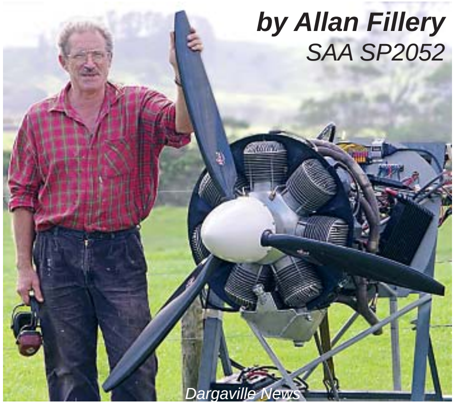
Building an engine

by Allan Fillery
SAA SP2052



From a wishful thought to reality is a tedious process of learning. As a professional plumber, I have learned most, if not all, of the skills needed. The process is painful at times but rewarding when one discovers how to get it right.

Burt Munro had a shelf dedicated to the god of speed. My shelf, which has become rather full, is dedicated to the god of powered flight. Not sure if such high-powered offerings have paid dividends, though; it may be a mite early to speculate. Burt still holds the land speed record for under 1000 cc, so just maybe his offerings worked. I have yet to find that out.

Anyway, it can be expensive in time and cash to prove that the way you tried was not the best. It helps to be able to draw a little and be able to see the drawings in 3D, without those fancy glasses. It is early days for the engine with the odd modification to do. The latest is to add some extra finning to the heads, but more on that later.

I had nursed the idea of building an engine for some time. Many have encouraged the idea and some have questioned my sanity, as I do when things get difficult. Circumstances earlier prevented projects like this, so I was content to play with model engines. I have already built a 9-cylinder radial with a capacity of 78 cc and weighing 2.75 kg. It drove a 20 x 10 three-blade propeller at 7000 rpm, giving 23 lbs static thrust. It was to have powered a model Fairey Swordfish.

Most engines, including lawn mowers, are overhead valves as they are more efficient, but their overall dimension for the horsepower range I was seeking was much too big. I wondered about the effect of a lower frontal area that a side valve would permit and whether the lower frontal area would reduce or even surpass the effects of side valve inefficiencies, particularly with this size of piston.

It appears that Jack Hereford of the USA was thinking along the same lines as he has developed a 5- and 7-cylinder radial side valve using VW barrels and two-piece heads. I purchased his 5-cylinder plans, but I took an immediate dislike to exposed valve springs and I would be very hesitant to use gudgeon bushes and link rod bushes that are small compared to most engines (21 mm diameter 12 mm long).

The cylinders proved to be problematic.

I was, however, buoyed enough to know that the concept works and that he was getting .5 hp per cu.in and about 1.5 hp per lb. Some of his weight saving initiatives could well be at the detriment of durability. However, these statistics are quite good.

As I was not prepared to purchase his 7-cylinder plans at $US500 and then modify them, I decided to tackle the job myself. Unfortunately I had no idea on how he did the internals so that was up to me.

The drawing started about 2000 when I had finished building our home. Researching ideas, trying to make off-the-shelf parts work took most of my spare time for six months with not much to show. Finding FE Mazda valves was a bit of a breakthrough, the length and head size suiting my layout. The rest sort of fell into place.

Soon after, the first blueprint grew out of the copious sketches that littered my half of what had been a tidy office. Condensing the internals into the smallest space possible was no mean task. Many times I would get designer block and never managed to draw Adrienne's cure to this problem.

I settled on Subaru pistons at 93 mm, cast iron sleeves, FE Mazda intake and exhaust valves, Nissan fuel injectors, throttle position sensors etc. The remaining parts needed to be made or cut out of solid plate — billet or cast.

The link rods and master rod would be Aluminac 89, a high-performance alloy rated at 75,000 psi. The crankshaft would be cast 4130. I would like it to be forged, but because it is so short at 300 mm I doubt there will be any casting induced stress. The crankcase will be cast alloy as will the heads and cylinders (alloy type yet to be determined at that stage).

The source of assisting information is *The Internal Combustion Engine in Theory and Practice*, $200 for newish information. It was here that I found the benefit of induction pipe tuning and the Internet to find a formula to do the calculation. A lot of 1930–1945 books provide excellent material, as does talking to many knowledgeable friends.

With the drawing sort of settled, the next stage was to make patterns for crankcase, cylinders and heads. The cylinders would prove to be problematic.

Many ideas would prove not to be the way forward. However, the first Customwood cylinder replica took shape, hopefully making all the necessary allowances for shrinkage. The easiest way to cast this would be the lost wax process, but even this would prove testing to one's tenacity.


Wax cylinders.

To create a wax replica involves making the male pattern and then a female impression in silicon rubber of that pattern. First, Plasticine 6 mm thick covers the pattern, then casting plaster is poured round this in its own special box that has support for valve ports and barrel. This then becomes the mould for the expensive two-pot silicon rubber and later support for the silicon rubber when the pattern is removed.

Liquid wax at 100 deg C is then poured into the void left when the pattern is removed. All parts of this process need to be made so disassembly will not damage the fragile wax replica.

Sounds simple, eh? It became clear that I was stretching the boundaries of silicon and wax in more ways than one. There were huge undercuts behind the valve guides. If the wax was too cold it broke, too hot and it came away with the silicon. When I did produce a good wax it was clear that the

The different stages of cylinder production.

cylinder wall was going to be too thin: bugger! A new pattern, a new silicon rubber mould. All for another 1.5 mm wall thickness. Another tenacity test!

"Take 2" cylinder was duly suspended in its casting box after 6 mm or so of Plasticine was placed over it. First efforts with pouring silicon (treacle consistency) proved that it was easy to create air pockets. Wax would catch in these pockets, making a rough-looking wax difficult to remove. This time I took 20 minutes to pour the 1 litre of silicon into the mould. Six hours later, silicon cured, a nice rubber mould in which to cast the wax.

The heads were a simpler process, made difficult by my using tube silicon to seal up cracks in a very simple mould. To my disgust methyl ethyl ketone (MEK), a solvent vapour given off from tube silicon, completely stuffed the curing of the two-pot silicon. I finished up with $200 worth of gooey, partly cured, stick-to-everything silicon to clean up. Needless to say this didn't make it to the offering shelf as it would have made things more than a bit sticky up there.

I now had nine cylinders and heads in wax and patterns, crankcase and head off to the foundry thinking a couple of spares to practise on would be enough.

When the foundry receives the waxes they attach the sprue (starts off being a handle and finishes up a funnel) and vents, all in wax. This is then dipped into ceramic slurry, dried and dipped again with a more coarse grit slurry several times. When the ceramic is thick enough it is dried, the wax is then melted out and the shell is fired in a kiln. This is now the mould for the aluminium.

At this point I considered that I had got over the biggest hurdles, as my chosen foundry man had said, "Casting the cylinders will be a challenge but not impossible."

Twenty-five attempts and three trips to Auckland later, even our foundry man was feeling the strain. The 85 percent failure rate was not conducive to a good business or client relationship.

However, I had three successfully cast cylinders with another four to come, hopefully with 100 percent success rate (I modified the wax pattern to aid the flow of metal in the casting). It appeared that the shell mould was cooling too fast, preventing the metal flowing in to the fins. The cylinder heads and crankcase pieces proved to be easily cast when one compares them to the cylinders.

At this point Adrienne and I decided to shift house, so I took a couple of years off from engine building.

A design change of the combustion chamber meant new heads. Not really a major as the old ones were crap castings anyway. One major near-catastrophe was a considerable difference in the way the wax set in the silicone mould. I was temperature controlling the wax being poured but not the mould, so sometimes the mould would be warm, and others cold. This gave different shrinkage rates of up to 2 mm for valve centres, something that was not picked up until jig making prior to machining.

There were some tense moments sorting the best average measurement. One of the reject castings was used as a test for fitting valve guides — seats and shrink fits for cast iron sleeves. All went together without any drama, although I was a little concerned when taking a sleeve from an overnight stay in the freezer. Ice quickly formed around the sleeve, but it still dropped into the 150 deg C cylinder with no bounce (you get only one shot).

Machining the crankcase had what I call normal stress moments. It is difficult to go into all the details, but notable snags were aligning the two halves and fitting the 9 mm fitted 4140 studs with ±zero fit. All mandrels and drills were made to suit from silver steel. A few experiments with off-the-shelf drills and reamers proved that drilling the perfect 9 mm hole 120 mm deep by seven times was too much to ask from my budget machines. The seven studs keep the engine halves in perfect alignment and also prevent the propeller from pulling the motor apart.

The crankshaft started as a casting made by Wade Engineering. I requested it be x-rayed to prove the quality of the 4140 alloy casting prior to paying the account. This done, it was duly sent to me. Upon opening the bag my "x-ray eyes" could see porosity from a

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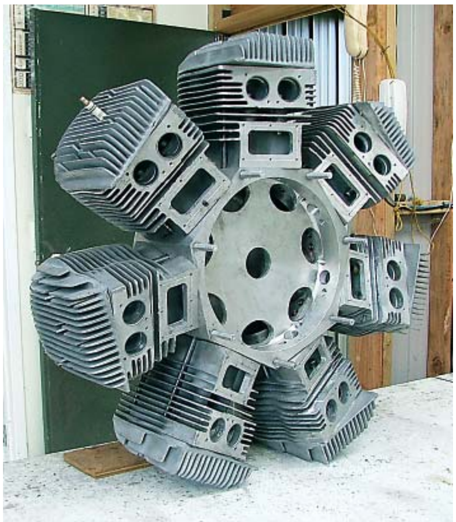
Crankcase and cylinders come together.



Crankshaft mandrel.

metre away. My investigations enlightened me that x-ray will not find porosity in solid objects.

Long story short — we settled in court, but it still cost. The next crankshaft blank, weighing some 90kg, started as a billet of EN36A steel. As this steel was 65 mm thick, cutting out the crankshaft profile was achieved by drilling about 300 x 6 mm holes (could not use gas and band-sawing was too expensive, as were other commercial methods).

Machining for the crank was done by Andrew Akers. It is made in two pieces with a 5 tonne press fit on the big end journal. It has had two lots of stress relieving and one process for hardening. The final grind was done by me.

Fitting the pressed-together crank-

shaft into the crankcase, spinning it and not detecting any misalignment or tight spots was a huge relief as I knew this was the point where I would either stop or proceed with the project. There is a limit to cost.

There were no major hiccups with the cam, cam gears, oil pump or master rod, with only a couple of items finding their way to the high-level "offerings" shelf. The cam has four lobes, rotates the same way as the crank and is geared down 8 to 1. The ramp up differs from the ramp down due to offcentre valve lifters.

Many of the interference fit items such as timing gears became press fit when they were hardened. There was some head scratching as to how to hone out .01 mm of a 25 mm hole 30 mm deep with a keyway. I will leave this one for you to solve, but remember the hole must remain parallel and centre.

It is difficult even for experts to determine pre-hardening fits; most are ground after hardening with far more sophisticated gear than I have. This is the sort of thing that happens with one-offs.

With all internals assembled, oil pump, ring gear made and fitted, finding a suitable starter motor had the guys at Northland Parts Warehouse really rolling their eyes. I finished up by casting and machining my own 7.5:1 gearbox, plus using parts off a left-hand and a right-hand starter of the same brand. This was to get the pinion clutch to engage and have everything turning the correct way.

It looks the part and works really well on the 60-tooth ring gear. Most geared starters have a 3 to 1 reduction and run on at least a 130-tooth ring gear. Space would not permit this. I now have the engine turning on the starter, checking valve timing, compression and oil pressure. All good.

"Bloody hell, it might even go!" I said, walking round it with spirits high, quite oblivious to future challenges.

As I have said, I researched induction pulses and inertia of gases, sound waves and inertia of exhaust gases. It became apparent to me that Burt

Each induction pipe is a the same length but a different shape to fit around accessories and mount frame tubes.

Munro had cottoned on to this in the 1960s. It allowed him to wring out huge rpm to attain his 200 mph record.

For me, tuning the exhaust was too much of a weight penalty. The calculation for each induction pipe worked out to 635 mm long and 30 mm diameter. It would prove challenging to house a total of 4.5 m of piping, not including the plenum.

Each carbon fibre/vinyl ester resin pipe has different radius bends and very different profiles to miss various unmovable parts such as starter and engine mounts, but all have a centreline length of 630 mm. They are deigned to give 98 percent volumetric efficiency at 2400 rpm, which is why I have a little heat problem to deal with now. After 2500 rpm the pipe length becomes a drag and efficiency plummets, but that is not a concern. Automotive engines from round year 2000 use this technology, often using two butterflies to extend the rev and torque range.

I had always intended to use an engine management system to minimise the side valve inefficiencies. When I first spoke to LINK Electro Systems Ltd at the design stage they said, "Yes, it can be done."

However, mid-way through 2009 they would not let me have their Xtreme ECU system until they had tested it on seven cylinders. I was to discover that nearly all auto EMS (engine management systems) miss out seven, which is understandable because this is the first fully managed 7-cylinder engine.

According to VEMS, its unit from Hungary would work. Their dialogue pre-purchase was OK but post-purchase was frustratingly slow, sometimes 10 days to reply to emails.

The situation was fast becoming hopeless. This was a tough time as I had no other means for ignition. I had no drive for a distributor, something I was beginning to regret.

By mid-February this year, LINK offered me a trial program to run 7 cylinders with their G4 Xtreme ECU. Their willingness to assist post-purchase was second to none. There were snags to overcome with timing issues and a little guesswork with base numbers, but after five or so calls to Jurgen at LINK, the engine fired and ran on 22 March 2010.

What a sweet sound!

Improvements to the oil delivery, crankcase breathing and cylinder head oil drains for numbers 4 and 5 were the first minor modifications. At this point the computer had not been tuned; maximum rpm was 2200, with cylinder head temperatures at 135 deg C.

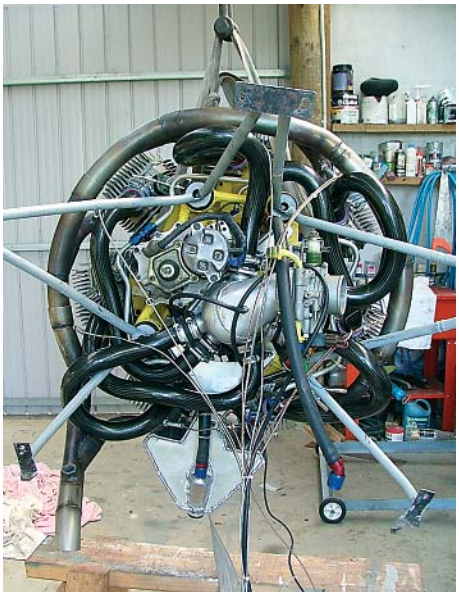
After tuning, the revs came up to 2500 and so did the cylinder head temperatures — along with a blown head gasket. This had me bluffed for some time, until I noticed that it was the spark plug that was stopping airflow to a small area of the head where the gaskets were failing. Adding to this is the tuned induction pipes becoming effective at 2400 rpm, resulting in a lot of heat to dissipate at this power setting.

I am in the process of adding fin area to the heads and cylinders, changing baffles and cowling to aid cooling. Hopefully these changes will have the desired effect.

Anyway, building a bigger shelf is not an option.

Engine statistics:

Cylinders: 7	
Radial:	side valve
Weight:	91 kg dry
Cowl diameter:	690 mm
Bore:	93 mm
Stroke:	85 mm
Displacement:	4 litres
Maximum revs:	2500 rpm
Oil:	6 litres
Fuel:	mogas 91
Propeller:	3 blade 64 x 53 in
HP:	125–130 (calculated from propeller dia/pitch/revs)
Management:	LINK G4 Xtreme controlling 7 individual direct fire coils and 7 fuel injectors
Ignition & injection timing:	7 tooth wheel on crank shaft and a single tooth on cam



Back to the beach

Bruce Cooke

by Bruce Cooke
SAA SP1980

THE ANNUAL BLACK SANDS Fly-in, hosted by the SAA Waikato Thames Valley Chapter, was held again at Raglan over the weekend of 6–7 November. This marks the fifth time the fly-in has taken place and once again Raglan turned on superb flying conditions.

The Waikato District Council had made sure the airfield was in excellent condition, and over the weekend a constant stream of small aircraft arrived to park in the pleasant surroundings beside the harbour. A great deal of fluent aeroplane was spoken and tales told as various clusters of aviators hovered around the varied aircraft.

Visitors had flown from all over the North Island, and even some intrepid Mainlanders made the effort to come up. Once again Don Howard won the prize for furthest travelled, by bringing Zenair ZK-NEN up from Rakaia, via various stopovers in Northland!

It was good to see a number of shiny new homebuilts among the ranks, some having their first outings.

Once again Baz McGahan and his team of volunteers turned out an impressive lunch spread. These guys are absolutely awesome and their efforts are much appreciated.

Saturday afternoon saw the popular beach flying workshop get under way, led by PA-18 Cub driver Bill Henwood. A short time later, just before a very low tide, a total of 27 aircraft landed on Gibson's Beach, a remote stretch of black sand north of the Raglan Harbour mouth. This number sets a new record for Black Sands beach landings, beating the previous record of 22 from two years ago.

The beach was also beautifully smooth, and the low tide exposed a deceptively large expanse of landing area. The beach is a living entity, though, and those who have landed there previously would have noticed a large shelf of exposed sandstone on the northern end where in previous years aircraft parked on smooth sand. A huge quantity of sand has been scoured out, probably due to the persistent south-westerly storms over winter — unless it is a sign of Global Climate Change™. The mussel rocks were well accessible and a fair number of very fat shellfish departed onboard the aircraft as they returned to Raglan.

The other flying event over the course of the weekend was a Poker Run around a selection of interesting airfields in the region. Organised by Noel Bailey, this exercise had participants collecting a "hand" of cards from the airstrips, with the best hand winning.

One well-known female aviator was heard to call on 119.1 "Don't start the strip poker without me …" —but we're not that sort of fly-in!

Once again Black Sands has been extremely successful, and it is gaining a great reputation on the flying calendar. The number of aircraft present varies depending on which figure you use — the list of arrivals taken by the comms caravan shows 105 aircraft, although the landing fees paid to the registration desk was only 76. We sincerely trust the other 28 percent did pay their fees eventually, as it is such a small cost for the privilege of using such a unique airfield.

We trust that we will see everyone back again in 2011 for the next Black Sands! *(More photographs next pages)*