinforcement this component failed a number of times during flight testing and was eventually replaced with a carbon fibre plate. The aircraft has three removable hatches on the top of the fuselage to allow access to avionics systems and batteries. Adequate aeroelastic stiffness at the tail was verified using beam element model in ANSYS [10].

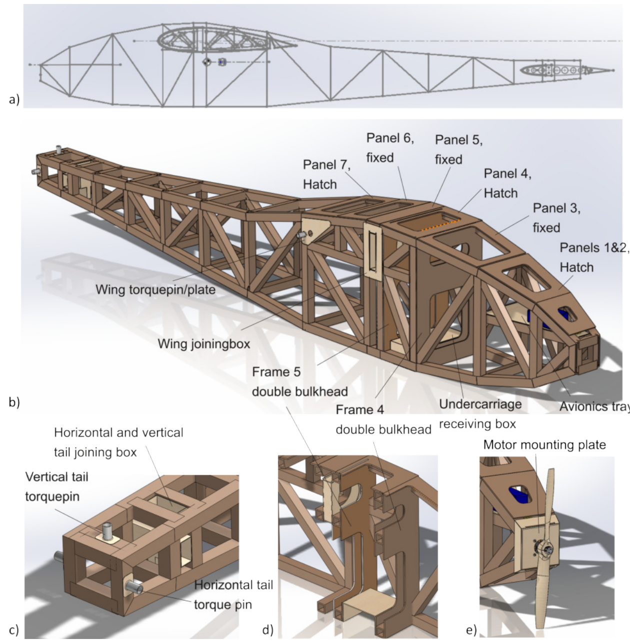

Fig. 8 GFA Mk.1 fuselage frame arrangement and detailed design features

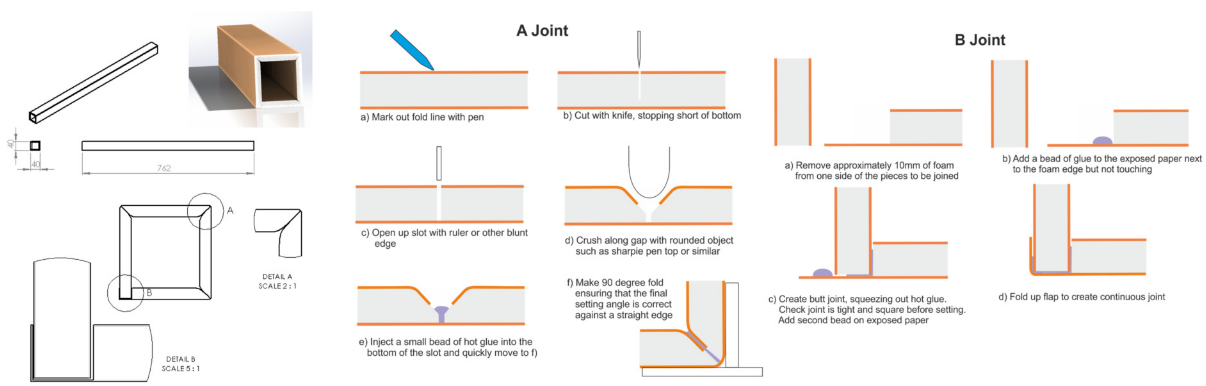

Fig. 9 Perrin tube detailed design and manufacture

The measured mass breakdown of the final aircraft is shown in Figure 10. The original design goal was to aim for a structural mass fraction of 50 percent. In the end the mass fraction was closer to 65 percent. Of note is that the mass fraction of the glue at 20 percent of the all-up mass was approximately double that allowed for. The reason was human nature: inexperienced builders tend to err on using more glue than is needed, just to be sure their joint does not fail. Additional glue in the final build meant the centre of mass was much further aft than planned, requiring around 3 kg of ballast in the nose to correct. Since the aircraft was already close to maximum weight, it was decided to extend the nose of the existing aircraft 600 mm instead, which would achieve the same balance without additional ballast. This major surgery to the aircraft was successfully completed in a day at the flight test site by a small team of students, see Figure 16, which is a testament to the robustness of the fuselage design concept. Whilst it was originally intended that foamboard was used for all the primary structure, using plywood for highly loaded parts such as the wing joint and undercarriage greatly reduced the design and manufacturing effort to get a workable solution, hence a pragmatic compromise was made for these components that still kept the spirit of the original ambition but at much lower cost and risk.

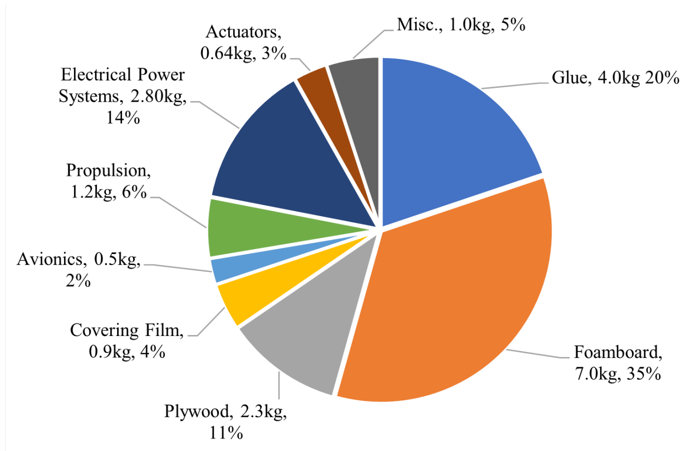

Fig. 10 Complete GFA Mk.1 mass breakdown

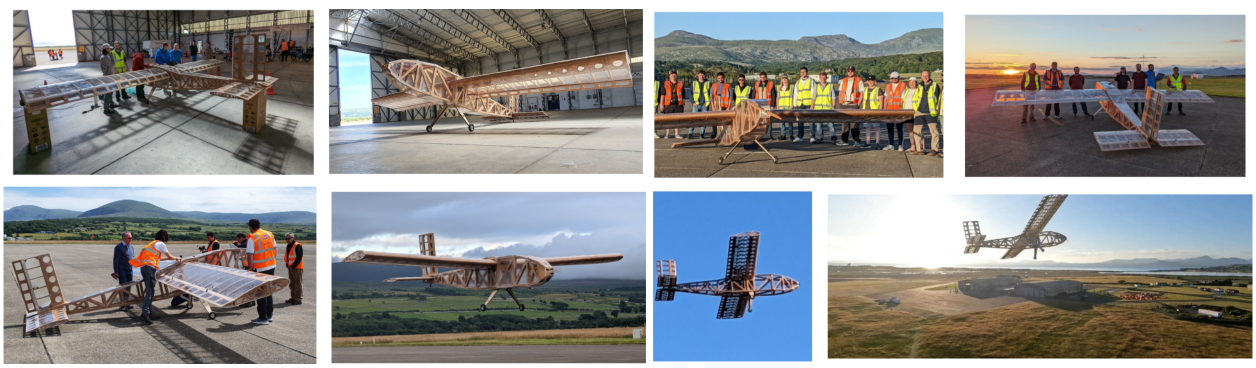

Fig. 11 GFA Mk.1 first flights at Snowdonia Aerospace Centre, UK, June 2022

Whilst the primary focus of design was on materials, structures and manufacturing, for completeness, a systems diagram of the vehicle is shown in Figure 18 and a complete list of components in Table 3, both found in the Appendix. The flight control hardware choices are based on standard large model aircraft practice.

Successful flight testing of the MK.1 vehicle was carried out in June 2022 at Snowdonia Aerospace Centre, Wales, UK, Figure 11. The vehicle was very straightforward to fly and was operated in manual and autopilot-assisted flight modes. The aircraft undertook five separate flights[†] and the foamboard airframe proved resilient to a dead-stick landing on rough grass following loss of the propeller and a belly landing on concrete following loss of the undercarriage. Early flights were witnessed by an entire cohort of second year aerospace engineering undergraduates from Manchester sparking significant interest in the project.

IV. Giant Foamboard Aircraft Society

The success of GFA Mk.1 provided undergraduate students with a first-hand experience of building something that the Aerospace world had never seen before and served as a catalyst for the formation of a new student society to further this ambition. Preserving the project's legacy became a crucial concern, as it presented an unmissable opportunity for future students. Prior to the society launch, all of the design, analysis and organisational work was carried out by a handful of summer interns and students using GFA as a case study for their dissertation. Increasing the human resources on the project has allowed for the expansion of the GFA design envelope - several GFA-class vehicles have now flown including a Giant Foamboard Quadcopter (6.3m frame size) (see Figure 1).

The society chose to differentiate itself from other engineering-related societies that primarily focused on participating in competitions. While the competitive aspect is motivating, it does not motivate everyone, particularly those more

[†]see www.giantfoamboardaircraft.com for flight video

interested in creativity and outreach opportunities. The goals of the new society were thus to:

- Cultivate engineering creativity by exploring extraordinary design ideas and methods of social building
- Develop aerospace outreach activities that would inspire the next generation of scientists and engineers
- Create an inclusive environment that prioritizes learning by sharing knowledge with others.

A timeline showing the development of the Crowd-Build Aircraft project and the impact of the formation of the Giant Foamboard Aircraft society is shown in Figure 13.

The GFA society developed an outreach programme in collaboration with 13 secondary schools in the Greater Manchester area based on a one-day workshop and a longer-term school-build project focused on a specific GFA part. The latter proposal aimed to support already running STEM clubs, with a University of Manchester undergraduate student remotely managing the building project. After the academic year, various parts from different schools would be brought together to be assembled and flown. The society participated in a STEM outreach day held at Khizra Community Hall in Cheetham Hill, Manchester. During this event, the society engaged with the public (mostly children under 14 years old) and provided basic aircraft anatomy lessons using gliders, Figure 12.

Fig. 12 GFA society stand at a community STEM event

Running a new society at The University of Manchester and organising outreach events have provided valuable lessons to the student committee running the society. Reflecting on this experience, several key lessons have are identified:

- Emphasizing inclusivity within the society is crucial. Providing opportunities for groups of people generally under-represented in STEM organisations is vital in motivating the next generation of aerospace engineers. By creating a diverse and inclusive environment, we can promote active participation and ensure that all individuals feel welcomed and encouraged to pursue their interests in the field.
- Striking a balance between providing support and fostering independence among participants is important. While volunteers play a key role in ensuring the smooth progress of build events, participants must be able to take ownership of their learning experience. Allowing them sufficient time and space to assemble items themselves and problem-solve encourages their development of practical skills and enhances their overall engagement with the project.
- Reflecting on the schools build day, it was observed that the children often completed tasks faster than more experienced learners, possibly because they were less worried about making mistakes. This creative momentum needs to be prepared for in future build events with younger children.
- As a leader, it is important to foster a collaborative environment where team members support and rely on one another. Leaders should delegate responsibilities and avoid shouldering all the tasks themselves. Encouraging every team member to contribute ideas and actively engage in problem-solving enhances the overall creativity and productivity of the team.

These lessons will guide future endeavours, ensuring the promotion of inclusivity, independent learning, efficient resource utilization, effective event promotion and fostering a strong sense of teamwork alongside individual engagement. The GFA model stands as a valuable benchmark for other new student-led STEM societies and collaborative organisations in general. From conception, it was decided that there would be an emphasis on ensuring a high degree of diversity amongst the society leadership - not just in terms of personal background but also field of study and experience. An organisation diagram for the society is shown in Figure 17. It is common in aerospace-based societies for the leadership team to be comprised of mostly of aerospace engineering students in the later years of their studies whereas many of the GFA committee are first or second year students and several study civil, mechanical or electrical engineering. It is also noted that the GFA society has a higher proportion of women in leadership positions compared to many of the more competitive engineering societies previously mentioned. Women tend to exhibit more balanced reasoning in their decision making than men and a greater number of female leaders in an organisation is often shown to improve collaborative performance [11].

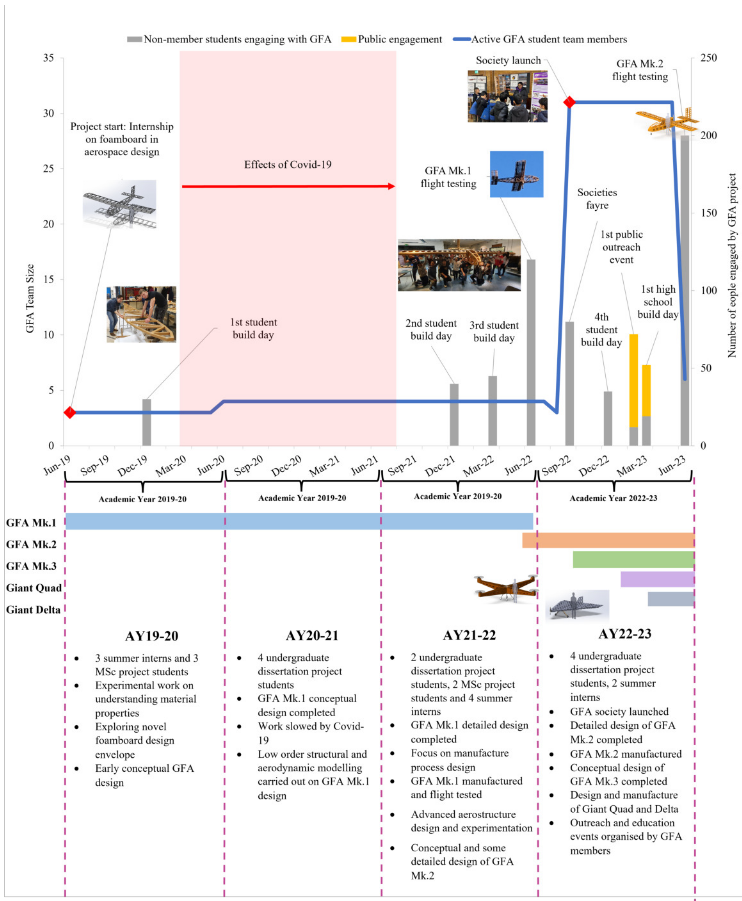

Fig. 13 Crowd-built aircraft project time line showing formation of the Giant Foamboard Aircraft student society and its impact on engagement and outreach

V. Crowd Build Events

Several crowd-build events have been hosted by the project since its conception. These have proven to have a high impact on the participants and resulted in the manufacture of components of a sufficient quality to be used in the primary structure of an aircraft. Each successive build day allows the project organisers to gain a deeper understanding of the process and optimize techniques to such an extent that the manufacture time of a GFA-class aircraft has decreased by an estimated three orders of magnitude since the first attempt. Crucial to this effort is the enthusiasm and valuable feedback of the volunteer participants. Though perceptively trivial, an important aspect of participating in a GFA build day is that every volunteer writes their name on a component that they built - this enhances the sense of contribution and ensures the final vehicle is immediately identifiable as a collaborative effort.

Key requirements of a successful build day are as follows:

- Minimal training should be required for inexperienced volunteers to complete tasks
- Where direction is required from supervising project members, this should mostly be top-level guidance as opposed to controlled step-by-step instruction
- All participants should learn something new about aircraft architecture, structures, materials, manufacturing or other applicable engineering field, no matter their level of engineering experience
- Where resources allow, the event should conclude with all primary structure assembled (this is just as much about impact as it is about productivity)

Pilot Event

The first crowd-building workshop involved a group of around 30 undergraduate volunteers. No laser cutting or pre-fabrication was carried out in advance and workers were cutting components from blank sheets of foamboard by hand using stencils. Originally, the wing spar was manufactured by layering whole sheets into a billet and cutting the desired profile from the solid block. The relatively complex internal geometry of the wing ribs also had to be cut by hand. These two tasks proved to be far more time consuming than initially predicted and so the first build of 8 hours resulted in only a partial wing structure being completed. After this attempt the decision was taken to laser cut the majority of components prior to build days. This required splitting the spar geometry into pieces which could be stuck together to form the individual laminae which were then carefully layered to create the complete spar.

Undergraduate Crowd-Builds

Following the pilot event, three more build days were held with undergraduate volunteers - in the final event all of the primary structure of the GFA Mk.1 flight vehicle was assembled in a single day. Each build allowed new designs and methods to be trialed and more in-depth understanding of the process was gained which contributed to the significant streamlining mentioned. Aside from the technical work, build days gave the opportunity to observe the more abstract benefits of crow building. Undergraduates showed great enthusiasm for the project and several volunteers commented that they felt a strong sense of pride in contributing to something so visually and technically impressive. The simplicity of manufacturing methods plays a large roll in ensuring universal accessibility to the project - this is a cornerstone of the inspirational impact GFA has on participants. Manufacturing large aerostructures is not something most undergraduates have the opportunity to do so the event also serves as a practical application of their regular studies. Furthermore, the parallel manufacturing process adopted in these events and the advantages and drawbacks thereof provide an excellent representation of industrial production. It is established that low-order, high throughput manufacturing techniques can serve as a valuable teaching aide in engineering [12]. Images of the undergraduate workshops can be seen in Figure 14.

GFA Mk.2 High School Student Build

March 2023 saw the first major involvement of an external organisation in the GFA project when a high school local to Manchester was invited to bring a class of Year 9 pupils to the University to participate in the first GFA Mk.2 build. The build was led by undergraduates in the GFA society who were each responsible for a small group of pupils and a specific build section. A much higher degree of preparation was required for this event and some of the more time-consuming components were pre-fabricated. This was necessary due to a lower number of workers and shorter workshop time window than previously available, not to decrease difficulty of the task. The pupils were extremely eager to engage with the task and the manufacturing methods remained accessible. In fact, it was noted that the young students had better dexterity with the craft knives and glue guns than undergraduates as they used them more regularly at school than an average university student would.

Equally as important as building the structure itself, the activity gave the opportunity for school students to interact with the supervising undergraduates in a dynamic and informal setting. As the build was going on, pupils were taught some basic principles of aircraft anatomy and design and they were asking undergraduates about their experiences of engineering at higher education. Furthermore, undergraduates had a rare opportunity to explain concepts they had been taught in their studies to people with no prior knowledge - this is an important skill for any engineer.

This event is, to date, the most significant validation of the primary GFA objectives - both accessibility of simple manufacturing and efficacy as an educational platform were well established. Feedback both on the day and in subsequent communications was excellent and staff and students felt that all participants had benefited greatly from the experience. Equally as important, the event resulted in successful manufacture of several major pieces of primary structure for the previously untested GFA Mk.2 design. Photographs from the workshop are presented in Figure 15

Following successful flight testing of GFA Mk. 2 at the Snowdonia Aerospace Centre in June 2023, several undergraduates visited the Dixon Brooklands Academy to give a presentation to the pupils who had built the aircraft as well as some of their peers. For enhanced impact, the aircraft was transported to the school and assembled in front of the high school students. The purpose of this visit was to show the pupils the subsequent work that had been carried out on the airframe to make it airworthy (i.e. installation of control systems) as well as giving them an overview of how flight testing was conducted. A large segment of the presentation focused on the issues encountered and mistakes made during flight testing and how these were overcome. This visit served as an impactful conclusion to the GFA Mk. 2 sub-project and contextualised the the students' manufacturing experience into a complete engineering project. The students were eager to inspect their finished aircraft and asked many questions about the new components they could see.

Testimonials

Jack Leask, Teacher at Dixon Brooklands Academy

As a teacher, I am always encouraging my students to take risks and try new things in the hope that they learn something but sometimes schools don't offer these spaces for students to do this. The GFA project is an amazing thing for any young learner to take part in - the educational value of the whole project is massive. For students to be a part of an engineering project like this is fantastic.

They were able to learn how this type of work is done, speak to professionals and undergraduates with a deep passion in what they do and be exposed to what university life has to offer. Speaking to these people and being at the university sparked an enthusiasm and interest in many of the student who were there. I had at least 6 students tell me that they wanted to do some form of engineering at the university after the day. To achieve something like this and see the final outcome really made the students think about life after school and really sparked an interest in their future careers.

Dr John Flemming, Teacher at Dixons Brooklands Academy

The build day was excellent, the way it was structured and the opportunity it gave our students to problem solve, talk to professionals and use the comprehensive facilities at the University. The students were buzzing. . .

Zahran Ayub, GFA Mk. 2 Project Manager

I enjoyed the day immensely. Seeing all the names of every school student who took part was extremely rewarding. We can't wait for these names to take to the sky in June!

Dixon Brooklands Academy Students

- *"The skills I learned on the trip could help me go into a form of engineering or STEM."*
- *"I enjoyed learning about all the different parts of the plane I didn't know before. I enjoyed helping with the building of the tail boom."*
- *"It has made me want to do a job like this. I'd like to be a mechanical engineer."*
- *"I enjoyed talking to the people helping who were very experienced."*
- *"The most valuable thing about the experience is being patient and at the end seeing a plane that we made."*
- *"It has definitely opened different options in the world of work which is useful."*

Fig. 14 Undergraduate Crowd Build Day for GFA Mk.1

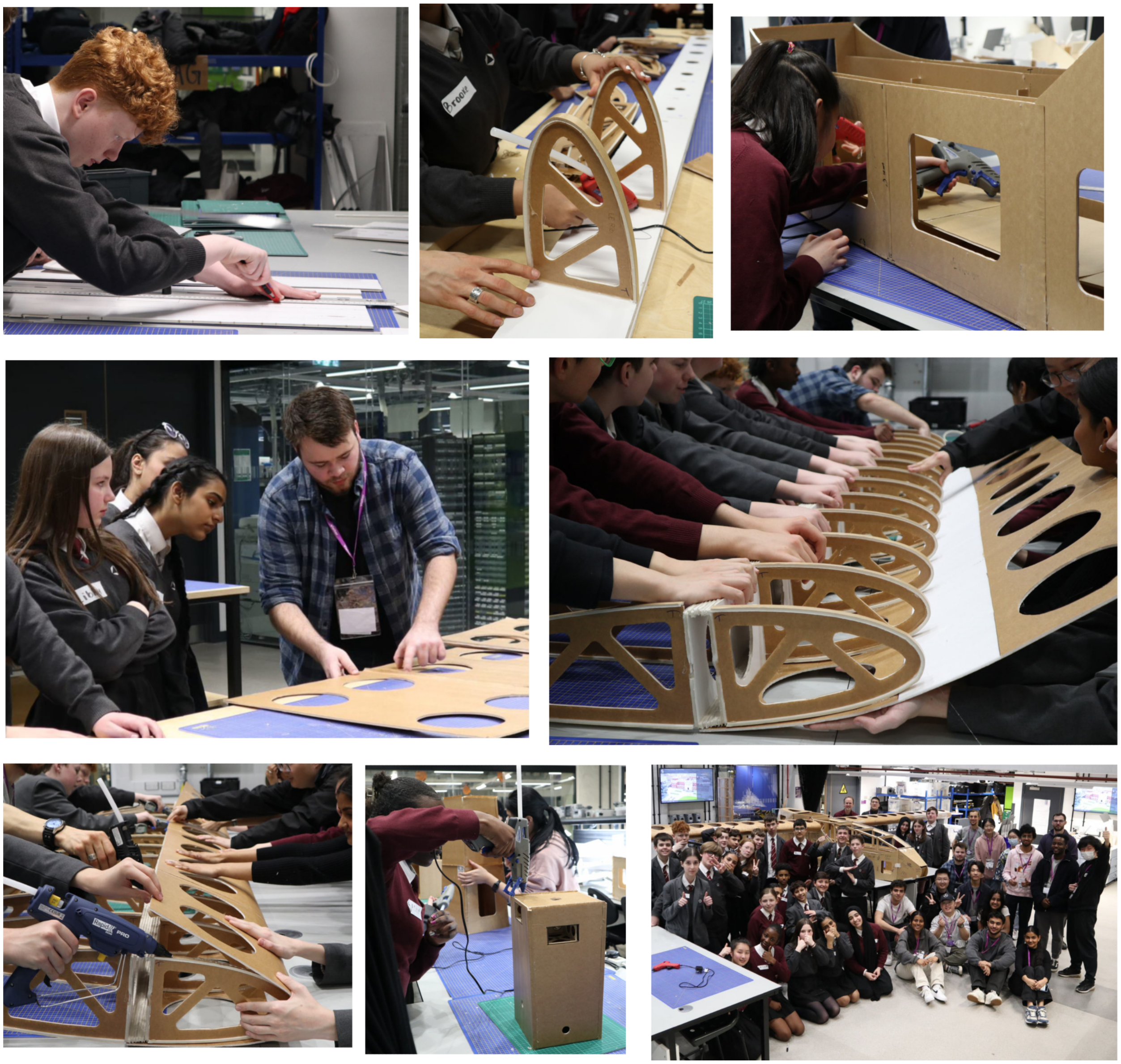

Fig. 15 GFA Mk.2 Crowd Build Day for Year 9 (8th Grade) High School Children

VI. Conclusions

1) Adventurous aerospace structural design can be successfully used as inspiration for engagement with aerospace. Whilst more recent developments in autonomous systems and associated technologies have informed many new aerospace competitions, there remains a broad audience that can be engaged by the opportunity to physically build extraordinary aerospace vehicles. Furthermore the build aspect gives means to engage learners much earlier on than undergraduate level, which is where many current aerospace competitions are aimed.
2) Foamboard has been properly characterised as engineering material and a range of manual and digital craft technologies have been developed for manufacturing large optimised aerospace structures using foamboard as the primary load-bearing material. Whilst foamboard has long been used for making model aircraft largely designed and built based on heuristic knowledge, the GFA project has applied formal engineering design and analysis methods to exploit the performance of the foamboard material to its limits and create structures unimagined by heuristic approaches.
3) A new class of model aircraft has been created based on the objective of maximising vehicle size for a given

weight classification, leading to very large aircraft with very low wing loading, as exemplified by the GFA Mk.1. This aircraft is similar in size to a small light aircraft, but a mass of only 20 kg, giving a stall speed of around 7 m/s (14 kts). The aircraft primary structure is principally foamboard, but with plywood used to simplify design and manufacture of highly loaded parts.
4) A new student society at the University of Manchester has been successfully grown around the crowd-built aircraft concept. The society has a distinct mission to other engineering societies at the University in that the primary technical objectives are less about competition and more around creativity, education and outreach. It is notable that the society membership and leadership is significantly more diverse than many of the other engineering societies.
5) Several crowd-build events have been hosted for undergraduate and postgraduate students which ultimately led to the complete build of a flight-ready airframe of the GFA Mk.1 in a single day by around 50 people. As a more challenging task, a build day was successfully undertaken by 30 high school children who completed a flight ready airframe for the GFA Mk.2 aircraft in a day. Key to successful build days for participants at any level is that attendees are able to build components of primary structure in a self directed way with a minimal amount of training and supervision. The symbolic act of writing your name on a component you have built creates future buy-in when the aircraft is flown. The key to successful organisation of build events is technical preparation such that participants can focus solely on the manufacturing task in front of them. A key barrier for more experienced participants to overcome is fear of making irreversible errors in manufacture. This is mitigated as far as possible by making the design simple and making parts only fit in the correct orientation.

VII. Acknowledgements

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Appendix

(a) Original nose

(b) Nose cut from fuselage

(c) Construction of extended nose structure

(d) Completed fuselage

Fig. 16 GFA Mk.1 nose extension surgery to correct aft centre of mass problem due to unaccounted for glue mass

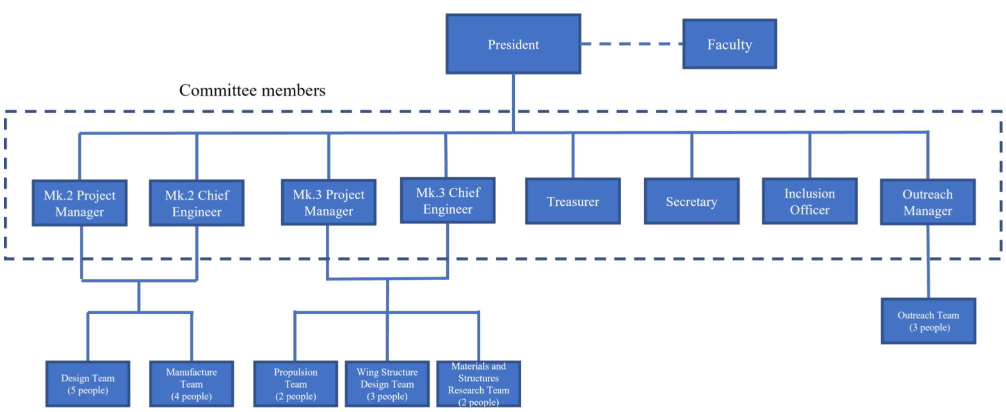


Fig. 17 Organisational structure of GFA society

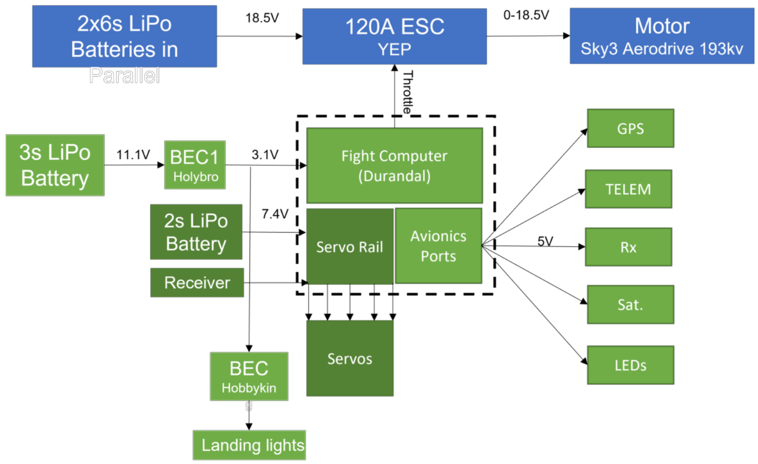


Fig. 18 GFA Mk.1 System Diagram

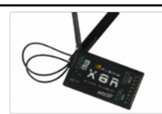
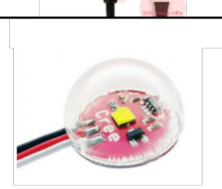
Component	Model	Image	Specs
Motor	Turnigy Aerodrive SK3		Voltage: 10~12S LiPo RPM/V: 192KV Max Loading: 80A Max Power: 2850W Weight: 858g
ESC	YEP 120A HV (4~14S) Brushless Speed Controller		Max Cont Current: 120A Max Burst Current: 140A (10 seconds) Input Voltage: 4-14S Li-Po Size: 68x53mm Weight: 164g (including wires)
Servos	TowerPro MG946R Metal Gear Servo		Weight: 55g Speed: 0.20sec/60deg (4.8v) - 0.11sec/60deg (6v) Torque: 10.5kg.cm (6.0v) - 13kg.cm (6v) Dimension: 40.7*19.7*42.9mm
Flight controller	Holybro Durandal		On-board sensors - Accel/Gyro: ICM-20689 - Accel/Gyro: BMI088 - Mag: IST8310 - Barometer: MS5611 Servo Rail Input: 0~36V Dimensions:80x45x20.5mm Weight: 68.8g
Telemetry radios	RFDesign - RFD 868x v2 Radio Modem		Frequency Range: 868-869 MHz Output Power: 1W (+30dBm) Receive Sensitivity: >121 dBm Size: 30x 57x12.8 mm Weight: 14.5g Power Supply: +5 V nominal
Receiver	FrSky X8R		Dimension: 46.5mm x 27mm x 14.4mm Weight: 16.8g Operating Range: >1.
	Motor: 2x Turnigy 6S LiPo Battery		Minimum Capacity: 5000mAh Configuration: 6S1P / 22.2v / 6Cell Discharge: 40C Pack Weight: 805g Pack Size: 144x51x56mm
Batteries	Servo rail: 1x Turnigy 2S Lipo Pack		Minimum Capacity: 800mAh Configuration: 2S1P / 7.4v / 2 cell Constant Discharge: 30C Pack Weight: 59g Pack Size: 55 x 30 x 18mm
	Flight controller: 1x Overlander 3S LiPo Pack		Minimum Capacity: 2200 mAh Configuration: 3S1P / 11.1v / 3 cell Constant Discharge 35C Pack size: 101x33x23mm Pack weight: 169g
GPS Module	M8N GPS		167 dBm navigation sensitivity 25 x 25 x 4 mm ceramic patch antenna Diameter 50mm total size Weight: 32 g
Lights	Strobon V2 Cree Edition Navigation Strobe Light		Supply Voltage: 3.5 - 6 volt Current Consumption per hour @5V Strobe: 100mA (1.5A when flashing) Blink: 110mA (250ma ON) Static: 200mA Dimensions: 21.5x13mm

Table 3 GFA Mk.1 systems components specifications