PEEMS
Pickering Experimental Engineering & Model Society

NEWSLETTER July 2022

Hello Everyone,

I trust you are enjoying our long-awaited summer and idyllic balmy holidays. I have a few things to report so bear with me before you get to the “meaty” part of the Newsletter.

PEEMS was well represented at Ken Hillier’s funeral. Afterwards I talked to one of Ken’s oldest pals from London, and he told me how Ken talked enthusiastically about us, and what a good bunch we all are with our variety of interests.

CaVCA had an open day at the Hungate Centre and invited us to have a couple of tables to promote ourselves. Thanks to all who helped, but I think there were more of us than there were visitors!

The ‘Bring and Brag’ was a good night but was a little short on content, and consequently finished a bit earlier than normal. Quite a bit of effort goes into organising the evenings, and we never know what the turnout will be. When we do not have a guest speaker on the evening, please feel free to join in and ask questions and help promote a bit of banter, especially in the second half.

Looking forward to the Mike Sayers Trophy night on the 7th September, if you wish to display any photographs on the projector screen, they will need to be on a PowerPoint Presentation. This is easy if you know how (I don’t), but Mike is willing to help you. All he needs are the photos emailed to him. Use a mobile phone or a tablet, or ask me, and I will get the photographs to him in the correct format. Please ask Mike first before bombarding him with work!

That is about it for now, take care.

Kind Regards, Jonathan.

☐ **Forthcoming Events.**

- **Wednesday 3rd August: Club Meeting. “Engineering Failures and Lessons Learnt (or ‘Tales From The Scrap Bin’)“**. A chance for members to discuss some of their project failures and the lessons learnt by those failures.
- **Tuesday 16th August: Workshop Morning.**
- **Wednesday 7th September: Mike Sayers Trophy Evening**
- **Tuesday 20th September: Workshop Morning**
- **Wednesday 5th October: Club Meeting:** Ivan Shaw will give a talk on the flight testing of his ‘personal’ aircraft G-SEKR.

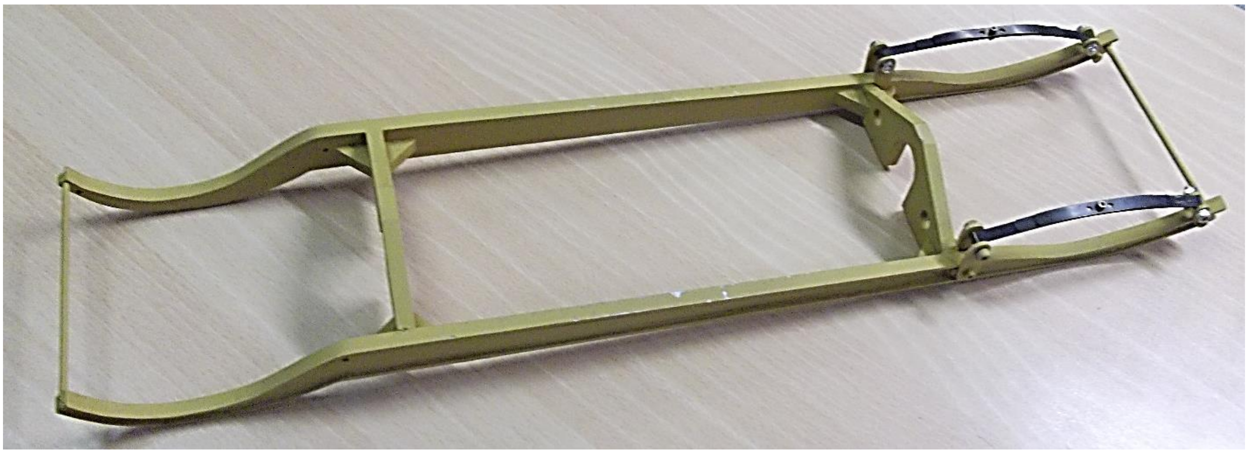
Photo Copyright Ivan Shaw

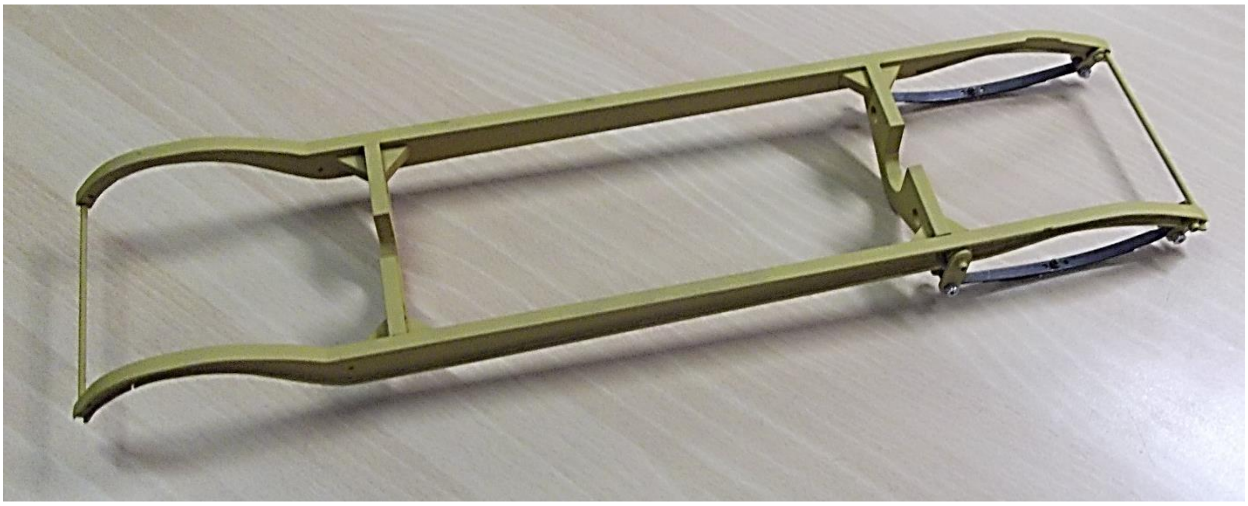
Ken Hillier.

PEEMS would like to extend their condolences to Anne and the rest of the Ken's family on his sad passing. Ken was a valued member of the Society and will be missed.

☐ **Club Meeting Wednesday 6th July ~ 'Bring and Brag'.**

- **A Chassis For A 1/6th Scale 4½ Litre 'Blower' Bentley Model ~ Iain Hale.**





This is Iain's first serious project, a 1/6th scale 4½ litre "Blower" Bentley, and he brought the chassis in for examination.

The method of construction of the aluminium chassis is interesting as the components have been jointed with structural acrylic adhesive and then with brass pins. The aluminium parts have been milled to shape.

As presented, the springs at the front of the chassis were bolted, but the intention is to use press fit bars at the final locations. The reason the cross braces are wide apart is because the model will eventually be radio controlled with a sound system. It will be electrically driven, and Iain will not be building a scale model engine and gearbox for it!

The approach was to buy a commercial 1/24th scale model and up-scale all the components by a factor of 4 to end up with a 1/6th scale model.

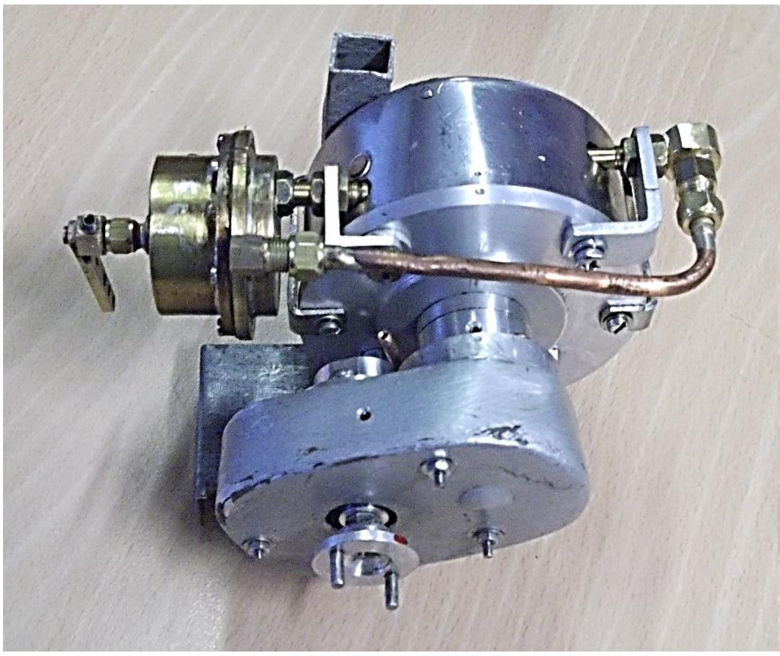
Iain found a kit of wheels which are the correct size. The wheels are supplied with a centre hub, and the spokes have to be installed by the modeller. The springs on the model were commercially made.

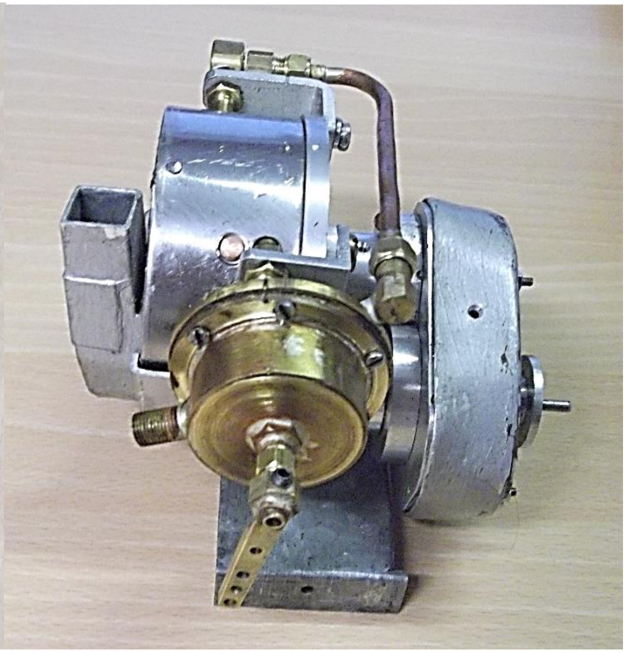
- **Continuing Development Of A Steam Turbine ‘Manoeuvring Engine’ For A Steam Launch ~ John Heeley.**

  - **Introduction**

At the May 2022 Club Meeting, John was discussing his steam launch progress and the future design idea of a ‘manoeuvring engine’, which would drive the launch forward, stop and then reverse. John has sent an article to *The Model Engineer* magazine about his steam turbine. However, the article does not cover the ‘manoeuvring engine’ shown at the Club evening.

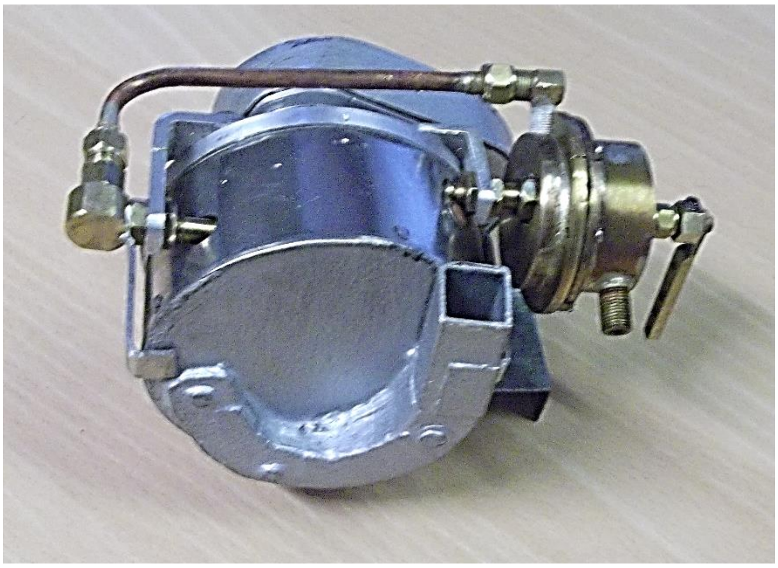
This ‘manoeuvring turbine’ has been developed over two months.





These photos show the ‘manoeuvring steam turbine, with the ‘Free Flow Valve’ which directs steam flow either into the forward powering Stumpf wheel, or into the reverse powering Stumpf wheel.

Note: the forward and reverse Stumpf wheels are contained in the same ‘can’.



  - **Description Of The Manoeuvring Engine.**

The manoeuvring engine is now set up with two turbines, one for forward and one for reverse. They are both on the same shaft.

The reversing turbine is a 2½” diameter disk and the forward is the original 3” diameter disk. The idea is to have clear space to get the exhaust off the turbines after they have ‘done their thing’. This system seems to work well.

  - **Experiments With The New System.**

For the first iteration, the turbine assembly was made up on the rotor, and it was put back in the boat. It was operated with the standard pipe going straight to the forward turbine jet only. This was done to see what losses occurred. In John’s assessment, 5% to 10% efficiency was lost by having the turbines revolving in the same ‘can’ (housing). John thinks these losses are down to the increased weight. It took quite a time to spool up because the revolving mass is about 75% heavier than before. It also takes longer to spool down. For this first iteration, this 5% to 10% loss of efficiency was considered acceptable.

The setup had a blind slot (i.e. it didn't go all the way through) through which the steam was fed in the back, and it would feed forwards or backwards. This meant that the steam had to pass through the slot and then go through 180° to turn each directional turbine. It didn't like it. Both directional turbines ran alright, and it stopped and started, but the power was substantially down. Steam doesn't like to go around corners, it wants a nice easy flow to the turbines.

This was the reason for the second iteration, known as the Free Flow Valve" (FFV), which is shown in the photos. This stage introduced a valve, so that the reversing turbine could be coupled up. The inlet feeds directly off the control valve. The control valve is basically a tube with a flange on, and a blank end which forms a 'top hat'. This is like a plenum. This contains a sealed gland where the control rod comes out. The steam is still coming from the superheaters and then it will go into the jet without too much restriction. The steam still passes through 90° but this design works a lot better.

In order to fit the valve onto the turbine, the turbine needed to be moved across the boat with the assembly having to be also rotated in order to fit it all in the width of the hull. The lubrication for the layshaft now has to go through a 'U' shaped pipe on the top. The turbine is very free running.

- **Operations.**

This engine has been running in a boat for half an hour. The engine is running at 75% of the efficiency that was achieved with the steam connected directly to the turbine. There is definitely a loss in performance.

The engine is a 'manoeuvring engine', but will travel forwards quite a distance before it reverses. Even after turning the steam off, the boat will travel 25 yards. There is inertia in the system. The movement of the boat turns the propeller, even after the steam is turned off, which in turn turns the rotor, the inertia of which keeps propelling the boat. It's almost an energy storage system.

The turbine makes an amazing noise when switching from forward to reverse. The noise then steadily decreases until all you can hear is the steam hitting the individual Stumpf wheel pockets. Then it goes quiet. It's quiet for 5 to 10 seconds, and it spools up in reverse. It reverses satisfactorily.

The conclusion is that the boat cannot really be manoeuvred with this type of engine, especially one that is radio controlled.

- **Some Ideas For Improvements.**

This project has been interesting to do, but whether it has been worth the effort is another thing. John wants to 'take time out' to really think the way forward.

i) Weight Reduction: One thing that needs doing is reducing the weight of the revolving mass of the two turbines, and hence the rotational inertia. John doesn't want to drill holes in them. However, the back of them can be recessed, producing a ⅛" disk with a ⅜" flange and a boss in the middle. That would save weight and improve the speeding up and the slowing down of the turbines between forward and reverse.

ii) A New Boiler: The long-term plan is to make a new boiler capable of producing more 'weight of steam'.
The current boiler is happy to go up to 50 psi, but it won't hold it. It's actually operating at 35 psi, and 35 psi is as much as it can maintain continuously. John would like to maintain a minimum pressure of 50 psi with an upper end of 75 psi.

The turbine will be installed with a centre flue boiler with cross tubes which will work with a blowlamp. It's not particularly efficient, but at least there is maximum heat transfer. That's the only way to get some decent steam pressure.

A larger more efficient boiler is required to give more steam pressure over longer periods. When John is running the boat on the pond, and starts the steam with the remote control, and waits a little while, the steam builds up and when 50psi is reached the safety valve blows. There is the expectation that a high-speed run will occur, but unfortunately that doesn't happen. All it does is spool up faster, but by the time it's spooled up, the pressure is back at 35 psi and it then travels at its normal speed. It definitely needs a larger boiler and fuel other than methylated spirits.

iii) The Free Flow Valve: Even with the FFV there is still a loss in efficiency. If the lever is removed and the steam pipe is attached straight onto the jet, there is a difference that can be seen. About 20% to 30% efficiency is lost by having the FFV. John wants to link this to a single servo.

There is an intentional 'slack' in the FFV. The valve has a slot across it. A cross bar goes into the slot, and has some movement in the slot. When the radio controller selects full forward, this cross bar comes back to its natural middle position, (and the R/C lever comes back to neutral) and the boat is still running forward. Similarly, in reverse the cross bar comes back to its original middle position (and the R/C lever comes back to neutral) and the boat is still reversing. It's taken quite a time with an air compressor to get this to work.

The turbine spools up in water quite well. Two drops of 2-50 motor oil through a hole onto the gears will stop it, but put it in water with a 2¼" coarse pitch propeller it works fine. It's mysterious how it works. It's always spooled up in water, in both forward and reverse directions quite satisfactorily.
John has gone away from WD-40 for lubrication and has his own patent mixture of 10% motor oil to 90% paraffin, which is as 'thin as water'. It runs satisfactorily with that.

iv) A New Boat: John is going to build a new boat. He now has a method for boat building ~ "30 days and 30 quid" to get a hull. That is then painted. The existing boat has a very flat bottom and is very 'sharp' at the bottom of the bilges where there is little curvature.

For the new hull there will be a 'bread and butter' construction for the last two planks at the bottom, cutting the middle out. That will give the option of curving the bilges in. The hull will be wider and curvier, allowing the engine to sit in the middle comfortably. The hull will have no internal structure or a 'keel' as before. It's a '*stressed skin monocoque'.* The curved hull, maybe with bilge keels should provide better handling and response than the current flat-bottomed boat which is harder to control in a turn.

John will install his reciprocating 'V' twin in the existing hull and continue to run it like that, as it was originally running with current boiler. The existing boat will stay like that as a complete working unit, and John will have a new boat, with the new boiler and turbine.

- **In Conclusion**

  The hope was always for the boat to run as efficiently as a reciprocating engine, and the turbine is not winning on that score. It's not far off, but it's not there yet.

Questions And Answers.

Q: Is part of your experiment to continue with a reverse running turbine, or could you maintain your efficiency with a forward turbine and a reversing gearbox?

John: The turbine will still have to be stopped to engage reverse gear.

Q: Couldn't you have two crown wheels on the same shaft and move the pinion over?

John: You still have to stop the turbine spinning. You can't engage reverse with a gear that's already revolving whether that's using a dog clutch or a tumbler. A reversing gear box is a possibility though, but I would need a brake on the turbine. My son says, just put a brake on the turbine so you can pick up reverse straight away (rather than waiting for it to stop). I thought that the sudden application of steam to the reversing turbine would act as a brake. It does to a degree, but it still takes time. There is a time elapse before it picks up in the other direction. Even if I could stop the forward turbine, and then immediately start it up in the opposite direction with the reverse turbine, it would still need to spool up. It takes 15 to 20 seconds to spool up to usable power.

Q: Couldn't you use a variable pitched prop to go from forward to reverse? With a reversing prop, that means you won't have to slow the turbine down at all, you just switch the blades.

John: Yes, a variable pitch prop is an option. I've thought about that for some of my other steam engines which I don't have any control over, with either direction and start and stop. That is a possible option.

The reverse pitch prop is probably the sensible way to go. I could also use that with the other steam engines. All my other engines aren't run with control gear. They just run in one direction and they're not self-starting.

Q: Could you use a tumbler with rubber tyred wheels?

John: Yes, you would need some type of friction, but whether there would be too much loss, I don't know. As demonstrated, the turbine moves incredibly freely in order for it to spool up to a reasonable torque. If I could throw 80 psi of steam at the reverse turbine, instead of the 35 psi at the moment, that is going to improve the reversing speed and provide more braking.

Q: With 50 psi, the turbine will be moving forward faster, but won't it still take an equal amount of time to slow it down when selecting reverse?

John: I agree, but I have a gut feeling that it will slow down faster under greater steam pressure. The new centre flue boiler (made from copper) with cross tubes will be better than the existing externally fired water tube boiler for which only half of the surface area of the drum is a heating surface. There's no real heat at the top. There are baffle plates in it to try and get maximum efficiency, but it's never going to be as efficient as an internally fired boiler where the copper tubes with steam in and are surrounded by water, and hence have greater surface area for heating.

Q: Have you considered a flash steam boiler like the one Paul Windross is building?

John: I'm reluctant to go to a tube boiler. Flash steam boilers do work with steam turbines. You've got to arrange some drive so you can feed water in, and it's the quantity of water that is fed into the flash steam tubes that dictates how much steam you get out.

Basically, Paul's boiler is a wound stainless-steel tube with a blowlamp system down the middle. Everything is controlled by how much water is squirted into the red-hot tube. It flashes into steam straight away and feeds it. For the turbine, I need a feed mechanism driven from the engine, and this has to be variable so I can control how much goes through. I don't think I need this type of super speed boiler. The whole idea of this project is that anyone can go home and make one next week.

Q: The energy that comes out of methylated spirits will be limited; would more heat energy be generated with say, petrol?

John: The problem with that is that there will be a lot of soot.

Q: What I meant is can you use a fuel that has a better calorific value than meths?

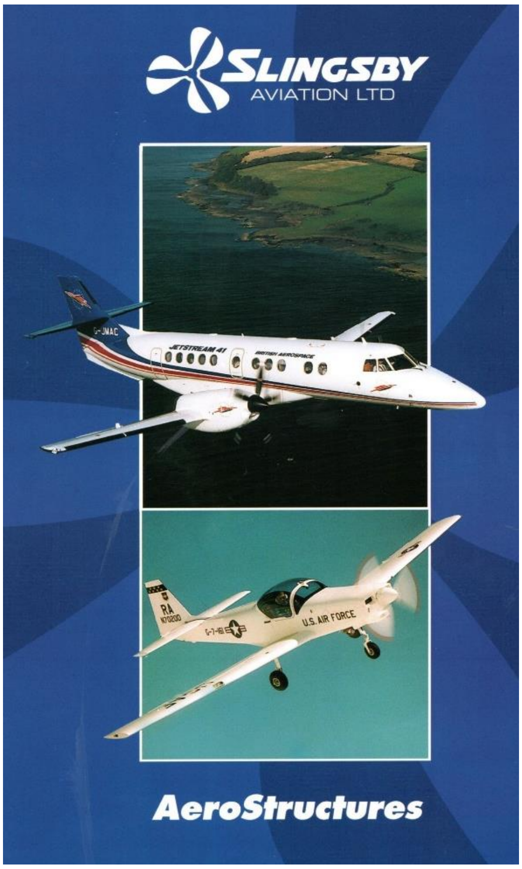
John: I was talking about the soot deposits. I can run it on paraffin, but the trouble is that after half an hour's running, such a quantity of coke is built up inside, the efficiency starts to drop. The beauty of methylated spirits is that it burns clean. There are almost no soot deposits in the first half dozen runs, and there is 'clean copper'. It is black now because the 'wicks' are burning. These are actually rolls of torn up blanket under a metal gauze. Someone suggested I try Fibreglass, but that melts, so that's no good. I coiled up some lamp wick but that's no better than the blanket.

I run the boat for half an hour, then I turn the blanket rolls over, to give a clean top again. I then get another half an hour of running. I then dispose of the blanket rolls. So far that's been the best way to go about it.

Q: Have you considered running it on gas? There are screw-on canisters that can be laid on their sides. They are used for gas camping stoves, and cost 'a tenner'. They have a regulator on them and a spark system for lighting. It's liquid gas.

John: Yes, if I build this centre flue boiler, with a blow lamp, it will probably be a gas fired blow lamp. You can get screw on blue canisters for picnic stoves. All you need is a swan neck tube on the top and give it a bit of length, to bring the burner down.

☐ **The Environmental Degradation Of Composites Under Hot And Humid Conditions ~ Nevile Foster.**



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The latest record breaking hot (and humid) conditions in the UK, led to discussions about how composite structures, especially for airframes, will degrade over time due to moisture driven into them by heat.

I was involved in carrying out some experiments to determine if the moisture uptake of the glass fibre structures of the Slingsby T67 Firefly Aerobatic Aircraft and the BARA++ Jetstream 41 Regional Turbojet Ventral Baggage Pod would lose their structural integrity due to heat and moisture uptake during their quoted life times.

Slingsby Aviation designed and built the Ventral Baggage Pod as a main contractor to BARA.

Typical aerostructures are designed for 25 year lifetimes.

The following is a talk and paper given to *The Institute Of Mechanical Engineers* in 1998.

++ BARA: British Aerospace Regional Aircraft.

Designing Composite Structures For Optimum In-Service Performance With Reference To The Slingsby Aviation's T67 Firefly Aircraft And The BARA Jetstream 41 Baggage Pod. ~ Nevile Foster.

- **Introduction and Synopsis**

When designing high quality composites that are optimised for cost, weight and durability, the advantages and disadvantages of the materials used, must be considered. This paper will discuss problems expected in a composite structure's life, as well as the airworthiness certification of composites. In the last twenty years of Slingsby composite design and manufacture, no noteworthy in-service problems have occurred. The emphasis in this paper will therefore be on how potential in-service problems are covered by careful design and testing.

The discussion of in-service performance of composites will concentrate on Slingsby Aviation's experience with the design, testing and manufacture of the Firefly all composite aircraft. The Firefly is a two seat aerobatic training aircraft, which is manufactured using glass fibre and hand wet layup techniques.

Reference will also be made to Slingsby test data relating to the performance of glass/Kevlar/Nomex honeycomb structures. This type of structure is used in the ventral baggage pod for the Jetstream 41 aircraft.

- **A Brief Outline Of The Composite Materials Used In The Slingsby T67 Firefly Aircraft And The BARA Jetstream 41 Baggage Pod.**

Before discussing the in-service performance of aviation wet layup composites, the primary structure for the Slingsby T67 Firefly aerobatic aircraft, and the BARA Jetstream 41 baggage pod will be described. The Firefly (ref Fig.1) is a two seat aerobatic aircraft certificated to +6G and -3G, and the Jetstream is a regional turboprop aircraft with the composite baggage pod attached under the fuselage.

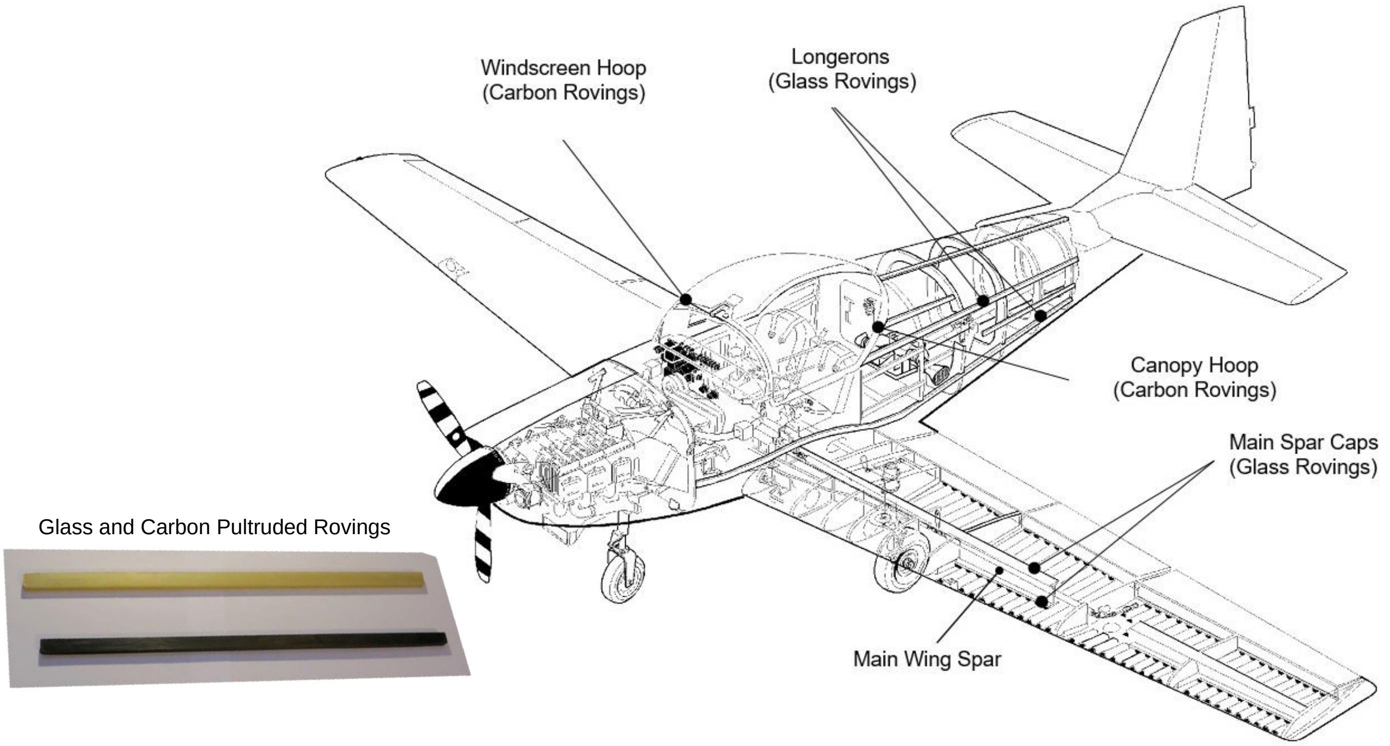


Fig 1 Structural Components Manufactured Using Pultruded Rovings

- **T67 Aircraft Skins Frames And Ribs**

The skins, frames and ribs of the aircraft fuselage, wing, tailplane and control surfaces consist of plain and twill weave glass cloths, wet layed up with epoxy resin. As these items are primarily loaded in shear in the plane of the component, the cloths are orientated at ±45° to maximise shear strength and stiffness.
The plain weave glass cloth consists of warp rovings (each roving consisting of a bunch of parallel glass fibres), running the length of the roll, with weft rovings at 90° to the warp, passing over and under each successive warp fibre. Plain weave cloths are often used for flat surfaces.

Twill weave cloths are often used where drapability is required. Twill weaves consist of pairs of weft yarns, passing over and under parallel warp yarns.

Wet layup composite laminates are produced by laying successive dry cloths of glass fibre, carbon fibre or Kevlar aramid fibre in a mould. Each cloth is impregnated with resin prior to laying in the next cloth. The fibres reinforce the surrounding resin matrix and the resulting laminate can carry tensile, compressive, shear and flexure loads. The resin matrix gives the composite laminate its rigidity, and during service protects the fibres from moisture or chemical attack. For aviation products, the epoxy resin system (162/113 Epikote/Epikure is used on the T67) is favoured, as there is much less distortion and dimensional change during cure than with polyester resin.

The resin comes in two liquid parts, a resin and a hardener. Once the hardener is mixed with the resin, a chemical reaction occurs and the mixture begins to solidify. Once the resin has hardened, post curing at elevated temperature is required for the resin to gain its full strength. Post curing is performed in a hot box, the cure cycle being 8 hours at 42°C and 16 hours at 78°C ±2°C. This results in a glass transition temperature around 92°C.

The moulds in which laminates are layed up, are also manufactured from glass cloth and epoxy resin and contain slate powder to give the mould surface high durability.

- **Wing Spar Caps and Fuselage Longerons**

The fuselage, wing, fin and tailplane of an aircraft are essentially beams loaded by inertia and aerodynamic forces which result in bending moments and shear forces. The fuselage and wing react the maximum moments and shear. In the fuselage, the shear is reacted by the ±45° fuselage skin laminates. The bending moment is reacted by differential tension and compressive loads in the upper and lower longerons (ref Fig 1). The longerons are solid unidirectional glass rovings manufactured as described below. The wing vertical shear and bending loads are reacted by the main spar and the torsion is reacted by the wing skins. The vertical shear loads are reacted by the ±45° glass laminate shear web and the torsional shear by the ±45° glass laminate wing skins. The wing bending moment is reacted by differential tensile and compressive loads in the upper and lower spar caps. The wing spar caps are manufactured in a similar way to the fuselage longerons, using unidirectional glass rovings. Unidirectional glass rovings consist of continuous glass filaments gathered together to form a collection of parallel fibres. The longerons and spar caps are manufactured by pulling rovings through an epoxy resin bath using a pultrusion rig and a tensioning device. The resin impregnated rovings are then placed together in a mould to produce the required shape of longeron or spar cap. The strength and stiffness of unidirectional rovings are shown in Fig 2.

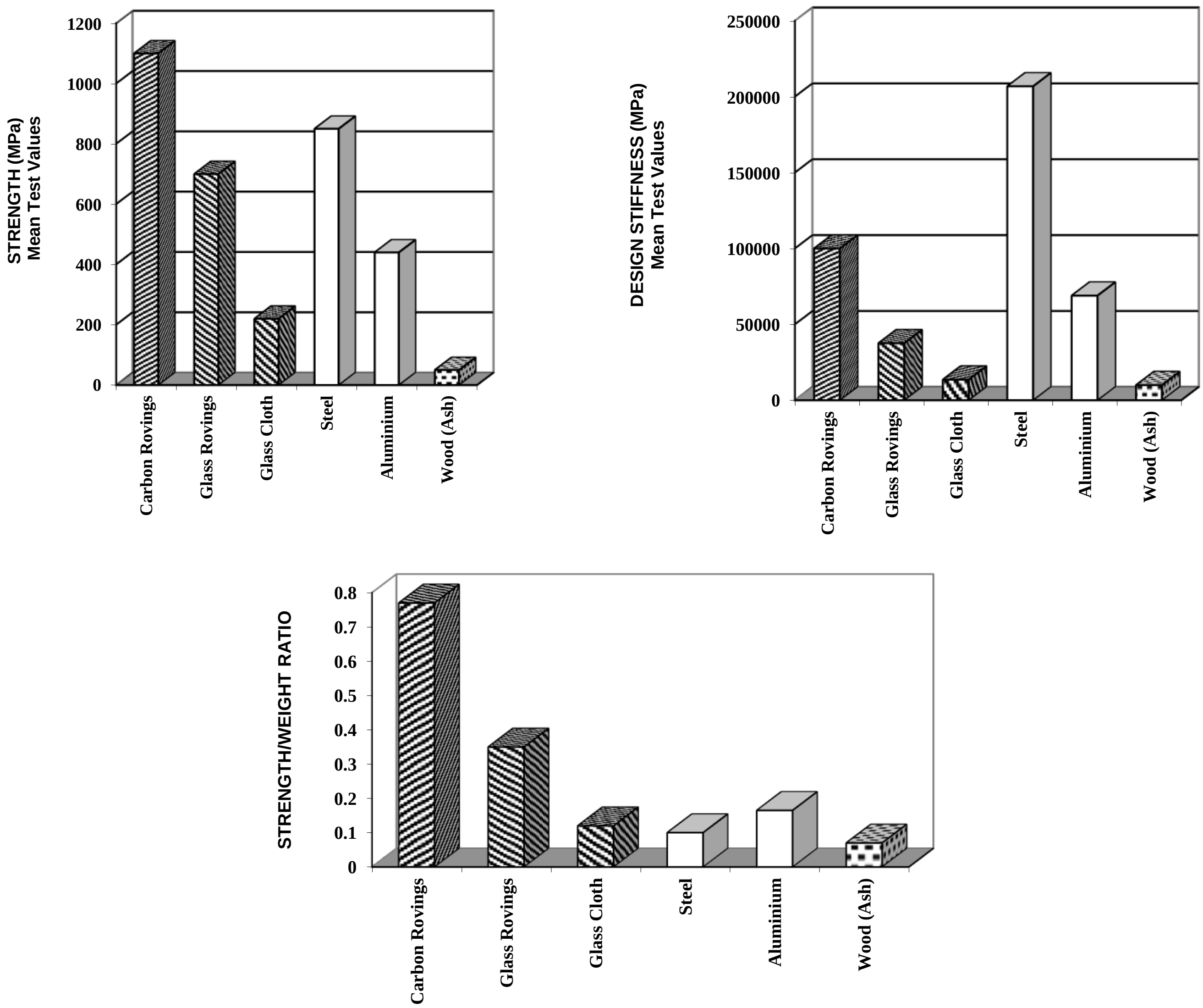
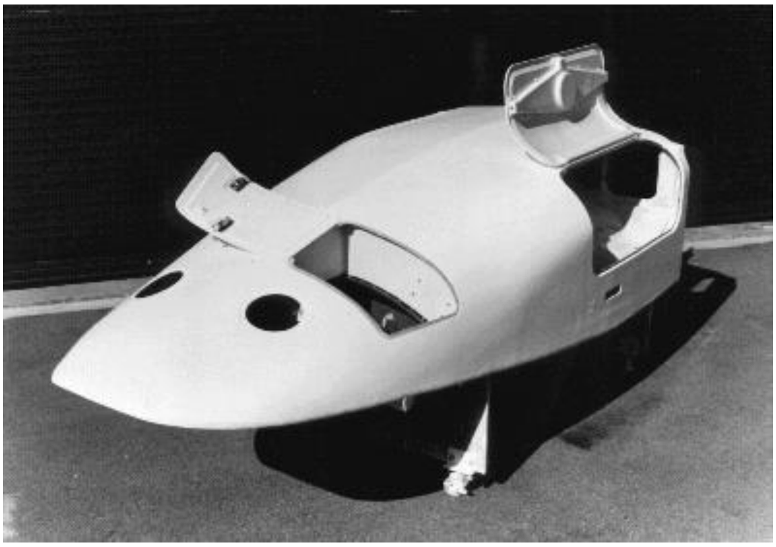


Fig 2

- **Jetstream 41 Baggage Pod**

The Jetstream 41 baggage pod sits under the fuselage and can contain up to 350 lbs of passenger baggage. The outer shell of the pod consists of glass fibre and Kevlar skins on each side of a honeycomb Nomex core. The sandwich construction results in a light weight pod with stiff walls. The pod is further stiffened with transverse bulkheads which also attach the pod to the fuselage. These bulkheads are manufactured from *Fibrelam*. The *Fibrelam* is supplied as flat sheets and consists of a phenolic coated aramid honeycomb core sandwiched between cross plied unidirectional glass fibre skins layed up with epoxy resin. The baggage pod skins are wet laid up in a mould with CTM epoxy resin. The skins are consolidated onto the core with vacuum bags and the assembly is post-cured in a hot box. The post-cure cycle is 12 hours at 78°C.



The Baggage Pod sits under the fuselage behind the wing. The Forward Fairing (of similar construction) sits in front of the wing and contains the hydraulics. The forward fairing was subject to a bird strike test.

Outer Shell Of Baggage Pod
Glass/Kevlar/Nomex Honeycomb /Kevlar/Glass

Bulkheads Made From *Fibrelam*
Glass/Aramid Honeycomb/Glass

- **Why Composites Are Used In The Construction Of Airframe Structures.**

At this stage it will be useful to consider what advantages composites bring to the design and manufacture of airframe structures. It must be stressed at this point that whilst composites have distinct advantages over the traditional steel/aluminium/titanium metals, there are some structural applications where the strength/stiffness/weight/cost parameters favour the use of metals. However, for aviation structures where the reduction of weight is of paramount importance, the use of composites has been found to be a distinct advantage

Some of the **advantages** of composites when compared to metals are:

i	Composites have good strength to weight ratios. Comparisons are shown in Fig 2.

ii.	Composites do not corrode in typical aviation and marine environments.

iii.	The strength and stiffness of composites can be tailored to specific requirements.

iv	Laminates can be moulded to form complex shapes. There is no need for expensive forming or machining and the problems associated with castings are avoided.

v	Glass fibre laminates are damage tolerant. This will be discussed later when dealing with fatigue.

vi	Smooth aerodynamic surfaces can be created which are uninterrupted by countersunk rivet holes.

vii Composites repair well, with smooth surfaces being maintained. With skilled repairs no obvious evidence of the repair should be apparent after surface preparation and painting.

viii Kevlar, which is an aramid fibre, is excellent in withstanding impact damage and abrasion. The T67 flaps are covered in Kevlar cloth wet layed up with epoxy resin. The flaps are directly behind the main landing gear, and are prone to impact damage from stones and debris.

ix Unidirectional carbon rovings are as strong as steel but have better strength/weight properties (see Fig 2). Unidirectional carbon rovings are used in the T67 canopy hoops (ref Fig 1) where stiffness is required. Canopies generate lift and deflections must be kept to a minimum. The carbon hoops have replaced steel hoops used on earlier aircraft.

x Slingsby composite aerostructures are operating without problems in such diverse environments as northern Canada, Norway, Turkey, Belize, Hong Kong, and Texas. This demonstrates that wet layup composites are not restricted by environment, providing their limitations are taken into account during design.

Composites also have disadvantages, some of which do not occur with metals. It is important for the composite designer to be aware of the disadvantages as well as the advantages of composites so that the structure can be adequately designed. When the advantages and disadvantages of composites are considered during the design process, then providing the structure operates within its design envelope, in-service problems should not occur during the lifetime of the structure.

Disadvantages of composites include:

i Hygrothermal Degradation. Hot and humid environments affect the strength of composites. The accumulative uptake of moisture over time will reduce the strength of a composite (and increase its weight). Surface preparation and finish can help to reduce this, but the method of dealing with this problem is to understand the material and to introduce 'hot/wet reduction factors' into the material design allowables. Slingsby performs tests where samples of laminates and adhesives are conditioned at 65°C and 85% relative humidity, in a humidity cabinet, for up to 210 days. The specimens are then tested at 60°C to derive hot/wet design allowables.

ii The manufacture of wet layup material can be labour intensive. Cloth has to be cut and resin mixed. Quality control is imperative. With composite products, the laminator manufactures the material as well as the component. In the aircraft industry the quality of the fabricated material determines the quality of the finished components. Control test specimens have to be manufactured alongside the components. Process control and controlled workshop conditions are vital to ensure the end product is as the designer intended.

iii Wet layup weight variance is usually greater than for prepreg composites or metals. Adequate process control is therefore vital. Overweight aircraft will result in lack of aircraft performance and/or the ability to carry the required payload.

iv For design purposes, the composite structural integrity is assumed to be limited by its Glass Transition Temperature (Tg). The Glass Transition Temperature, is that temperature above which the resin matrix starts to soften and flow. The Tg depends on the resin matrix and the temperature at which the composite structure is post-cured. The maximum service temperature dictates the choice of composite fabrics and resins. The fabric and resin chosen should have a post-cure that results in a Tg greater than the maximum service temperature world-wide. T67 wet layup composite components are typically post-cured at 78°C with a resulting Tg of 92°C. For white painted aircraft, operations world-wide present no problems as white surfaces result in minimum surface temperatures (ref Fig 8). If an aircraft needs to be painted a colour other than white, then the surface temperature of the laminates needs to be kept below Tg with an adequate margin. The relationship between the colour chosen and the maximum ambient temperature in the theatre of operations needs to be known. The relationship between composite surface temperatures and colours is discussed later.

v Resin degrades when subjected to ultraviolet radiation (UV). On gliders and early versions of the Firefly aircraft, a layer of gelcoat on the outer surface of the laminate prior to it being painted, protected the glass laminate from UV. On later versions of the aircraft the gelcoat has been replaced with an epoxy varnish, which prevents 'pinholing' when paint is applied. The clear varnish also allows the demoulded component to be checked for voids prior to painting. After inspection, the surface of the laminate is painted with primer and polyurethane paint. Blockers in the polyurethane paint provide the UV protection.

vi Kevlar aramid fibre has poor compression properties and is difficult to cut.

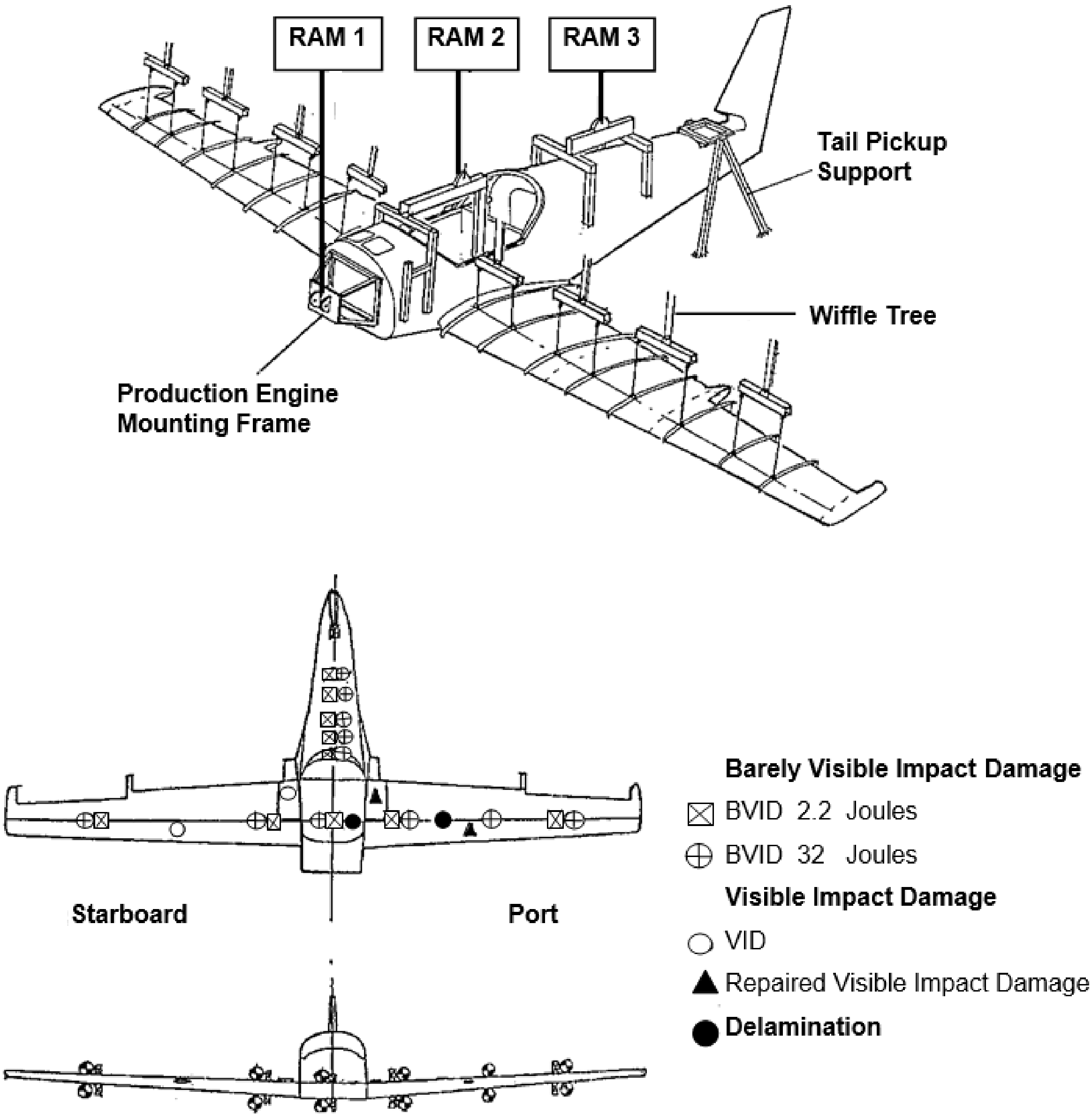
vii Carbon Fibre is expensive and compared with glass fibre and Kevlar, has poor impact resistance.

- **Designing Wet Layup Composites For Optimum In-Service Performance.**

  - **Fatigue and Damage Tolerance**

In order to ensure that the Firefly airframe met all fatigue and damage tolerance requirements of the CAA, FAA and Air Transport Canada, substantial fatigue testing has been performed. The fatigue testing was performed with an airframe consisting of a production fuselage and wing as shown in Fig 3. The fuselage was loaded by jacks to simulate vertical inertia loads. These inertia loads were reacted by wiffle trees mounted along the wing. The wiffle tree reaction loads represent the summation of the aerodynamic loads on the wing and the wing inertia relief. The fatigue testing was performed on an airframe with various types of damage induced in it as shown in Fig 3. Two fatigue tests have been performed.

A T67B fuselage and wing, which are common to the 160 hp and 200 hp engined aircraft were fatigue tested first. The same T67B fuselage fitted with the strengthened T67M260 wing for the 260 hp engined aircraft was fatigue tested next. The T67B wing and fuselage were fatigue tested to a total of 105,000 flying hours (with load G levels ranging between +6G and -3G), the final 30,000 hours with induced damage. No induced damage progressed during the course of the fatigue test. Following the first fatigue test, the T67B fuselage was fitted with a strengthened T67M260 wing. Damage was also induced in the T67M260 wing and the fatigue test was continued for the equivalent of 18,000 hours. No induced damage progressed during the course of this fatigue test. Following the fatigue test the T67B fuselage fitted with the T67M260 wing was statically tested at 60°C failing at the equivalent of 11G.



Induced Damage

Fig 3

A typical airframe lifetime is 18,000 flying hours. The T67B wing and fuselage therefore experienced the equivalent of 6 lifetimes and almost two lifetimes with no damage progression. If the correct composite strength reduction factors are used to statically design the aircraft at ultimate load, then the microstrain levels during the fatigue test should be in the non-damaging range. For example, the material ultimate design allowable stresses are taken as the test specimen 'A' value multiplied by a 0.8 environmental factor (to take into account hot/wet strength). The 'A' value is the value for which there is 95% confidence that 99% of the test population can reach or exceed that value. The use of the 'A' value x 0.8 as an ultimate design allowable results in the maximum strains at 6G (limit load) of around 4500$\mu\varepsilon$. As a 'rule of thumb', when the materials used in the structure are coupon tested 'as manufactured' at ambient, ultimate design strength allowables can be derived from the mean test strengths divided by 2. This latter rule is used where limited numbers of specimens are tested and meaningful ‘A’ values are unobtainable. Using these criteria the microstrain levels at limit load should then be at a level that results in a durable and damage tolerant structure.

The type of damage induced in the airframe consisted of Barely Visible Impact Damage (BVID). The damage was induced by dropping steel impacters on to the upper and lower fuselage at the frame positions with energies of 2.2 and 32 joules. BVID damage was also inflicted on the upper and lower wing skins along the main spar caps.

The 2.2 joules damage simulated sharp-ended impacters such as screwdrivers being dropped onto the wing and fuselage surfaces. The higher energy of 32 joules, achieved using round ended steel bars, simulated the effect of hail stones and similar impacters. Visible Impact Damage (VID) was inflicted on the starboard and port upper wing skins to simulate the dropping of heavy objects, such as tool boxes, etc. One critical area for VID was the walkway area next to the cockpit. The walkway area, although protected by a thin rudder surface, can receive abuse in service from pilots' boots. In creating the visible impact damage in the walkway area, the impacter actually penetrated the wing skin resulting in a hole, which was left unrepaired on the starboard side. All induced VID damage on the port side was repaired, using standard repair techniques to give Repaired Visible Impact Damage (RVID).

For certification purposes it was necessary to demonstrate that any in-service VID was not critical before or after repair. None of the VID areas increased in size and no induced damage progressed during the fatigue test.

Deliberate delaminations were also formed in the wing skins using *Melinex*. No delaminations increased in size during the fatigue test.

- **Hygrothermal (Hot and Wet performance)**

Composites and adhesives generally absorb moisture during service due to the combination of temperature and relative humidity, and experience a reduction in strength as a result. The higher the temperature and relative humidity, the more moisture is absorbed. Eventually, a composite will reach saturation and moisture content quasi-equilibrium. Some typical glass composite and adhesive performances are shown in Fig 4 where mean test strength values are plotted. To certificate the aircraft for world-wide use, it was necessary to prove that the hot/wet factor (1.22 reserve strength) demonstrated by the aircraft static test at ultimate load and 60°C, would not be reduced to 1.0 in the lifetime of the aircraft. Three techniques are used to predict the airframe performance over its lifetime.

- **Accelerated Conditioning of Coupon Specimens.**

As the lifetime of the aircraft is 18 years, accelerated conditioning of coupon specimens was required in order that the composites used in the aircraft could be validated quicker. Coupon specimens of glass rovings, glass cloths, resins and adhesives were conditioned in a humidity cabinet at 65°C and 85% relative humidity. The steady state relative humidity of 85% was taken as the world-wide worst. This coincided with the maximum relative humidity at Hondo Texas where the aircraft operates (ref Fig 5). The conditioning was accelerated by raising the temperature to the maximum allowable for the aircraft resin system such that the diffusion behaviour did not alter from that obtained during natural exposure. The 65°C and 85% relative humidity combination for accelerated conditioning was validated by flexurally testing two batches of glass roving specimens with identical moisture contents. One batch was conditioned at 85% relative humidity and 45°C and the other at 85% relative humidity and 65°C. There was no noticeable difference in the strengths of the two batches after conditioning. During the accelerated tests, the moisture content was measured at regular intervals. The measurements were taken daily over the first days of testing, when the moisture content trend against time is linear, and then weekly over the first months and monthly thereafter. After the accelerated tests were complete, the coupons were strength tested, flexural tests in the case of rovings, tension and compression in the case of laminates and double lap shear in the case of adhesives.

Some results are shown in Fig 4.

Fig 6 shows the difference in time taken to achieve a certain moisture content in the coupon specimens by accelerated conditioning, and the time taken in the real environment as predicted by hygrothermal analysis.

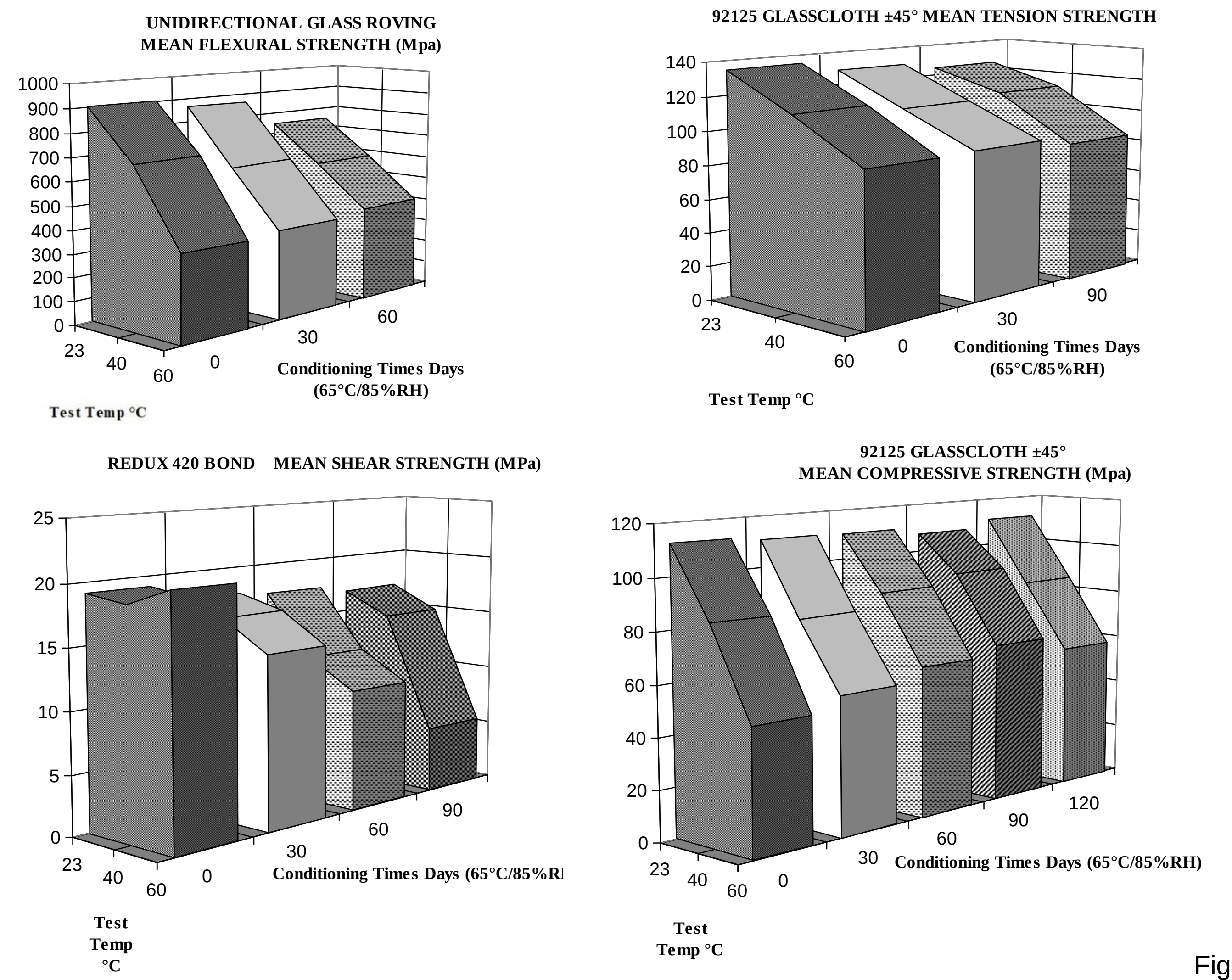


Fig 4

o Hygrothermal Analyses

Hygrothermal analyses were performed using the daily temperature and relative humidity trends throughout the year in the areas of the world where the aircraft operates. Local meteorological stations produce these trends. The analyses were confined to those areas which were considered to be the most environmentally detrimental to the aircraft composite structure. In the case of the T67, data from the hot humid conditions of Hondo, Texas where the aircraft are stationed were used in the analysis. An example of the temperature and relative humidity trends throughout the year in Hondo is shown in Figure 5. The analyses used diffusion coefficients for the aircraft materials, derived from the moisture uptake during the accelerated tests. The diffusion coefficients represent a material's capacity to absorb moisture with temperature. The moisture content of the various critical aircraft elements (spar caps, longerons, etc) and hence their strength degradation, were determined after various time periods in Hondo.

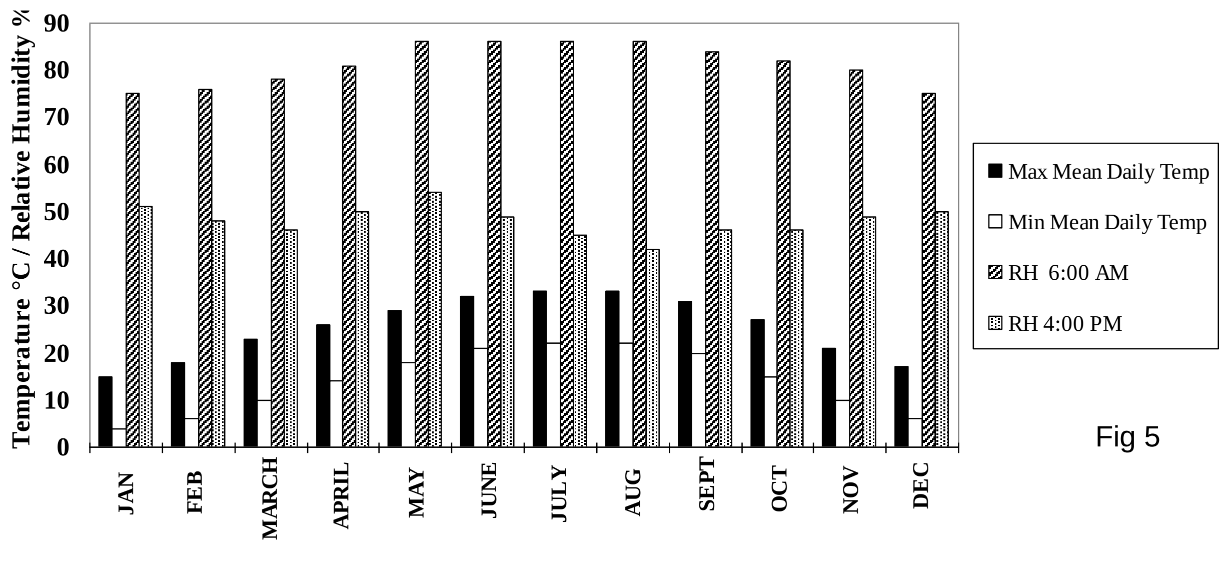


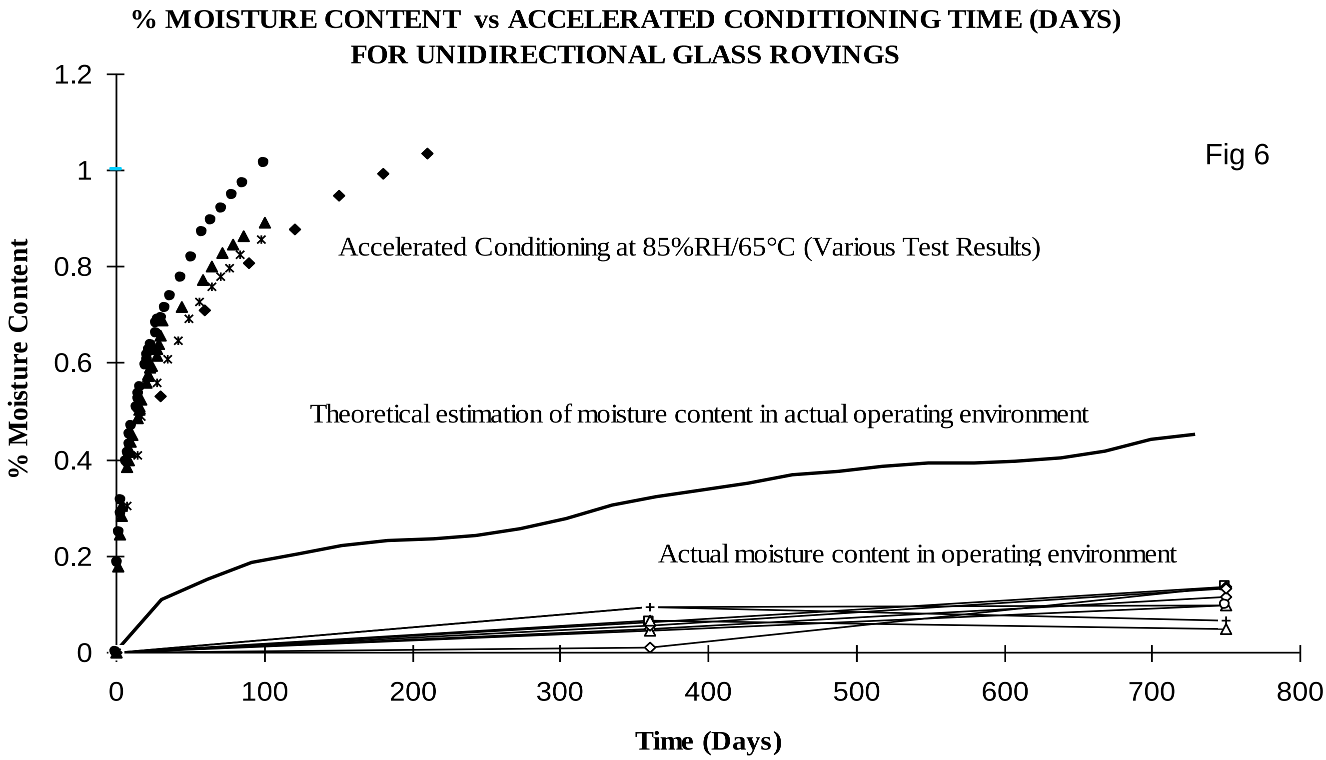
Fig 5

- **Travellers**

In addition to the accelerated conditioning and the hygrothermal analyses, validation of the moisture uptake of the structure is being carried out by the use of travellers in Hondo. Travellers are coupon specimens, which are carried on the aircraft and are positioned on the ground in and around the aircraft hail shelters. These travellers are similar to those used in the accelerated tests. Every year the travellers are weighed and the moisture content determined. The traveller moisture contents are then compared with the predicted moisture content from the hygrothermal analysis, (ref Fig 6). Whereas the coupon specimens in the humidity cabinet require 4 days to achieve a moisture content of 0.2%, the hygrothermal analysis predicts that the same specimens would require 7 months to achieve the same moisture content. The travellers have taken four years to reach this level.

The hygrothermal analysis and coupon testing demonstrate that the moisture absorbed during the lifetime of the T67 airframe, will not compromise structural integrity. This applies especially to the wing main spar caps which are manufactured from glass rovings and are considered to be the critical components in the aircraft. The travellers give even more cause for confidence.

Analysis and testing have also shown that in environments where the relative humidities are greater than 50% there is always a net increase in the moisture content of the composite structure. Drying environments are those for which the relative humidities are consistently less than 50%. For instance the relative humidity in Hondo, Texas varies annually as shown in Fig 5. Analysis indicates a net uptake of moisture throughout the year with no drying period.



- **Jetstream Baggage Pod Shell**

The Jetstream 41 baggage pod shell skins consist of 1 layer of glass fibre and one layer of Kevlar on each side of a Nomex core. The glass and Kevlar cloths are wet layed up with CTM epoxy resin. The baggage pod has been statically tested at ambient, 'as manufactured', with BVID induced and 'built in' delaminations. The ultimate loads were factored up by 'hot/wet' factors of 1.5 to cover the pod for world-wide use.

The static test on the full scale baggage pod indicated that the pod could react 3.2 x limit load. The 3.2 factor included the 1.5 ultimate factor on the loading and the 1.5 hot/wet factor for the composite material. The 3.2 factor also included the static reserve strength of 1.43 indicated by the static test.

The Kevlar is a hygroscopic aramid. The aramid fibres absorb moisture, expanding in the process. It was therefore necessary to validate the hot/wet factors used on the static test by long term tests on coupon specimens. In order to perform the validation, flexural coupon specimens were cut from a flat hydraulic access door of the same construction as the pod. The specimens were then saturated in a humidity cabinet at 65°C and 85% relative humidity. Figure 7a presents the moisture content trend for this particular type of sandwich construction. The trend indicates saturation within 60 days of the specimens being placed in the humidity cabinet. The worst case scenario is of a saturated baggage pod, at the certification temperature, and under critical load. Flexural testing was carried out on 'as manufactured' specimens at ambient and on saturated specimens at the certification temperature of 57°C. Test results (ref figure 7b) indicate that the saturated specimens at 57°C have a flexural strength 59% that of the 'as manufactured' strength at ambient. Therefore, under critical load and a temperature of 57°C, a saturated pod had a static strength of 3.2 x 0.59 = 1.9 x limit load. The integrity of the structure was validated because the strength requirement for a saturated Pod at 57°C was 1.5 x limit.

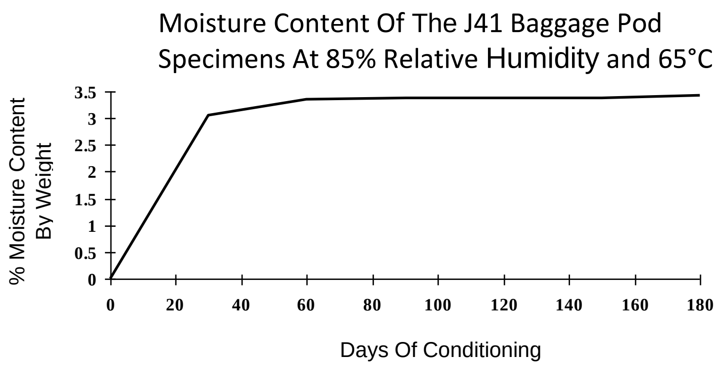


Fig 7a

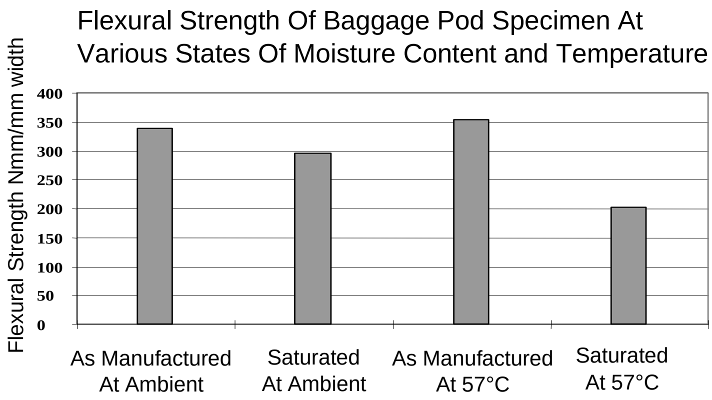


Fig 7b

- **Solar Heating Of Composite Structures**

The majority of Slingsby aircraft that are operating world-wide are painted white, and this is the optimum colour for minimum surface temperature. Recently however, operators such as the RAF have requested colour schemes, which enhance the visibility/conspicuity of the aircraft for collision avoidance. Currently RAF Fireflies are painted yellow on the upper, vertical and side surfaces and black on the lower surfaces. Originally black was requested for the upper wing, tail tips and for the vertical fin surfaces. The temperatures of the aircraft's yellow and black surfaces were mapped using thermocouples. On a sunny summer's afternoon in still air in North Yorkshire, the black upper wing tips were approaching a temperature of 90°C - too close to the composite Tg of 92°C for comfort! The colour scheme was therefore changed to remove the black wing and tail tips and the fin black surface.

Further research is being carried out using thermocoupled glass composite panels painted every colour used on the aircraft. The panels are mounted on hollow polystyrene boxes and sheltered from any moving air. Thermocouples are mounted at the centre of both the inner and outer surfaces of the panels. The boxes are constantly pointed at the sun and the thermocouple readings recorded automatically by data logger. Some results are shown in Figure 8.

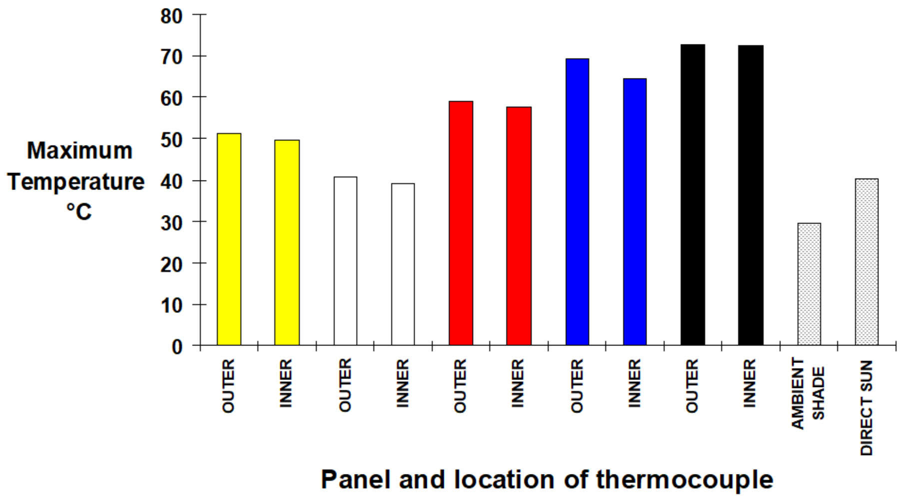


Fig 8

- **Conclusions**

Slingsby Aviation's experience with composites has shown that such structures can be designed for durability. The strength properties at the maximum service temperature must be known along with the expected lifetime's moisture content. The moisture content can be predicted by test and analysis using relevant annual climatic data. Composite structures should also be fatigue tested and then statically tested at maximum service temperature. Reasonable levels of impact damage, delaminations, voids and debonds should be present in the test structure. Loads applied during static testing should include hot/dry to hot/wet factors derived from tests on coupon specimens. Knowledge of the structure's Tg and its relationship to the surface temperature of painted surfaces also needs to be known.

John Arrowsmith's Visit To PEEMS On Tuesday 17th May 2022.

When John Arrowsmith from *The Model Engineer* visited PEEMS, he took a photo of the members (including a honorary member for the day) all of whom contributed to the success of the day.

Photo kindly provided by John Arrowsmith. This photo should not be used without John Arrowsmith's permission.

Contact:
If you would like to contribute to the Newsletter,
the contact is: Nevile Foster Tel 01751 474137 or e-mail nevf123@outlook.com