The lost rocketplanes of Scotland

(A lockdown detective story)

Introduction

Just over a century ago, Scottish rocketeers correctly predicted that the Aerospace industry would soon need propulsion for very high-speed aircraft. This is just as true today for nascent Scottish Spaceplanes. So they designed and built an air-breathing rocket engine, fitted it to a model aircraft, and successfully fired it across Loch Lomond at high airspeed in 1920. Their story is remarkable.

Firstly, they got exceedingly good at rocketry very quickly – in a matter of months - and secondly, they were only sixteen; Glaswegian schoolboys. And yet strangely of all, they – and all the years of rocket research performed by them– has completely vanished from history: one lone technical article in the learned 'Flight' magazine of December 1943 is the only evidence we have that they ever existed (a short follow-on article plus a reply to a reader's letter appeared in the same journal in Jan 1944 and Feb 1944 respectively.)

Rumours of this 'Glasgow Group' of rocket researchers have circulated for years in Scottish rocketry circles, but with the necessity of 'lockdown' there was spare time to do some rocketry Archaeology on them in their centenary year.

Part 1: the first rocketplane flight

By 1920, our young rocketeers were churning out very creditable rocket motors.

Note that rocket engines utilising solid propellant have only one moving part – the propellant – so are known as ‘motors’. ‘Engines’ are defined as having *more* than one moving part.

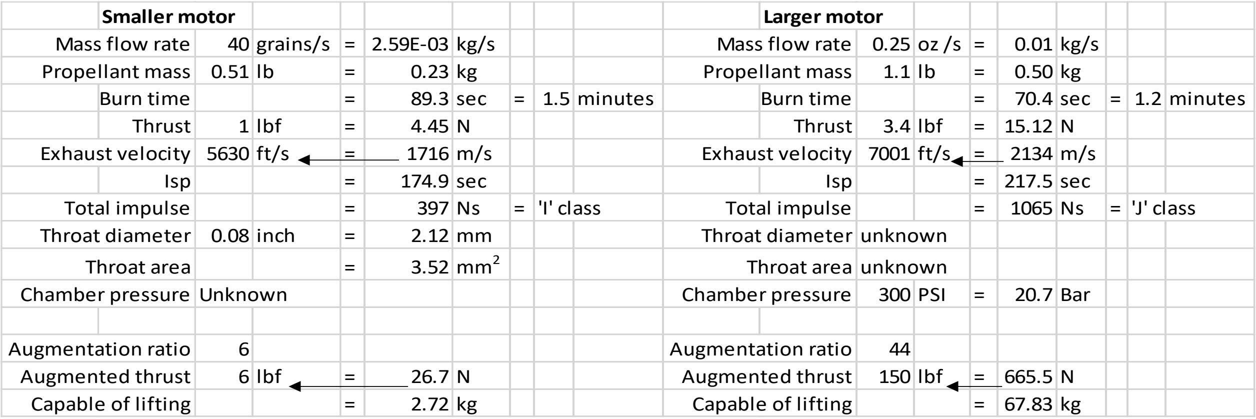
Rocket engines can easily be compared by ‘Specific Impulse’ (Isp); a measure of performance similar to the ‘miles to the gallon' (kilometres per litre) of cars – the higher the number the better. For dimensional reasons, Isp can be measured in seconds so that both America and the civilised metric world can agree on performance. (Many Brits prefer more physically correct units.)

The propellant

Typical solid rocket propellants of the 1920’s were still based on Black Powder (a type of Gunpowder) and had a typically feeble Isp of only 80 seconds even when used with a decently-designed rocket nozzle. It wasn’t until sometime later that rocketeers did noticeably better with ‘Double base’ propellants – invented in Britain and given to the USA during World War Part Two.

Working with the data from their ‘Flight’ journal article, calculations show that our boys’ propellant reached a sea-level Isp of 175 seconds – more than double that of their contemporaries, and still creditable today for model rocketry uses. (See table 1.)

Within a decade or so, this rocket research group were regularly achieving a quoted velocity of 7000 feet per second from the hot gas exiting their ‘de Laval’ rocket nozzles, which equates to an Isp of 218 seconds. This was achieved at an internal (Combustion chamber) pressure of only 21 Bar; many propellants of that period would have literally fizzled-out below 69 Bar Chamber pressure due to their crude ‘binder’ (the glue holding the propellant together.)



Smaller motor									**Larger motor**								
Mass flow rate	40	grains/s	=	2.59E-03	kg/s				Mass flow rate	0.25	oz /s	=	0.01	kg/s			
Propellant mass	0.51	lb	=	0.23	kg				Propellant mass	1.1	lb	=	0.50	kg			
Burn time			=	89.3	sec	=	1.5	minutes	Burn time			=	70.4	sec	=	1.2	minutes
Thrust	1	lbf	=	4.45	N				Thrust	3.4	lbf	=	15.12	N			
Exhaust velocity	5630	ft/s	=	1716	m/s				Exhaust velocity	7001	ft/s	=	2134	m/s			
Isp			=	174.9	sec				Isp			=	217.5	sec			
Total impulse			=	397	Ns	=	'I' class		Total impulse			=	1065	Ns	=	'J' class	
Throat diameter	0.08	inch	=	2.12	mm				Throat diameter	unknown							
Throat area			=	3.52	mm^2				Throat area	unknown							
Chamber pressure	Unknown								Chamber pressure	300	PSI	=	20.7	Bar			
Augmentation ratio	6								Augmentation ratio	44							
Augmented thrust	6	lbf	=	26.7	N				Augmented thrust	150	lbf	=	665.5	N			
Capable of lifting			=	2.72	kg				Capable of lifting			=	67.83	kg			

Table 1: motor performance calculations

One can only guess as to the chemical makeup of their solid propellant, though presumably Glaswegian schoolboys couldn’t afford exotically expensive chemicals. The article describes it as “*a composition resembling gun powder,*” but that deliberately leaves the field wide open, presumably so as not to divulge the recipe. Hobbyist rocketeers would be more than happy to buy some of that propellant today!

The magazine article describes a 10–inch–long (254 mm) steel tube of 1.5 inches (38.1 mm) outer diameter filled with just over half a pound (estimated as 0.51 pounds = 231 grams) of his propellant. From the quoted performance parameters, this classed it as an 'I'-class rocket motor: 397 Newton-seconds of Total impulse.

(The letter code is a handy guide to the motor's Total impulse, which is effectively the motor's average thrust times its burn time, hence Newton-seconds. The metric unit of thrust – and in fact all forces – is the Newton of course. There's a special hell set aside for BBC presenters who erroneously spout kilograms or tonnes.)

'I'-class engines are used by student research groups and hobbyist rocketeers today. A nearly identical motor in terms of size, shape, and performance, would be the 'Pro38' three-grain from Cesaroni Technology Inc of Canada, except that the Cesaroni motors require three times our lads' Combustion chamber pressure (60 Bar versus 20 Bar) to achieve the same Isp at sea-level.

Pro38 three-grains typically burn all their propellant in around two seconds. Any slower than that leads to a low thrust force that can't prevent gravity and the wind pulling the rocket vehicle's initially vertical ascent over to the horizontal, leading to a low, flat trajectory arcing over the faraway hills. This leads to several hour's trekking and searching to get it back, and a lot of profanity!

Cesaroni's slowest-burning propellant is aptly named 'Mellow', and is used for special rocketry purposes. It burns out an 'I'-class three-grain in just over seven seconds. However, our boys' rocket motor could keep burning for a quoted *75 seconds* – phenomenally slowly - giving an extremely low thrust of 4.5 Newtons. No use whatsoever for military missiles or other vertically–launched rocket vehicles, though one suspects our lads had no intended military uses.

(Incidentally, 'Mellow' propellant has a quoted Isp of 179 seconds, which is nearly identical to our lad's 1920 value of 175 seconds, but considerably less than his 1930's best of 218 seconds. A modern military solid propellant can produce 245 seconds with a decent nozzle.)

Instead of today's standard electrical igniters, good old-fashioned 'slow fuse' was used.

Nozzle design

This Glaswegian rocket research group's rocket nozzles were bespoke. Failing to satisfactorily manufacture ceramic nozzles (a clay nozzle throat of only 2.12 mm diameter that won't erode significantly wider over a very long burn time is a big ask), they exclusively used metal ones. These were properly-designed de Laval supersonic conic rocket nozzles with an exit-cone angle of 9.5 degrees (half-angle of 4.8 degrees). (The de Laval nozzle was a fairly new technology in the marine steam turbine research labs in Glasgow.)

A 4.8 degree half-angle keeps the exhaust gas flowing straighter (less flow divergence) than today's popular value of 15 degrees, and they took the trouble to radius the sharp edges of the nozzle throat (the narrowest bit of the nozzle) which again, measurably increases performance.

Such long conical nozzles don't package well in missiles or vertically-launched rocket vehicles and they weigh more, but these are less important issues on horizontally-flying rocketplanes. (Today, a bell-shaped 'Rao' nozzle which is shorter and has less draggy wall area, would be used.)

Their 1920 nozzle was manufactured from Monel metal, an expensive cupronickel alloy that maintains its strength in the high-temperature oxidising/corrosive environment of a rocket nozzle. It was being used in advanced superheated steam engines on Clydeside.

The article claims the Monel nozzle was thin (walled) and spun, which on such a tiny nozzle with such a small cone angle takes some doing. If it wasn't turned on a lathe, then only Clydeside's finest Machinists could have spun it as it's a difficult material to work with – it 'work-hardens' horribly easily.

The fact that our lads managed to get hold of Monel and get it machined for them suggests a mentor: a father, uncle, or teacher, with access to Clydeside facilities and the odd filched bit of material!

Later, the research group switched to pure copper nozzles (same cone angle), but machined with external cooling fins (copper has exceptional heat transfer properties). A steady trickle of water from soaked cotton wool stuffed between the cooling fins convectively cooled the copper. (Similar experiments with water-cooled nozzles were taking place in German rocket clubs at the time.) A strong airflow supplied down an air-duct was then blown over this arrangement to greatly enhance the cooling – more on this below.

If going to the trouble of getting high-spec metal nozzles machined, one might hope that they could be re-used more than once. (Note that the article refers to their rocket nozzles as 'jets' as was the custom of the time.) At a Combustion chamber pressure of 20 Bar, their nozzles would require an area ratio of around three (nozzle exit cross-sectional area divided by throat cross-sectional area).

Our boys' propellant can therefore be characterised as: slow-burning, giving of high motor Isp, and with a non-erosive exhaust that wouldn't excessively sandblast a metal nozzle over a long burn time. (Today's metal-laden solid propellants would've eaten it quickly.)

There were several Cordite factories in Scotland in the early 20th Century. Cordite is a British family of smokeless solid propellants which continues to be produced in the UK primarily for firing large artillery shells and mortars. It consists mostly of nitrocellulose, nitroglycerine, and petroleum jelly. Using acetone as a solvent, it was originally extruded as spaghetti-like rods called 'cord powder'.

Another possibility was a 'nitroguanidine' (Guanidinium Nitrate) based propellant; originally prepared in 1877. GN oxidiser is essentially a compound of Guanidine (NH_2--C(NH)--NH_2) and Nitric acid (HNO_3) radicals. GN propellant is used in low-temperature gas-generators for airbags, and 'Jetex' GN-based rocket propellant was patented in 1948 by Alexander C. Hutchison of Imperial Chemical Industries (ICI) Nobel Division, Ardeer (a factory just north of Irvine in Scotland).

However, Cordite's ingredients - particularly nitroglycerine - would be impossible to get unofficial access to, and it's not the sort of stuff to try cooking-up at home as it's notoriously shock sensitive: Nobel's brother (he of said Prize) blew himself up experimenting with it. Similarly, GN's ingredients are tricky to get hold of (and are not the 'bat-sh*t' of rocketry legend!) So British solid propellant experts consulted for this article discount them both for these reasons.

They suggest that Catalysed Ammonium Nitrate ('Cat AN') is much more likely. Again, it's often used for gas generators. Its Ingredients are much easier to get hold by 'home-brewers'.

Ammonium nitrate (NH_4-NO_3) is the ammonium salt of nitric acid, and is sometimes known as 'ammonium saltpetre' as it's an ammonium analogue of saltpetre. Its use in rocketry is as an oxidising agent.

Amateur (but informed) rocketeer Richard Nakka has posted extensive non-accredited research on the subject of ammonium nitrate and aluminium solid rocket propellant, but experts say that American 'home-brewed' AN propellants are quite different to British 'Cat AN', but nobody will tell this author why – something to do with a particular rocketry definition of 'catalyst'. (Under the UK's Orwellian Secrets Act, I *could* be told, but then they'd have to kill me.)

AN is also heavily used as an agricultural fertiliser, so is easy to get hold of. A bit too easy unfortunately; terrorists love it - so stockpiling it at home sends the Police round at dawn, and rightly so.

AN propellant produces a low-erosive exhaust which is relatively non-toxic and will not harm the environment or leave traceable pollutants. Cat AN exhaust can be of low temperature, and the propellant permits long burn times.

The military like this propellant because the exhaust is invisible to the enemy (in the visible range): the above-mentioned ICI-Nobel Division at Ardeer were the experts for Catalysed Ammonium Nitrate propellant, which suggests some sort of tie-in/mentoring with our boy. The Ardeer peninsula isn't that far from Glasgow on the direct train line.

Who was he?

What was the name of the wunderkind who designed the 1920 homemade rocket engine? It's hard to say because the article deliberately doesn't tell.

This could be for security reasons – the article was published in the middle of a War – or equally as likely, not to dump the kid in it, as manufacturing one's own solid propellant in the UK has been illegal since the arcane Explosives act of 1875, which has been over-applied by certain zealous officials to the point of their 1969 ban on water-rockets due to their 'explosive propellant'!

The article does list the likely suspects: the research group eventually comprised: Mr. G. Aldred, Mr. P. Blair, the article's joint authors J.J. Smith and J. Dennis, and one Naomi Roberts who appears to have been one of the first female rocket propulsion engineers: the right-most rocket engine of the article's 2nd diagram is entitled 'the Roberts 1936 rocket'. (One 'Mr. John Algar,' is also mentioned as commenting on the Loch Lomond flight.)

The Roberts 1936 rocket

The article also relates that: "*the writers (article authors) and Naomi Roberts joined in the work in 1936. Mr. P. Blair, who had done some work on rockets for military purposes (during the Spanish Civil War) came along later."* This leaves G. Aldred as the likely original schoolboy rocketeer, and indeed the article states that when civilian rocketry research was stopped by World War Part 1, "*it was resumed by Herr von Opel in Germany, by Mr. P. Blair in Spain, and Mr. G. Aldred in Scotland*."

Still, it appears that the rest of the research team were no intellectual slouches; the article's main author Mr J.J. Smith was clearly as accomplished as Aldred. In fact, he might be the real 'hero' of the research if it was only co-author J. Dennis who didn't join the group 'till 1936.

Horizontal takeoff

Back in 1920, our young rocketeer – who will now be referred to as ‘Mr Aldred’ for brevity - was just warming up. He now had a very effective solid rocket motor, of long burn-time and low thrust.

Many rocketeers would see that as a serious handicap, but we’re only just beginning to realise that the ubiquitous post-WW2 practice of vertically launching non-military rocket vehicles from the ground – particularly with Astronauts on top – is fundamentally daft when you stop to think about it; so many ways it can go lethally wrong (just the day before this summer’s momentous SpaceX crewed launch, a SpaceX vehicle blew-up on its pad because of a fuel/oxidiser spill puddling in the pad flame trench.) It’s an enduring fad.

But back in 1920, Wernher von Braun was only eight years old, and the iconic German film (the excellent ‘Frau im Mond’) that inspired the German’s enduring vertical-launch ‘missile mania' was nine years in the future.

In contrast, our Glasgow Group figured-out that the proper way to launch into Space - particularly from windy Scotland - is to take off horizontally down a runway in a Spaceplane, which is a Spaceship with wings to glide home with: a rocketplane. Spaceplanes use low-thrust long-burn rocket engines, and he had one.

A century later, both Prestwick and Machrihanish (Campbeltown) airports have the necessary long runways for Scottish Spaceplane operations, and are actively working to introduce Spaceplanes into service.

Trim the aeroplane or toast its airframe

Whichever member of the Glasgow Group designed their 1920 rocketplane was clearly an aeronautical genius. Without the benefit of today’s gyro-stabilised radio control electronics, model rocketplanes are a swine to fly. All he had were clockwork timers and pyrotechnic time-delay fuses.

The problem is the tremendous shift in ‘trim’ (the delicate settings needed to make an aeroplane fly level) caused by the considerable increase in airspeed created by the thrust of the rocket motor, and particularly, the large forwards wander of the centre of mass (‘C of G’ or ‘CG’) of the aeroplane as all that rocket propellant mass is expelled from its rear.

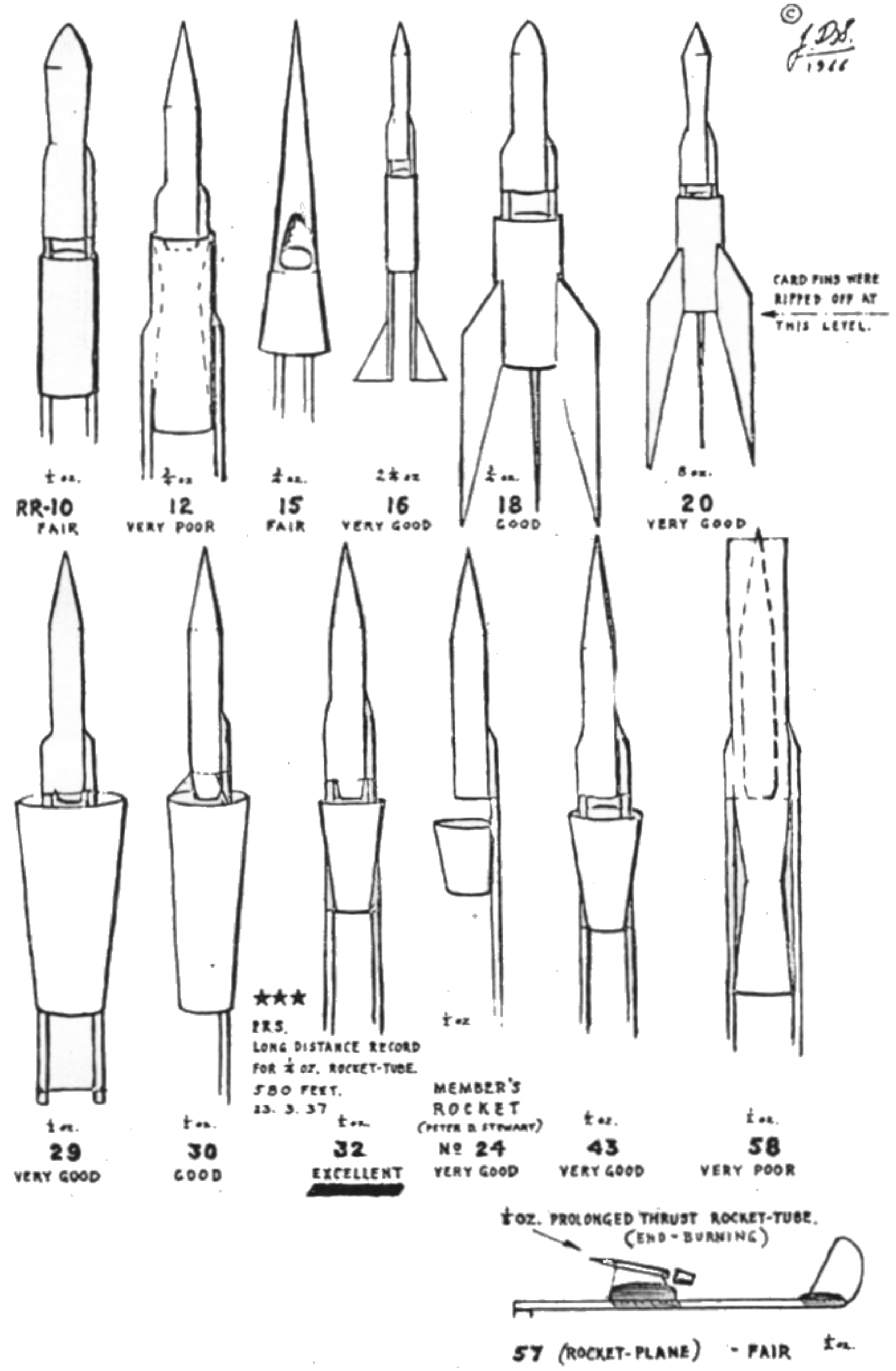
For the latter problem, this author coined the phrase ‘Trim-or-toast conundrum’. The only way to solve it is to position all the solid rocket propellant *right at* the aeroplane’s centre of mass so that it has zero ‘lever arm’ to cause mischief with as its mass diminishes. But then the scorching rocket exhaust obliterates all of the aeroplane fuselage to the rear of the nozzle.

Note that British military rocketeers have the freedom to employ a ‘blast pipe’: basically, taking the motor casing (or its nozzle throat) downstream of the propellant charge, and stretching it right to the rear of the aircraft. Under the British 1875 explosives act, modifying one’s motor in any way is classed as an ‘act of manufacture’ (of an explosive) which is horridly illegal without an impossible-to-obtain manufacturing licence.

Paisley Rocketeers Society

John Stewart of the Paisley Rocketeers Society notes in a 1990 letter that the Glasgow Group’s Flight Magazine article “*I first noted on my visit to my Uncle Charles... during the war (WW2). He was a regular subscriber (to Flight). Many years later (1950’s) I requested it at the Mitchell library, Glasgow, and they made photocopies of the pages for me.”*

Ergo, he and his brother Peter told this author that they didn’t remember hearing about the Glasgow group prior to this 1943 article. And yet from 1936 to 1939, in the whole world there were two amateur rocketry groups working on exactly the same ‘Rocket Ejector’ technology as will be described in Part 2. Both were based in the central belt of Scotland and only ten miles apart: Paisley and Glasgow. Credulity suggests there had to have been some sort of cross-fertilisation.



Paisley Rocketeers Society Rocket Ejector experiments 1936 to 1939 (utilising firework solid motors described by their weight in ounces)

Definitively taking the high road

But back to 1920, before any of the Paisley Rocketeers Society had been born.

The Glasgow Group built a rocketplane and flew it across Loch Lomond. Either by accident or design, they simultaneously solved the Trim-toast conundrum whilst at the same time boosting the thrust of their rocket motor six-fold: their rocketplane flew straight-and-true three miles across the Loch in one timed minute: a groundspeed of 180 miles an hour.

This is astonishingly difficult to pull off even today with a gamut of modern electronics, especially on the first go. It's almost impossible to get the trims exactly right in all three axes on a free-flight at 180 mph. And it was no fluke, as over the following years they built successive rocketplane models that flew faster and further.

A lone photograph in the 'Flight' magazine article – and indeed the 'thrust' (ahem) of the article – describes how they did it. With the benefit of modern software, this ancient photo has been digitally enhanced and shown here, with dimensions added (in inches) as per the article:

The 1920 rocket plane. Also shown here (bottom left) is the 16-inch-long whitish tape-measure mentioned in the 'Flight' article, as well as the 10-inch-long rocket motor; displayed for this photo with its metal nozzle (probably) pointing to the left.

Straight off, the Group's rocketplane designer realised that the 'tail first' or 'canard' arrangement of wing surfaces is best for rocketplanes. This is because the centre of mass ('CG') of a canard aeroplane is considerably rearward, which reduces the Trim-toast conundrum trim issue. So the aeroplane in this photo would actually fly off to the left.

Even 100 years later, the old wives' tale that canard aeroplanes are tricky to trim still persists. That you don't see many flying around is simply because a little creativity is required to get traditional flaps to work on a canard aeroplane, coupled with the fact that nervous passengers won't get aboard anything that doesn't resemble an ancient 1930's Douglas DC3.

The airframe

Take a look at this photo with an aeromodeller’s eye: clean lines, no struts, a monoplane, a high aspect-ratio wing of four-foot (1.2 metre) wingspan. Contrast this with your typical 1920 biplane – all draggy struts and wires.

Furthermore, the airframe stayed in one piece at an average groundspeed of 180 miles per hour, probably peaking at around 210 mph (180 knots) airspeed at rocket motor burnout. The article mentions that their early aeroplanes utilised plywood wing skins: plies of wood bonded together with Casein; a practice invented in mediaeval Europe. (Balsawood wouldn’t be introduced into British model shops for another decade.)

Casein glue (from the Latin *caseus* ‘cheese’) is as old as cheese-making itself. It was very popular pre-WW2, and is made by adding an alkali (such as sodium carbonate, sodium bicarbonate, or better still slaked lime/calcium hydroxide) to low-fat cottage cheese, and generally gives a 40% stronger bond than useless modern PVA wood-glue. One can buy it online.

Casein milk phospho-protein is a very long chain molecule which was used in early plastics such as ‘Galalith/Erinoid and ‘Lanital/Fibrolane/Aralac’. Its modern equivalent is the polyester Polylactic acid (PLA) which is very popular with the 3D printing community. Both Casein and PLA are referred to as ‘Azlons’: plant fibres which have been chemically broken down then reassembled into fibrous structures again - PLA is typically made from fermented plant starch. (Azlons are non-oil-based and quickly biodegrade.)

Composites

Later on in the mid-1930’s, the Glasgow Group switched to manufacturing composite-construction airframes (you did read that right) by: “*building up layers of wood, cloth and casein glue… set under clamp-pressure between concrete moulds covered with tinfoil or waxed paper… the result is cheaper, lighter and stronger than any of the older methods.*”

This is a very early example of the Compression moulding process for composite construction, used today to make lightweight carbon fibre cars. And indeed, they did make small boats and car-bodies for themselves.

Later, they decided that Casein glue had shortcomings, so following the detailed advice provided by Casein Industries Ltd and I.G. Farbenindustrie, switched to a synthetic plastic produced by the “*Aldol condensation reaction*”. Aldol (aldehyde + alcohol structural units) condensations provide a good way to form carbon–carbon polymer bonds.

The classic Aldehyde condensation-reaction results in Phenol formaldehyde, better known as ‘Phenolic resin’. This was initially mixed with wood flour filler (in the manner of modern composites ‘microballoons’ or ‘fumed silica’) to yield a rigid product trade-named ‘Bakelite’.

Phenolic resins were then further developed for use with composite fabrics in the 1920’s. ‘Novotext/Tufnol’ are modern tradenames for cloth or paper sheets bound by phenolic resin. As well as being seriously tough, phenolic composite chars/ablates at very high temperature rather than burning, which is why it is used today for hobbyist rocket structural and engine components.

This author’s opinion – having tried it personally - is that the Glasgow Group manufactured their own ‘Tufnol’ composite fuselages. It’s slightly trickier than using modern laminating epoxies because it requires mixing three chemical components in carefully measured proportions rather than two.

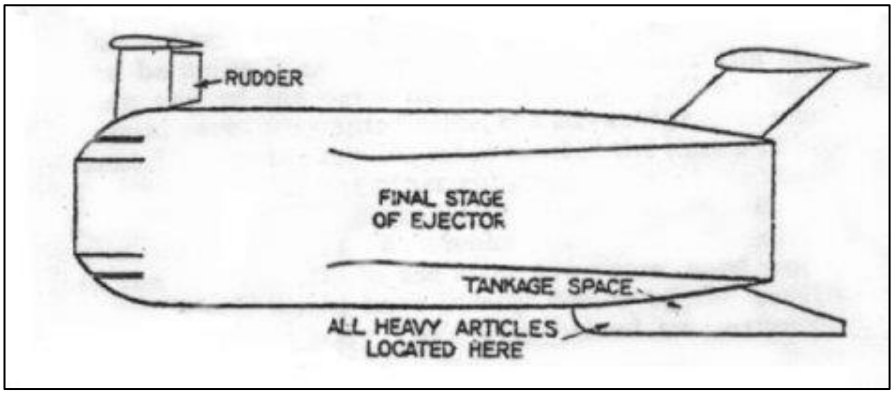
(For the record, commercial production of glass fibre began in 1936 in America. In the 1960's the potential of carbonised fibres was successfully exploited by commercial firms in America and Japan, but Britain fluffed it commercially, except for niche military missile uses.)

First rocketplane design

Back to the Group's rocketplane photo shown earlier. The plane appears to be on display on some sort of cloth in the photo (or undergrowth), but unfortunately the cloth is obscuring the trailing edge of the rear wing, so it's difficult to judge the rear chord length, or how it might vary across the wingspan.

The article mentions that the model took off and landed on water. Floatplanes were very popular in the pre-WW2 era, because the long bomber runways constructed in World War Two were as yet unbuilt.

No floats are discernible (perhaps removed for display), so maybe it took off using a floating 'dolly': a catamaran that separated upon takeoff. Also unseen are any rear vertical fin/s that aircraft need for directional stability. These could've been part of wingtip floats, however the article shows a sketch with a large strake mounted directly underneath the fuselage tube which, again, might have been removed for display purposes. Underneath is a perfectly good location for a fin, and would've helped maintain course in the water during the takeoff run.

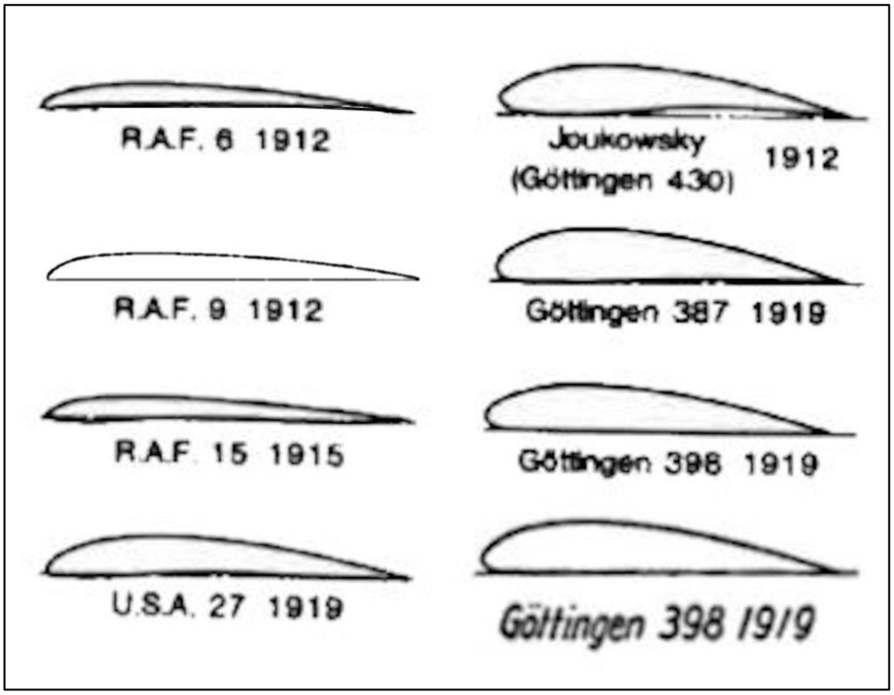


The Flight magazine's article's sketch of a proposed large cargo-carrying canard rocketplane

There's little detail left in the grainy old photo of the wings, but what can be seen of the canard appears to show a typically British WW1-era aerofoil; the bulk of which were tested at the National Physical Laboratory in London at their aerodynamics division. The other main pre-1920 aerodynamics labs were Prantl's research team at Göttingen in Germany, and Eiffel's lab in Paris. (Eiffel became interested in aerodynamics in his retirement – his first windtunnel was situated directly beneath his famous tower.)

In 1922, Prantl's prize student Munk emigrated to America, and revolutionised windtunnel research with fine gauze anti-turbulence screens on the tunnel intake, and the proper consideration of the effects of Reynolds Number (effectively a speed/size scaling law) in taking data from little models in a windtunnel and then applying them to full-sized aircraft.

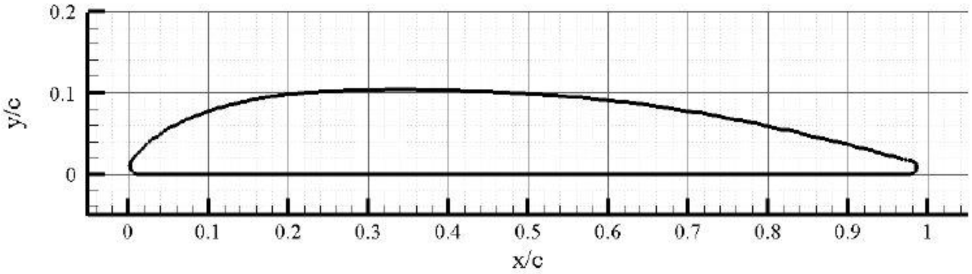
Before this, effects of Reynolds Number on aerofoil data hadn't been appreciated, so most full-scale aeroplanes were still using very 'thin' (thickness-to-chord ratio) aerofoils designed in overly slow windtunnels. Only Göttingen's aerofoils were designed with Reynolds Number and Prantl's Boundary layer theory in mind. Göttingen's aerofoils had been demonstrably superior during WW1 on Antony Fokker's warplanes, but even by 1920 most Brits and Americans weren't aware of their significance.



Aerofoils circa 1920

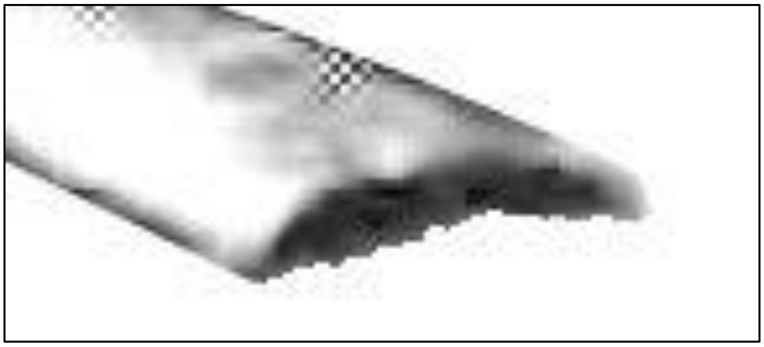
So in a nutshell, most of the world were designing aerofoils which were ideally suited to windtunnel-model-sized aeroplanes, but not full-sized ones (and are therefore well worth looking at today for small unmanned aircraft). So whatever aerofoils the 1920 rocketplane designer chose, they were quite adequate for his size of model even by modern standards.

There's not enough remaining visual information in the photo to identify the rear wing's aerofoil, but the RAF 6E looks a likely match for the canard aerofoil.



RAF 6E aerofoil (circa 1912)

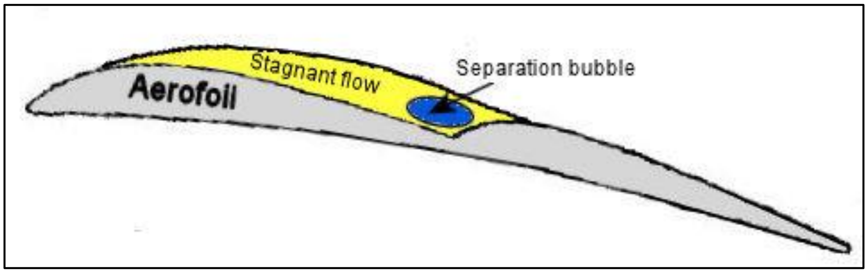
Having said that, there appears to be a definite 'valley' around the 40% chord (4/10ths of the distance from the leading edge) of the upper surface of the canard aerofoil.



Closeup of the canard

There are a number of possible explanations:

1. It’s just a phantom artifact due to photography/subsequent photocopying/subsequent computer enhancement. And yet, there appear to be several circular depressions across the canard wingspan at the 40% chord.
2. It’s a balance horn, as used on the Fokker Triplane of 1917. Why would a model aeroplane need an aerodynamically-balanced elevator? Because the article mentions clockwork timer-actuators used on subsequent models, and clockwork hasn’t the power of modern electric servos. As the 1920 model was recovered intact from the other side of Loch Lomond, this implies it didn’t land at its 180 mph average speed or it would’ve broken up. Rocket-boosted model aeroplanes generally require a change in elevator setting sometime after the rocket motor has burnt out to raise the nose to reduce landing airspeed.
3. A bit left-field but very intriguing: several of Eiffel’s 1914 aerofoils literally had two humps! This author reckons that Eiffel stumbled across a shape able to deal with the yet-unknown effects of ‘Laminar separation bubbles’ on model-sized wings: sausage-shaped vortices of separated airflow that are a draggy encumbrance. With a modern Aerodynamicist’s eye, Eiffel’s humped aerofoils look like the answer to the question: could you hide a separation bubble by cutting a recess for it spanwise across the wing?



Eiffel 47 aerofoil (0.15 m chord at 25 m/s ⇒ Re = 2.6×10^5) with an suggestion of the airflow

With no other information available, one has to assume that the rear wing had the same aerofoil and chord as the canard wing, as this would’ve enabled a quicker cutting-out of all the wings ribs.

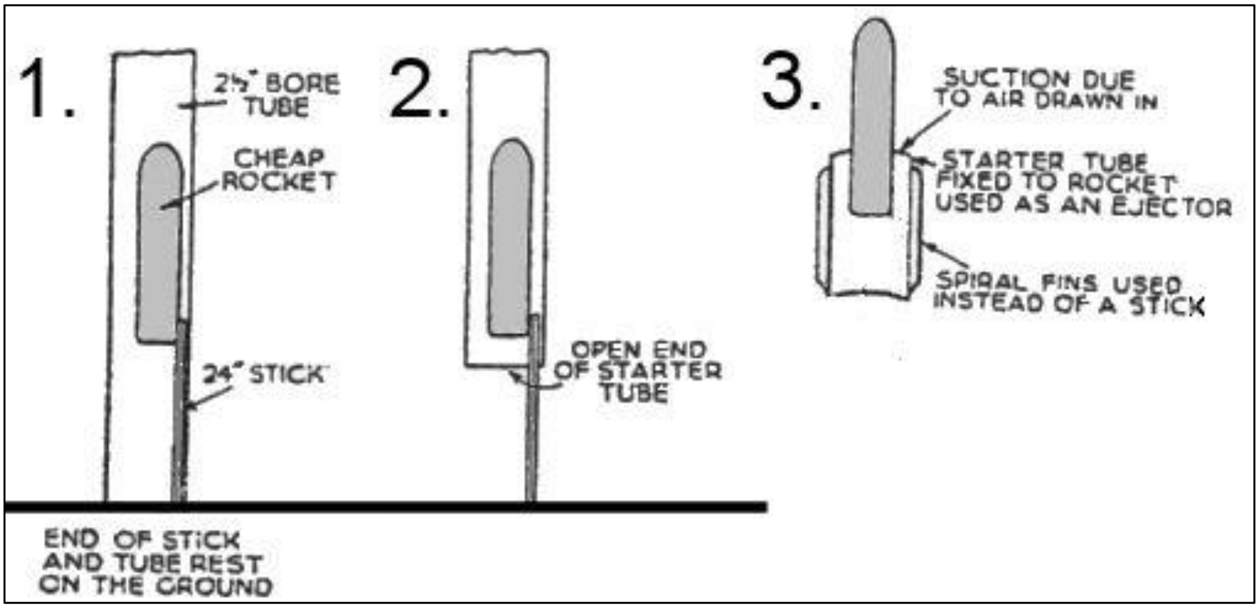
Boosting the thrust

Then the Glasgow Group's rocketplane designer mounted Aldred's rocket motor inside a long cardboard tube fuselage of four inches external diameter, which let him position the rocket propellant *directly at* the aeroplane centre of mass ('CG') as required to thwart the Trim/toast conundrum.

But then he did an extraordinary thing. As you can see from the photo, he didn't close the front-end of the fuselage tube but instead left it open. Every other rocketeer then or now would have plugged the front with a nosecone.

A forward closure would have stalled the rocket exhaust due to what rocketeers now call the 'Krushnic effect': a killer back-pressure due to a build-up of rocket exhaust gas inside the tube. Typically, 80% of the thrust is lost. (Richard Krushnic's effect was correctly interpreted in the 1960's, forty-plus years after the Loch Lomond flight.) Instead, introducing a flow of air down the inside of the fuselage tube amplified the thrust of his rocket motor roughly six-fold, for reasons described in Part 2.

How did he know to do this? The Flight magazine article suggests that readers might like to recreate a series of experiments with little firework rockets, that the Glaswegian schoolfriends performed, doubtless prior to their first rocketplane flight.



Three firework experiments (original Flight magazine article diagram, enhanced)

Experiment 1: fire one out of a long mortar-tube.

"*The first experiment… is easy to try. The writer (J.J. Smith?) used a rocket 1½ inches diameter and 6 inches long in a 20-foot-long (6.1 metre) rain-water pipe of 2¼ inches (internal diameter). This was set down tight (into the ground, sealing the lower end of the pipe-tube) over the rocket while the slow fuse was burning. See diagram 1. You may find your rocket covering twice the distance, due to its better start.*"

Note that the stick kept the rocket motor's nozzle 24 inches (0.6 metres) off the plugged lower end of the 'starter tube'. This - and the very loose fit of the rocket in the tube - prevented the Krushnic effect.

Experiment 2: "*The rocket is put in the tube, (but instead with) the (lower) end of the tube wide open. (The tube is still affixed to the ground, but some distance above it, leaving an air gap). (You) will find that the rocket will fly almost as well as it did with the end of the tube resting on the ground. The remarkable thing is that the tube is jerked upwards while the rocket is inside and after the rocket has left the tube.*"

Author's note: I tried Experiment 2 but didn't observe the tube being jerked, so it's probable that their ascending motor's stick-fin snagged on the bottom of their tube, creating a brief upward tug.

It was then only a small leap for the schoolfriends to bolt a bit of the tube to the rocket vehicle to see what happened. This was experiment 3: the creation of an Ejector tube.

"*The simplest ejector consists of a plain tube of steel or cardboard. If the rocket (motor) is of 1½ inches (external diameter), the tube should be about 2 inches or a little more, and 4 inches long.*"

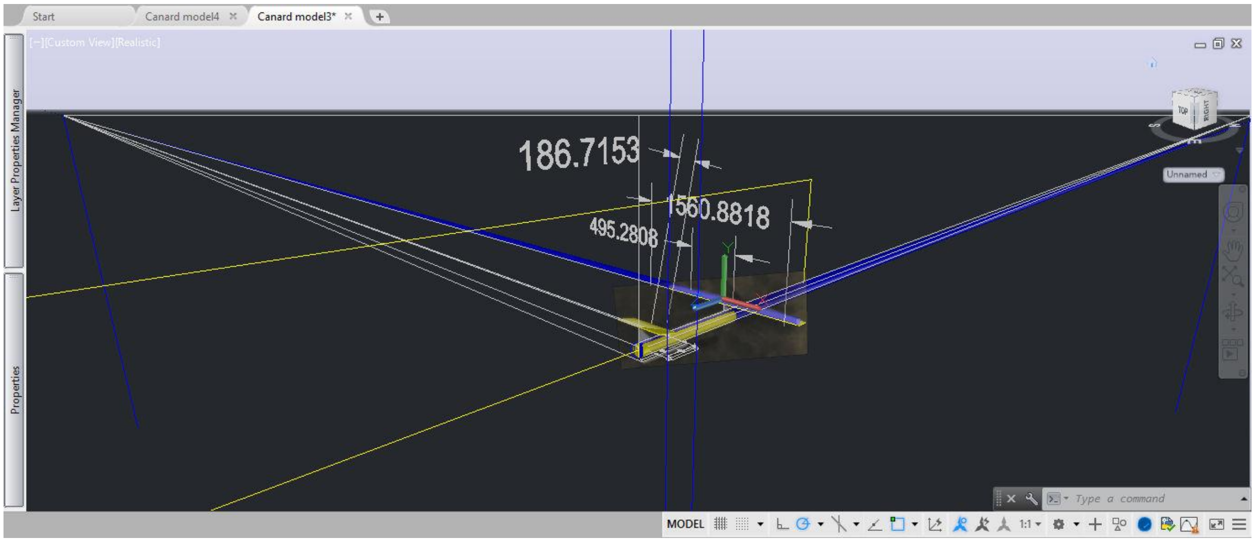
Obviously, a cardboard duct needs thermal protection. John Stewart of the Paisley Rocketeers Society suggested this author try soaking cardboard Ejector tubes in a powdered Alum (Aluminium sulphate) solution because Alum will fireproof paper to a certain degree (it is used in aqueous solution to produce rocketry 'wadding'). Unfortunately, the alum protection failed.

The Glasgow Group's 1920 rocketplane cardboard Ejector tube/fuselage had the benefit of Clydeside technology: its inner wall was thermally protected by "*a flame-baffle tube*", a terminology that meant a specific device to Steam turbine Engineer and article co-author J.J. Smith. One can envisage a metal pipe of the diameter – or just less than – the inner wall of the cardboard tube. However, experts tell me that a low-temperature Cat AN exhaust could also have allowed a paper-phenolic tube to survive.

Recreating the model

In an effort to recreate the Glasgow Group's 1920 rocketplane, one first has to convert the above ancient 2D photo into a 3D CAD drawing. Modern photogrammetry software requires two or more photos taken from different angles to construct a 3D object, so is of no use.

Instead, two-point perspective projection had to be used, reversing the usual procedure to convert a perspective photograph into an orthographic 3D model. Fortunately, aeroplanes are usually symmetrical in plan-view, with wings orientated at right-angles to the fuselage, which is a simple cylindrical tube in this case. Furthermore, the lack of visible vertical fins results in an original model with minimal vertical height, therefore two-point projection is adequate for reconstruction, rather than requiring three-point projection to deal with perspective effects on height.



Perspective deconstruction of the rocket plane with two vanishing points.

It was possible to create a 3D CAD model which tallied with the dimensions given in the article to a few percent (about +-12 mm):

Main/rear wing: span 48 inches (1219 mm), chord 5 inches (127 mm), planform area 0.155 m^2

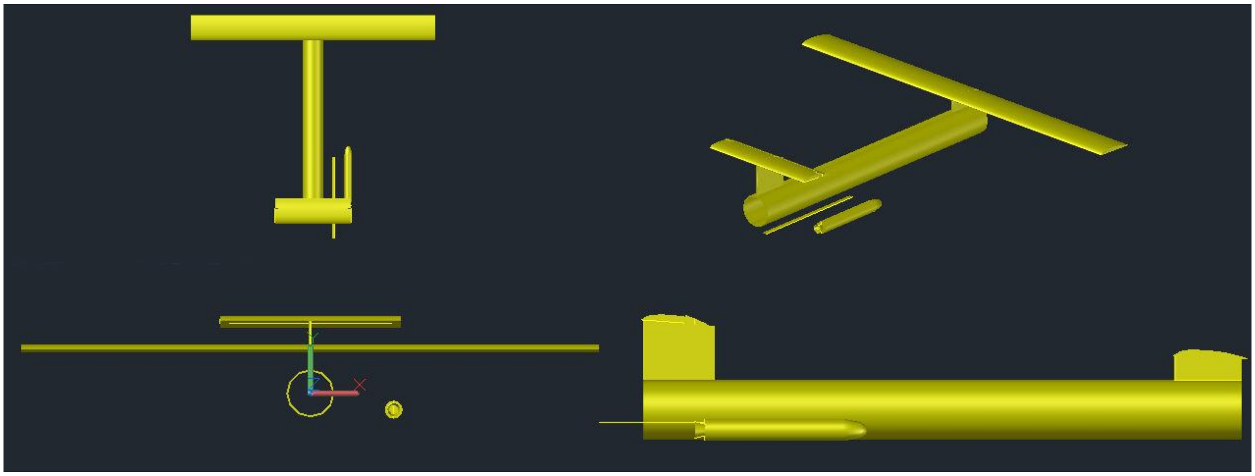
Canard wing: span 15 inches (381 mm), chord 5 inches (127 mm), planform area 0.048 m^2

Total wing plus canard planform (‘wing’) area: 0.203 m^2

Fuselage tube: 4 inches (102 mm) external diameter, approximate length 40.4 inches (1027 mm)

The fuselage wall is about 4mm +- 1mm in thickness.

The canard appears to be rigged at +4 degrees to the fuselage tube, so the rear wing was assumed to be rigged at around +2 degrees for typical longitudinal dihedral stability.



The resulting CAD model including the rocket motor and tape-measure from the original photograph.

The 1920 flight

Loch Lomond in 1920 was very much the recreational area it is today, but with much more personal freedom and less Tourism larceny. It was a Loch the author Arthur Ransome would've approved of; the late, great, powerboat champion Lady Fiona (Countess of Arran) was brought up mainly on the Loch's Inchconnachan Island.

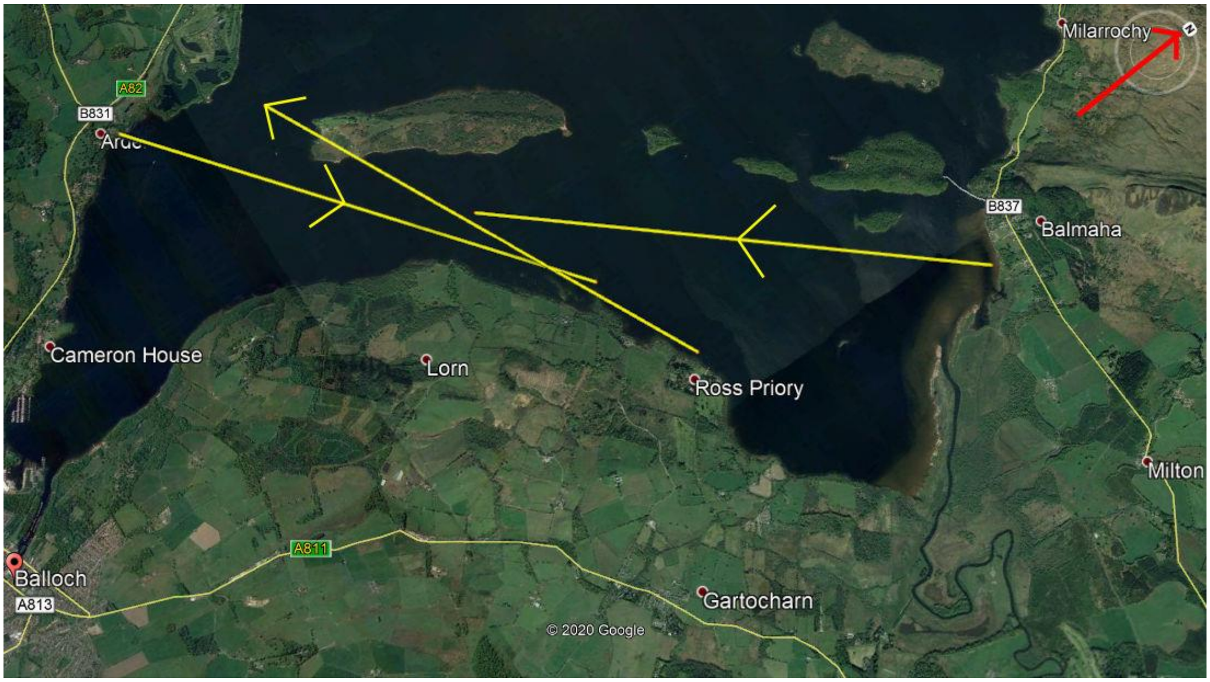
There were many houseboats on the Loch in 1920, and many places where poorer folk could hire little rowing boats, and you could camp where you liked of course. Nowadays, the Park's Fun-Police regularly fine visitors, and tow their vehicles away to be crushed.

History doesn't record where the 1920 flight occurred, The Flight magazine article merely states that "*The early models had been carried out of Glasgow by lads on bicycles and used on Loch Lomond with the help of rowing boats and other paraphernalia*,"

Boating experts at Loch Lomond advise this author that the water south of the chain of islands demarcating the ancient Highland Boundary Fault would've been the most suitable location, as this end of the Loch is wider and calmer. And it was also easier to reach in 1920 because a railway line used to run between Balloch and Drymen (now a cycle track), and another linking Drymen to Glasgow (now the southern end of the West Highland Way walking route).

Railways in 1920 (National Library of Scotland)

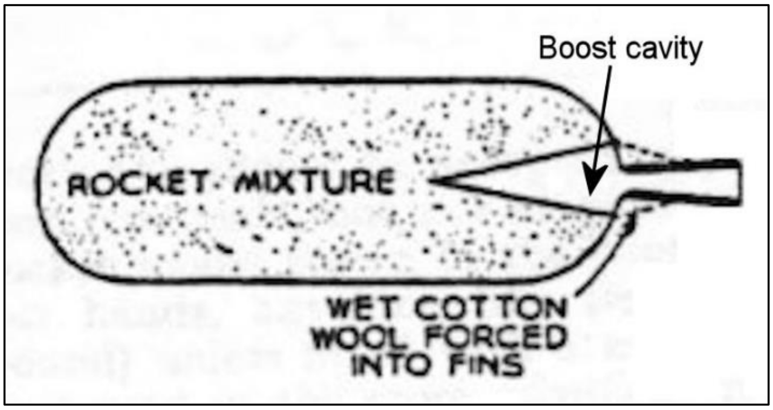
The alternative is the unremitting slog from Canniesburn Toll, climbing up the A809 Drymen Road to the Queen's view by the Whangie ridge. Their bikes might not have had gears!



Possible flightpaths of three-mile length (the flightpath mightn't have been that straight in reality).

The rocketplane raced off its floats and into the air. Though the rocket motor could cigarette-burn for 75 seconds, that would've been longer than the actual one-minute flight, so Aldred may have moulded a boost cavity or central port into the rocket propellant charge.

Locally increasing the propellant's burnable surface area in this way uses up the propellant more quickly, perhaps resulting in a 20 second burn time. The article shows a boost cavity (this author's annotation) in the propellant grain of a sketch of a later Aldred motor:



A later Aldred motor with conical propellant cavity. Note the diminutive long and narrow nozzle.

The article makes it clear the rocketplane flew further than expected, nearly right across the Loch but fortunately not, because if it had landed in onshore undergrowth, they may never have found it. Instead, it was recovered floating in the Loch (presumably intact), even though it can take nearly an hour to row across that wide stretch of Loch Lomond.

Part 2: Rocket Ejector duct research

Emboldened by their success, our Schoolboys formed a research group to try and discern *why* their rocketplanes managed to fly so far. Even committing the High School physics cardinal offence of ‘neglecting air resistance’, Aldred’s rocket motor could never have sent the Glasgow Group’s rocketplane that far at that airspeed, unless its thrust had been amplified many times over (around six-fold).

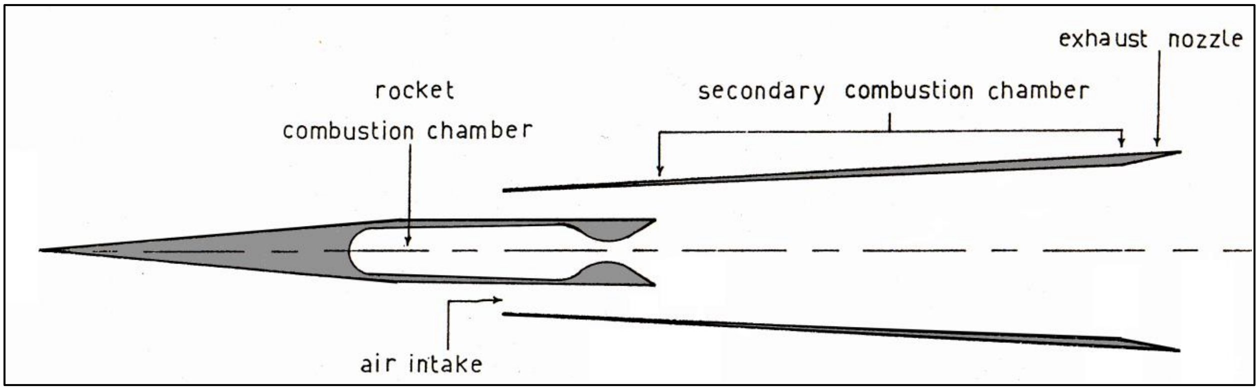
The question is, how was the thrust increased?

Terminology

A Rocket Ejector consists of a primary rocket exhaust which is discharged into the confines of an aerodynamic shroud, or duct. As the exhaust leaves its primary nozzle, it undergoes turbulent mixing with the surrounding secondary airstream within the duct, and as a result, introduces an entrained flow-field about the device.

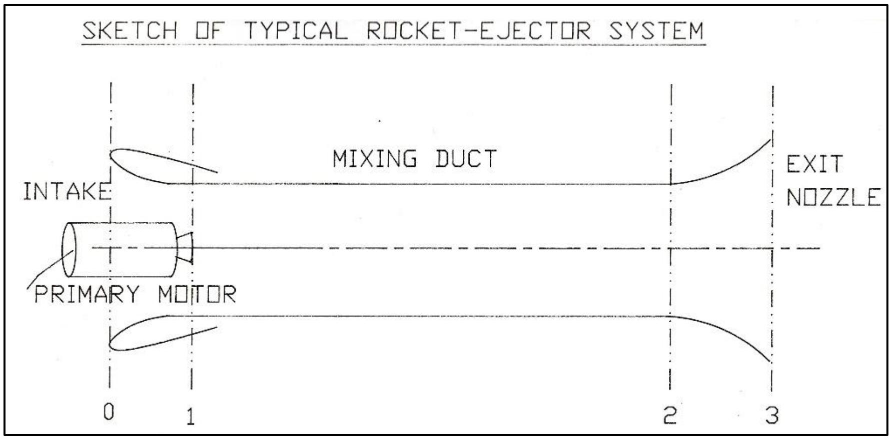
Augmentation in thrust is realised through the combined effects of the exhaust being discharged into a region of lowered pressure, the induced pressure distribution on the surface of the duct, and the expansion of the mixed flow down to ambient pressure through a nozzle at the duct exit.

Rocket Ejector systems are a subclass of air-augmented rocket systems. In an air-augmented rocket, the primary rocket motor is burned fuel-rich, providing excess fuel to be burned in a secondary combustion chamber immediately downstream of the rocket nozzle. The primary nozzle efflux substitutes as a flame-holder to anchor the combustion in the secondary chamber.



Air-augmented rocket system (a type of ramjet).

A Rocket Ejector system doesn’t employ secondary combustion because its primary rocket engine burns ‘stoichiometrically’ (neither fuel-rich nor fuel-lean).



A typical rocket-ejector.

The myth of 'thin air'

Physics teachers and popular culture have it that Earth's Atmosphere at sea-level is nebulous and can be ignored; "thin air". Actually, A force equal to the weight of six adult Elephants presses in on our skins; sea-level pressure and density are enormous.

It was well-known even a century ago that rocket engines suffer the Atmosphere. Rocket engines work because of the difference in pressure between their inner Combustion chamber and the world outside. Thick sea-level atmospheric pressure pushes backwards up the rocket nozzle and reduces this difference in pressure, which therefore kills a lot of the thrust. This is the reason why launching any kind of rocket vehicle at ground level is a fundamentally daft idea, unless that ground is the peak of Ben Nevis.

Rocketeers compensate by upping the pressure inside the Combustion chamber, but this ploy doesn't work particularly well. Common sense suggests that simply upping the Combustion chamber pressure by one (sea-level) atmosphere would restore full thrust, but the physics decrees this is not to be.

You get perhaps 75% of the thrust back, but at the cost of a much thicker-walled - and hence heavier – Combustion chamber, and the rocket propellant pumps have to work much harder to supply the higher chamber pressure. All this results in far more expense, and a far greater risk of 'the boiler exploding'.

Aldred's motors operated at relatively low Combustion chamber pressure, so suffered particularly at sea-level. Therefore, they benefitted most from the air augmentation effect that I'll now describe, as the Glasgow Group discovered.

Slowing the exhaust down

First off, a properly-shaped duct can create a venturi which lowers the pressure around the rocket nozzle exit. But even if it were possible to drop the pressure inside the tube to vacuum – which it isn't - this would only increase the rocket engine's thrust by less than twice.

However, the laws of maximising propulsion efficiency state that the gas exiting the rear of any air-breathing engine should do so at exactly the same airspeed that the vehicle is moving forwards, and thereby ends up with zero exit speed relative to the Atmosphere: the exhaust gas then literally hangs motionless in the sky. This is well known to aero-engine designers; the air/gas leaving the rear of the most efficient propellers or jet engines does so with zero residual 'kinetic energy'.

But a rocket nozzle spews out its exhaust gas at 9000 kilometres per hour, which at low flight-speed spears into the atmosphere creating a great deal of noise, waste heating, and an unwanted suction on the base of the rocket vehicle known as ‘base drag’ which commercial rocketry could do more to eliminate.

Alternatively, you can mix air into the rocket exhaust in a controlled manner inside an Ejector duct. Air at low altitudes is relatively dense, so this mixing (known as ‘entrainment’) slows the rocket exhaust such that the mixed flow exits the duct at the required zero airspeed relative to the Atmosphere outside.

The ‘base drag’ vanishes, to be replaced by a serious increase in performance; the thrust can be amplified tenfold at low flight-speeds. It’s both a momentum exchange between the rocket exhaust and the incoming air, and it’s also a recovery of the otherwise wasted heat within the rocket exhaust which is then used to expand the mixed flow.

It’s the same principle as using a core Jet engine via a reduction gearbox to drive a large-diameter fan in a turboprop or turbofan: the airflow leaves the large fan at the same speed the aircraft is moving forwards.

But the devil’s in the detail: get the duct shape slightly wrong, and you can negate the thrust augmentation and thereby create a *loss* of thrust. And you can even ‘stall’ the duct and lose *all* the thrust in a Krushnic effect.

Spurred-on by the Glasgow Group’s Flight Magazine article, this author investigated Rocket Ejectors at University in the 1990’s, but the mathematical tools used weren’t much improved from their time. Despite being such a simple engine, there’s so much going on inside the mixing duct of a Rocket Ejector engine that the only way to investigate properly is to literally construct one. Nowadays, we can create a virtual engine using Computerised Fluid Dynamics (CFD), but back then the only recourse was to build actual hardware.

For example, going back to the Glasgow Group’s 1920 rocketplane with its textbook basic engine: the Ejector duct was the simple cylindrical tube forming the fuselage; ergo the intake and exhaust ends of the duct had exactly the same cross-sectional area. Therefore, only a higher pressure at the exit as compared to the intake could’ve generated the extra thrust.

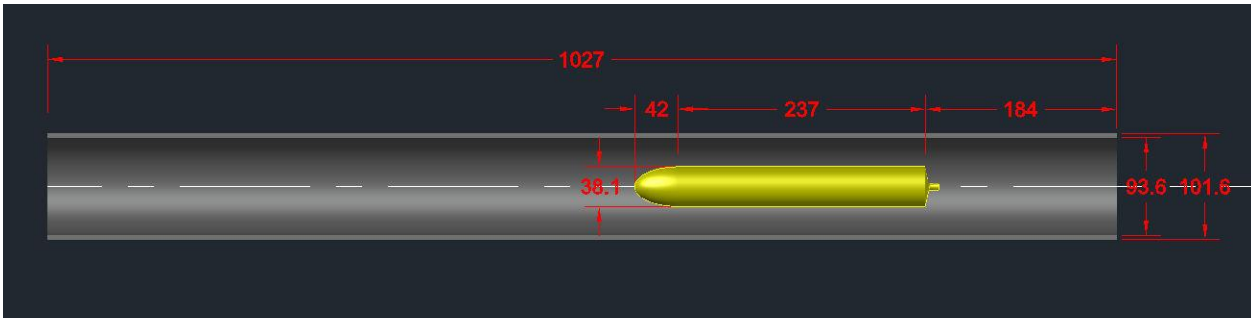
And furthermore, all aero engines generate thrust by dint of gas pressure pushing on *something* angled in the flight direction, be it the propeller blades, the front of the Combustion chamber, or the conic wall of a nozzle. But the Glasgow Group’s first duct was just a cylinder which has zero taper: there *is* no component of wall surface area in the flight-wise direction for pressure to push upon, so how did it generate thrust?

The article states: “*We can say it is clear that the stream of escaping (rocket motor exhaust) gas sets up a high-velocity stream of air (through the duct) which drives the whole system along, but just how is a matter for aerodynamic experts to decide… Our guess was that the escaping flame drew in a lot of air and so created… (a ‘suction’ at the intake)*.”

Ironically, subsequent research in the 1980’s showed that the most efficient shape for an Ejector duct (assuming the rocket engine exhausts into the duct at ‘stochiometric’ conditions) is in fact a simple cylinder. This explains the decent results obtainable with cylindrical ducts fashioned from of old tin cans.

Simulating their engine

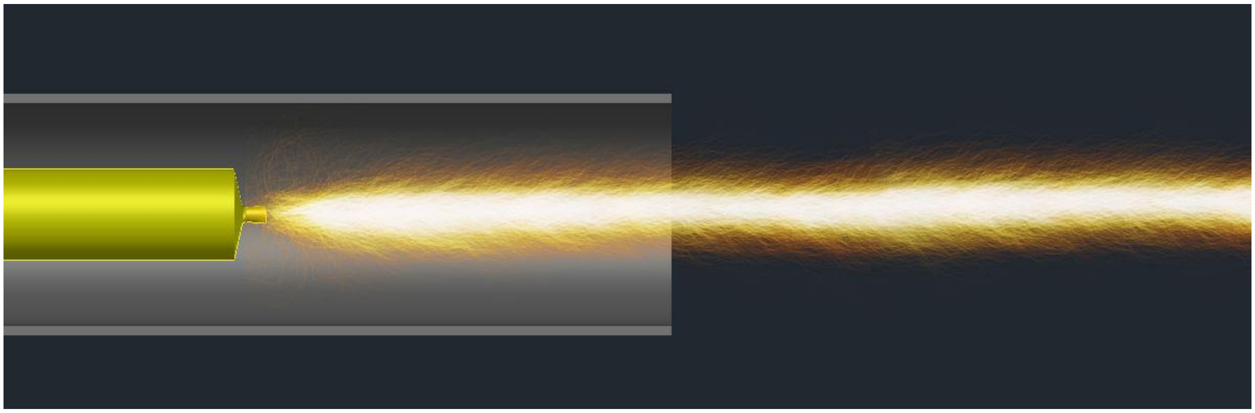
Just at motor ignition, the Glasgow Group’s 1920 rocketplane was at rest on the Loch. Here’s a cutaway sketch of the inside of the fuselage tube:



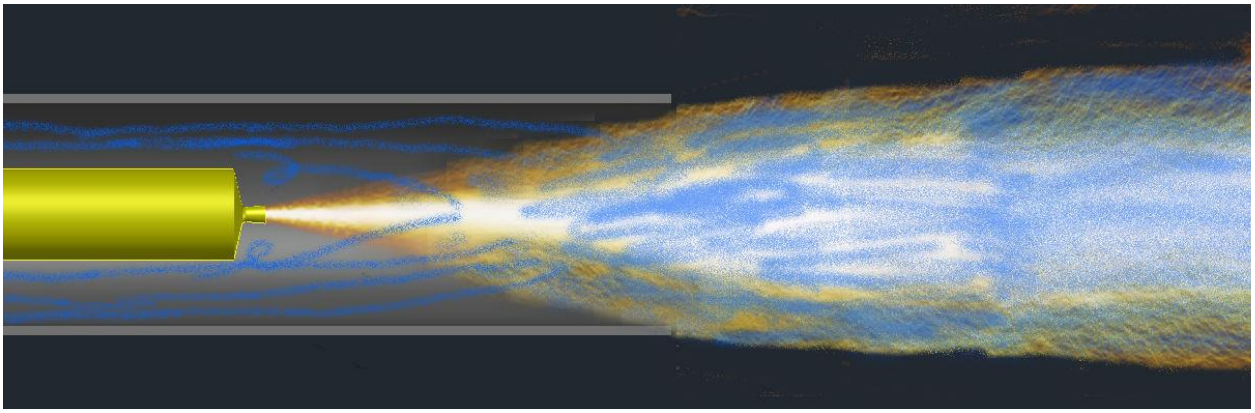
Simplified cutaway of 1920 rocketplane fuselage/Ejector tube.

The ‘flame baffle tube’ isn’t shown; neither are whatever vanes supported the motor in the tube.

Just after ignition, the motor then built-up thrust, and exhausted roasting-hot gas out of its nozzle, producing a plume inside the fuselage tube:



But almost immediately, the edges of this bar of flame sucked-in air within the tube, sucking an airflow into and along the tube upstream of this entrainment region:



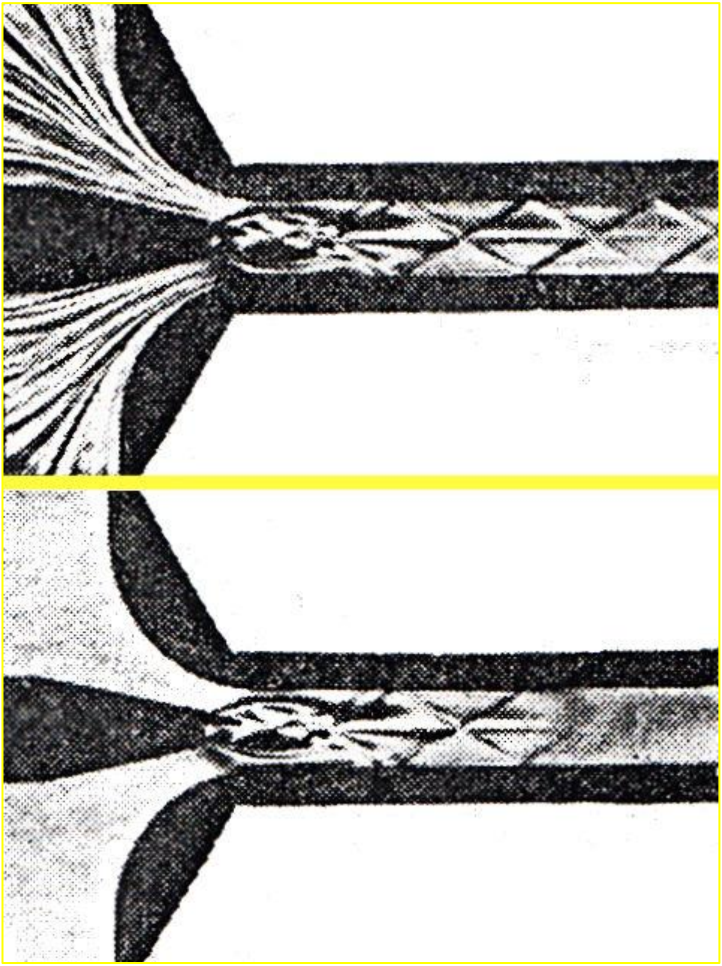
The two flows mixed, and the flow of air dropped the local pressure in the mixing region, resulting in a much cooler, fatter (‘under-expanded’) rocket exhaust, which exited the rear of the duct at a speed similar to the eventual forward airspeed of the rocketplane that the duct was bolted to.

But here’s the rub: just as the entrainment mechanism set-in but the rocketplane was still at rest, what was the flow rate of the air being sucked down the tube and into the rocket exhaust? Once this is known, the thrust of the Rocket Ejector can be estimated using standard thermodynamics. There’s no propeller in there however, so the conundrum is how to pre-guess this airflow either with the duct at rest or at higher rocketplane flightspeeds.

Air-augmented ejectors were studied for military missile uses post-World War 2, but most of this research is still classified. The hope is that the Glasgow Group developed rules-of-thumb to estimate this airflow based on the results of their experiments, and that this knowledge still exists in a cobwebbed filing cabinet somewhere in Glasgow.

The throat of the rocket motor nozzle has to ‘choke’ in order to maintain a reasonable Combustion chamber pressure, which thermodynamically implies that the nozzle flow adjusts itself such that the flow through the throat is travelling at Mach One relative to the nozzle (and Mach One equates to an ever higher flow speed the hotter the gas travelling through the throat gets).

The flow exiting the rocket nozzle throat does so at supersonic speed relative to the nozzle, and therefore ploughs into the duct airflow at high Mach. This greatly enhances the mixing/entrainment, but also results in an annoyingly complex field of shockwaves emanating from the nozzle exit that literally bounce off the duct wall, as these Shlieren photographs show (a photographic technique that reveals shockwaves):



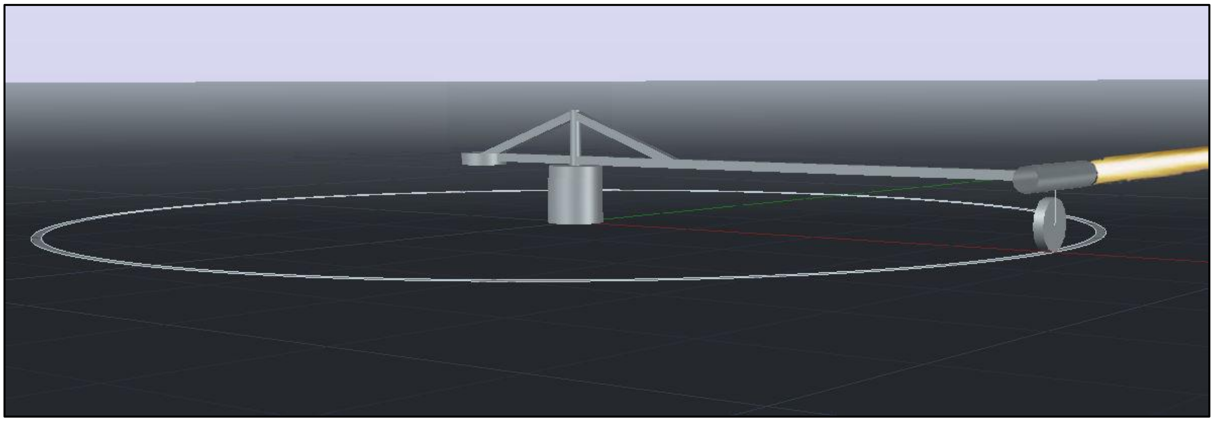
Shlieren photographs of a Rocket Ejector system (with a wide intake on the left).

The mixed flow properties (pressure, temperature, flow speed and direction etc) change abruptly as the flow passes through each ‘reflected’ shock, which makes mathematically modelling the process exceedingly difficult without resorting to CFD analyses.

Testing actual hardware

The internal aero/thermodynamics of a Rocket Ejector duct and its mixing are horridly intriguing, and certainly piqued the interest of the Glasgow Group. Over the next decade their research group became credibly well-equipped. They built two research stations at deliberately remote locations: one in Sutherlandshire – the very north of Scotland – and another in Cumberland (now part of Cumbria) just south of the border with England. Ms Roberts and Mr. P. Blair appear to have owned property/had contacts at these locations.

These research stations had large instrumented arms 30 feet (9.1 metres) long rotating in the horizontal plane. These arms were supported on a massive vertical axle and boss at their root, and at their tip by a wheel running around a circular concrete track (the tracks probably still exist). On the tip of the arms were mounted Rocket Ejector engines of fair size, which whirled round at high airspeeds. They knew this ‘felled wind turbine’ test-rig was intrinsically dangerous, but it was too useful a research tool to ignore.



An interpretation of their spinning-arm test rig.

They mounted a cine camera on the arm to record their experiments, using the known frame-rate of the camera for timing information. We do exactly the same today with miniature wireless video-cameras.

The article claims they reached airspeeds equivalent to Mach 2 at the tip of the arm, which equates to that 30-foot arm revolving 11 times a second under rocket thrust. That would be a sight to behold, but preferably through binoculars from a long way away!

‘Centrifugal’ acceleration at the tip of the arm would’ve been a hefty 50 gees at that RPM, so there must have been a large counterweight on the opposite side of the axle otherwise the rig would’ve spectacularly disassembled itself. (Such high gees might have skewed their data somewhat, but would have ensured that the engine exhaust was flung clear rather than be re-ingested on the next revolution.)

Variable geometry intakes and nozzles

As aero engine designers know to their cost, airbreathing engines can only be designed for one airspeed. To get them to work efficiently at other airspeeds requires ‘variable geometry’: altering the pitch of the propeller blades, or varying the areas of the engine intake and exhaust nozzle on a Jet engine, to retune the internal airflow.

And when the aeroplane goes supersonic, the flow into the intake changes dramatically. So it requires a completely different intake design, generally involving some sort of cone or ‘spike’ sticking out from along the intake centreline to generate a conical shockwave.

This author couldn’t figure out how the Glasgow Group’s Ejectors could remain efficient at Mach 2 with just a circular tube opening – a ‘Pitot’ intake. But of course, the rocket motor and its little nosecone (as seen in the above rocketplane photo) formed a central body ‘Aerospike intake’ providing the requisite conical shock. (Not to be confused with an ‘Aerospike nozzle’, which looks like an Aerospike intake but works differently.)

Variable-geometry – particularly supersonic intakes – are mechanically complex and generally heavy. The Glasgow Group reckoned this would involve too much complexity during prototyping, so by necessity came up with a singularly cunning solution based on the principle of rocket vehicle staging.

Rather than installing a variable-area mixing duct plus variable-area nozzle on their Rocket Ejectors, they simply jettisoned successive parts of this duct-plus-nozzle combination at a predefined set of increasing airspeeds. Somehow – this can’t have been easy to calibrate – each part was designed to separate at a particular value of Dynamic pressure (square of airspeed). This ensured that each section ‘staged’ at the requisite airspeeds (of typically 240, 550, and 1230 mph respectively).

The use of a timer wouldn’t have worked, as the time taken for each engine to reach a particular airspeed couldn’t have been accurately predicted in advance.

DECEMBER 2ND, 1943 FLIGHT

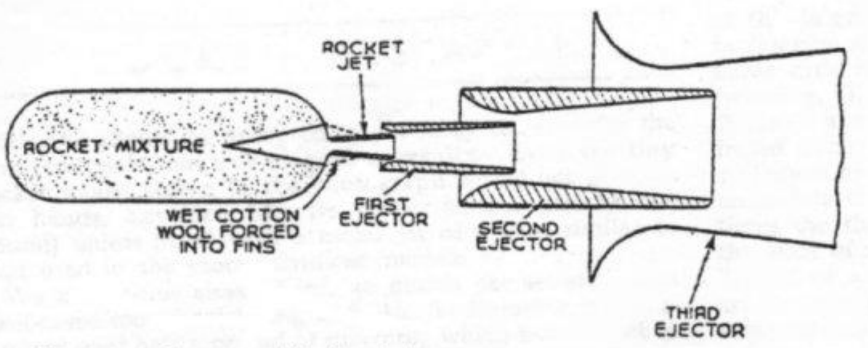


Diagram 4 shows an Aldred rocket.

Note that this diagram reverses later rocket-vehicle staging convention: the 3rd Ejector is staged first at the lowest flightspeed.

The few modern researchers who’ve considered Ejector augmenting their vertically-launched rocket vehicles have baulked at the mass, drag, and required complexity, of the Augmenter duct.

But the Glasgow Group’s ethos of simply jettisoning successive parts of the duct when no longer required obviates these worries, especially with modern composite construction and 3D metal printing. As you can see from this diagram, successive Ejector duct ‘stages’ are smaller and lighter.

On later experiments, ‘flights’ of more than 30 minutes had been accomplished according to the ‘Flight’ article, though it isn’t stated how: a 30-minute-burning solid-propellant grain seems improbable (though a Cat AN grain can do so), which suggests a switch to liquid propellants; the merits of which are discussed in the article.

Anticipating much later 1990's experiments by this author and others, the Glasgow Group found that multiple motors set around the internal wall of the Ejector duct (rather than one motor on the central axis of symmetry) yielded better mixing and hence greater efficiency: their article describes a cluster of nine motors.

In 1939, the Glasgow Group achieved a successful flight trail for the Ministry of Aircraft Production, who were unimpressed by the fact that the group used a Rocket Ejector engine to launch a full-scale Tiger Moth aeroplane into the air, using just one pound (454 grams) of rocket propellant. The Moth's pilot was certainly impressed!

That Ejector duct was 11 feet (3.4 metres) long, and 22 inches (559 mm) in diameter, and massed just over 33 pounds (15 kg). It developed 150 pounds-force of thrust (667 N) up to 50 mph airspeed, which reduced to 100 pounds-force thrust (445 N) by 100 mph.

Assuming an augmentation ratio of 10 at lowest airspeed, the core rocket engine would have developed around 15 pounds-force of thrust (67 N), which corresponds to the 'larger engine' mentioned in the 'Flight' article (a 'J' Total-impulse class) which had a burn time of 70 seconds. The fact that a long-burn J-class could be augmented sufficiently to give a sizable kick to 700 kilograms of full-size light aircraft is remarkable.

Where did they go?

What happened this Glaswegian rocket research group? Just as their research was bearing fruit, mankind decided to have another war.

The article authors state that all but one of their research group (presumably Ms Naomi Roberts) "*are in the Army now.*" The January 1944 reply to a reader's letter refers to the main article having been written by "*Private Smith*". I fear that none of them survived World War 2, or too few of them to reform the research team.

Perhaps they felt that advances in Jet engine propulsion had rendered their technology obsolete, and yet the article states that: "*we can see the next step… the advantage of drawing air from an engine and compressor is obvious.*"

In a very short half-page article published in the same Flight journal two months later (Feb 3rd 1943) J. Dennis describes their future plans "*the design due to J. J. Smith… (which we would have made between September 1939 and May 1940 if the war had not intervened) would have used a 500 horsepower (373 kiloWatt) engine which uses all its power in compressing air.*

This air would have been fed into a ring of two-stage injectors… and fed with fuel oil. The engine would have consumed about three quarters of an ounce of fuel oil per second (1.3 kg/minute), and the injectors about a quarter of a pound in the same time (6.8 kg/minute). The propulsion power should have been about 400 horsepower (298 kiloWatts).

Using a Williams internal combustion turbine engine as (the) compressor, that would have scaled about 4 hundredweight (203 kg), and the jet system about 1 hundredweight (51 kg)."

This *would* essentially have been a Jet engine, but without the power coming from a turbine in the exhaust. Had this enhancement – known as a 'fan rocket' - been built, it would be a very fine Spaceplane propulsion unit today.

(Incidentally, it's unlikely that the 'Williams' referred to in the above quote was the late Dr. Sam Williams of 'Williams International Jet engines' USA, because he didn't earn his Degree from Purdue University until 1942.)

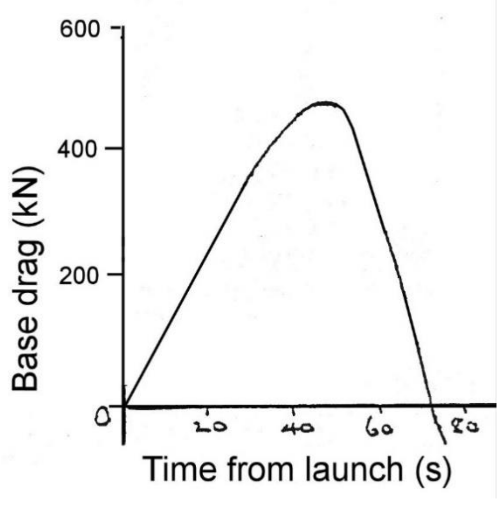
Their 'Flight' Magazine article ends prophetically: "*aircraft were not ready for ejectors in 1939; they were too slow. Because of this we could not expect much notice to be taken of our work in the Misty North.*"

Sadly for them, they were ahead of their time. Ironically, Jet and rocket engines would take aeroplanes way beyond the Sound barrier only a few years later.

Spaceplane designers such as myself would love to review the Glasgow Group's research data, because they had created a low-cost engine that could start from rest and potentially reach Mach 5 without the need for turbines (that tend to melt). We need that engine today.

The fact is, that for over a Century Ejector augmentation of low-altitude rocket vehicles has been demonstrably shown to work; most impressively at subsonic flightspeeds, but still usefully at supersonic flightspeeds.

For example, the venerable Space Shuttle was a wonderful Spaceplane, but the way it was launched was awful. As well as being a highly dangerous launch – even *without* the tying of firecrackers to both sides of the propellant tanks – the Shuttle 'stack' suffered horrendous base drag during ascent, and the liquid Main rocket engines had to be red-lined to ludicrous Combustion chamber pressure to generate the necessary thrust at sea-level. For the initial 70 seconds (up to Mach 3), up to ½ a million Newtons of base drag could have been negated and doubtless converted into a positive thrust, using a Rocket Ejector duct system.



Space Shuttle Stack base drag (from flight data – Townend)

Bear in mind that the Glasgow Group's 'air-breathing' engine didn't actually breathe (utilise the oxygen) so would work happily within other planetary atmospheres around our Solar System, and also underwater. Also bear in mind that the rear of an Ejector duct can be swivelled to provide steerable ('vectored') thrust.

As for Mr Aldred, it’s possible that his superior propellant (and possibly he with it) was spirited away to a wartime rocket research lab such as the nutty Directorate of Miscellaneous Weapons Development (the *original* ‘Q’ branch). He didn’t go to Wescott or Ardeer, nor wrote in the usual rocketry journals. He seems to have simply disappeared.

Father Time decrees we’ll never get the chance to chat with the Glasgow Group research team; like the original Paisley Rocketeers, they’ve passed away. If only a Time machine could bring them forward 100 years: how they’d love today’s 3D printing, first-person-view (FPV) goggles, and drone autopilot technologies. It’s likely they’d immediately apply for jobs with Reaction Engines Ltd, as the SABRE engine is in many ways the latest extension of their technology.

It’s this author’s dearest hope that some reader of this article might have the Glasgow Group’s precious research data stored away in an attic. They deserve proper historical recognition, and the use today of their hard-won rocket science.

References

J.J. Smith and J. Dennis, *'An account of experiments carried out in Scotland from 1934 to 1939: some startling results obtained - fresh field for Amateurs'*, Flight magazine (UK), 2nd December 1943, pp 610 – 613

'*A one-dimensional flow model for air-augmented rocket*', JBIS vol 26, pp 18-27, 1973

David Newey, '*Optimization of ammonium nitrate solid rocket fuel'*, BSc thesis, Department of Physics of Brigham Young University Idaho, December 2013

Eguchi et al, '*A study on airbreathing solid rocketmotors'*, AAS journal 89-659 pp 619-636

J.H. Keenan et al., '*An Investigation of Ejector design by analysis and experiment'*, Journal of Applied Mechanics, pp 299-309, September 1950

John D. Anderson Jnr, '*A history of Aerodynamics and its impact on flying machines'*

'*Aerodynamic characteristics of Aerofoils'*, NACA Technical Report no. 93, 1920

L.H. Townend, '*The Waverider'*, APECS 1995

https://aerospaceengineeringblog.com/fundamentals-versus-finite-elements-a-case-study-on-the-fokker-d-vii-biplane

https://www.boldmethod.com/learn-to-fly/aircraft-systems/aileron-horns