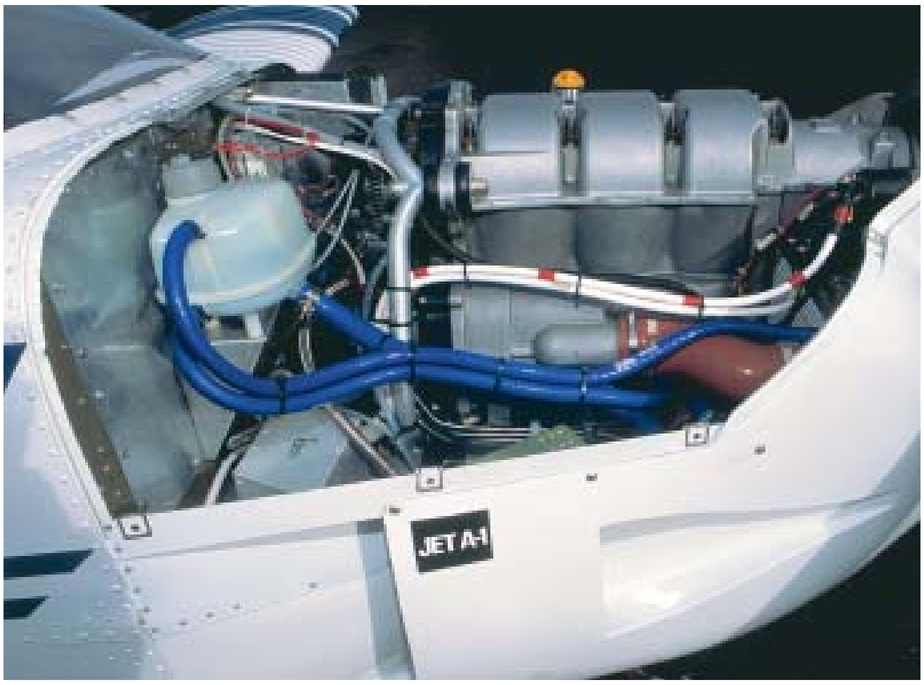
FLYER

Reprinted from *FLYER*
August 2003

Photos: Aussie Brown

TRIPLE WAMMY

It's taken ten years, but Wilksch's WAM-120, triple-cylinder diesel is finally ready for the kitplane market – **Mark Hales** finds out whether it was worth the wait



Neat installation, allowing plenty of room. The coolant bottle cap sensor is a pre-flight check item

Website is important to Wilksch Airmotive – both for promotion, and for customer support services

Side exits are Thorpe feature – most installations will use a more conventional exit underneath

Oiled foam conical air filter is a WAM item – scat hose will be replaced with a moulded silicon version

The exposed oil sump helps with cooling – flight trials are continuing to assess its effectiveness

Engines are something we take for granted, whether they be in cars or aeroplanes. This is because they utilise whatever technology and meet whichever legislation prevails at the time and that's what we expect. What lies beneath the bonnet of the latest Ford or Vauxhall will perform like anything else in its class, will meet the required emissions criteria and will use a similar amount of fuel. Someone will have sorted the best set of compromises and the market will ensure we have a choice.

It's a similar thing with aircraft. One old donkey is much like another. They feel much the same and, like your car, they are controlled by a set of knobs and levers which are familiar. The only thing we tend to worry about is whether it will keep going and get us to our destination, then start when hot to bring us home again. Only if you'd sat behind a Porsche Flugmotor of the mid-1980s would you have some idea of how it all could have been, and since few people have been fortunate enough to do that the secret is safe.

Aviators really should be more concerned that the technology their engine represents is from the 1940s. No car in the world is even allowed to have a carburettor these days, let alone choose to use magnetos. But even if flyers developed such concerns, the frustrating thing is that they have been powerless to exercise any choice. Whereas the motor industry is driven by the twin engines of legislation and fierce competition, general aviation is a small and irrelevant activity practised by a minority who should know better. Not enough people do it, so manufacturers can't make any money to offset the cost of development and the bureaucrats have no popular pressure to keep them honest. If the DSA legislated motoring in the same greedy and restrictive manner that the CAA runs GA, it would last about five minutes.

Neatly detailed

But there is hope at last. Rotax started the ball rolling with its lightweight, four-stroke petrol 912; it bore the pain and expense of certification, and reaped the rewards. Then the diesels began to appear. Frank Thielert converted a Mercedes A-Class engine and that too is certified and flying. The clean sheet D-Air twin-cylinder opposed

wilksch reprint 2 28/8/03 5:27 pm Page 3

piston engine has flown for hundreds of hours in an airship, and over 50 hours in a Luscombe test bed. And then there is Wilksch Airmotive's WAM-120 – another original design – which has completed about 1000 hours on the testbed and, having been installed to the PFA's satisfaction in a homebuilt version of the Thorp T211, has now flown nearly 10 hours, for one of which yours truly handled the controls.

The Thorp which carries Wilksch's handiwork is hardly pretty. Conceived in the late 1950s as a basic trainer by the father of the Cherokee, John Thorp, it is nevertheless clever and simple (and most important to a company which has to manage funds carefully, it was free). But pretty it is not, and the addition of a flat-fronted cowl with a gaping mouth does nothing to improve it. Wilksch may yet regret his common sense insistence that the radiator and intercooler and associated pipework should be an integral part of the engine so that people can't mess with it and get it wrong…

Once the cowl is removed, though, the view improves. The engine is neatly detailed with the supercharger casing integral with the crankcase (no external pipes to feed the air to the cylinders) and the exhaust manifold and turbine housing are all part of one structure, while much thought has been given to things such as ancillary drives. At the moment the pitch of the MT propeller is fixed, but all it takes to wobble it is the addition of a Czech-made Jihostroj governor (three-quarters the price of a Woodward and two-thirds the weight). The drive is there and so are the drillings in the crank and it's a half-hour job to fit. A 28-amp alternator is driven direct via a cush from the back of the crank, there are no belts anywhere and the water hoses are few but bespoke, moulded with all outlets.

Reduced output

Installation items still needing revision are the exhaust silencer box – the one fitted was a rush job with small diameter pipes which reduced power – and the inlet trunking. A diesel needs twice as much air as the equivalent petrol engine and any restriction here also hurts power, so the final spec will be a smoothly moulded hose rather than good old wire-braced SCAT. These two details, together with a fixed-pitch prop, reduced output, says Wilksch, to about 95hp.

There will also be a new coolant reservoir to replace the automotive item, complete with the low coolant light sensor, which is an essential preflight check as we would soon see; the cowling also requires some modification to exhaust the hot air from the radiators – diesels produce considerably more heat than a petrol engine and on our test the water temperature soared if full power was held for more than a minute or so. It came back almost the instant the power was reduced, suggesting it was a radiator or airflow problem rather than an engine one. However, the deluge of hot air under the cowl made the firewall and the cockpit rather hotter than would be comfortable on a summer's day.

Also on the soon-to-be-fitted list is the data logger and engine display. This is a 6.25x3in box (same as a Garmin 430) which sits on the panel (another thing that WAM are doing themselves because the Palm computer originally planned became obsolete every two years) which features two analogue/digital displays for percentage power and percentage speed. It will also calculate fuel consumption from time, manifold pressure and rpm – which is displayed on screen.

The pilot, however, doesn't need to know any of the raw data such as manifold pressure or rpm, says Wilksch. As with a turbine, it's just the percentage that matters and if the box dies, the engine is extremely difficult to overspeed and impossible to detonate, so you are unlikely to hurt it. The logger will also feature a card which records all engine functions and its contents will be downloadable to your PC and e-mailable to WAM to maintain complete records on every engine. It should, hopes Wilksch, also be acceptable to the CAA as a more reliable logbook entry. We can always hope…

Inside the cockpit and ready for start, the anti-climax is about to begin. Former Navy Sea Vixen pilot Paul Chaplin is the PFA-approved test pilot and he checks the fuel for water and fungal growth (as oil is an organic commodity, it can happen), makes a visual check on the wooden dipstick and then pulls the metal dipstick from the seven-litre sump at the bottom (top) of the engine (consumption is so far averaging 50cc in seven hours). Lift the coolant cap to check the warning light in the cockpit and check that the fuel valve is 'on' – the authorities require a 'secondary stop control'. Wilksch agrees and adds there is little other reason to have a fuel cock, as everything up front is fire resistant and pressure tight.

'MEANWHILE, IT'S ACCEPTABLY QUIET, A LITTLE NOISIER THAN A SILENCED CONTINENTAL… BUT NOT MUCH'

Start-up

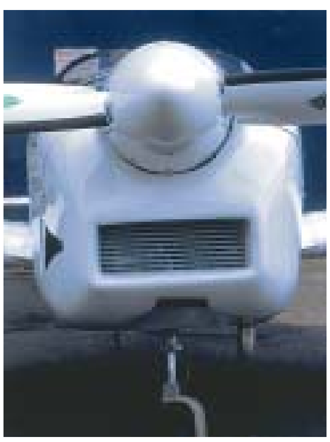
The diminutive Thorp lists and sags on its oleos as two big blokes get in a cockpit which is only just big enough for them, but once settled there turns out to be just enough headroom, the visibility is excellent and you feel immediately at home. Look around for something else to check, and you'll find nothing, so it's Master on, turn the key to glow, count to six, and then turn the key to start.

The starter does battle with the compression for half a dozen blades then there's a rattle worthy of a Massey Ferguson coming to life and a puff of smoke from the exhaust, followed immediately by a steady 800rpm tickover.

With three high compression cylinders this diesel will never be as composed as a petrol engine at tickover, but it's a different frequency of vibration which is quite acceptable and certainly no worse than an in-line Gipsy or Walter. Up the revs to the 1300 that Wilksch prefers for warm-up and the thrum halves. Meanwhile, it's acceptably quiet, a little noisier than a silenced Continental thanks to the combustion clatter but not much, and Wilksch does have the option to make the silencer bigger. Then it's just a case of twiddling the thumbs while the water temperature rises.

That's followed by a taxi against the brakes (the tickover needs to come down some more even if the vibration is greater) and power checks at the hold. This is just a surge to 2200 static and a check that the stop control is

The O-200 engine installation actually has larger inlet – $500cm^2$…



…compared to the WAM's $400cm^2$. This, however, still requires refining

Side NACA duct feeds the oil cooler. WAM makes no apologies for the boxy but functional cowl – future installations will probably feature elliptical inlet

Data logger display (bottom right) is a dummy – real item is imminent, when other engine dials will go

Bonus Aviation at Cranfield oversaw the build…

…and enthusiastic group will ensure high usage

Proven practices and new technology

Miles McCallum examines the inside of the WAM-120

Engine development is a funny business: on one hand, there's absolutely no point in reinventing the wheel. On the other, if you want a proper job, you'd better be prepared to do it yourself – and getting it right is treading a very slim line between the two.

The major development headache was sorting out the pistons and rings – any number of calculations as to the thermal and physical stresses involved in operation only go so far, and at the end of the day it's a slow process of trial, failure, refinement, and more testing that cracks the problem. Much of the WAM-120 is tried and tested proven technology. Crankshafts and bearings, gear train and valve gear, most of the fuel injector system – all of it is pretty much straight out of the textbooks. Granted, there has been some clever thinking in implementing a great deal of the detail design – and as we know, the devil is in the detail: invest a bit of time and money up front, and further down the line it makes life easier, cheaper, and more reliable. A case in point is

New injectors WAM (left) is lighter and lower profile; (top) is from car working, a survey of the gauges and call for lineup. Then it really is anticlimactic. You advance the throttle as you would any engine and off it goes.

There's a subdued three-cylinder growl which only triples can make, but the amount reduces as the revs rise rather than the other way around and the performance is like any other 90 or 100hp engine. A reduced power climb at 2300rpm equals 600fpm (a brief 2500rpm shows 1000fpm) then 2250rpm gives a cruise of 85kt or about the same as you'd get from the O-200 turning at 2400rpm. This isn't truly representative because the installation doesn't allow the engine to give its 2750rpm max, but it's already close and we were easily able to keep station with the O-200-powered Cessna 150 camera ship.

After that, there really is little to report. The temperatures stayed steady, the gentle thrum was perfectly acceptable and the response to the swift in-out of the throttle required to keep station for the camera was no different from any other engine. Only the subdued braying and the way the prop judders almost instantly to rest when you pull the stop control says there's anything different up front.

'IN 30 MINUTES OF FLYING THE ENGINE USED LESS THAN FOUR LITRES OF FUEL – JUST OVER A QUID'S WORTH'

As I said, we take engines for granted and provided they perform, you forget about them. What is clear, though, is that the installation is a great deal more critical than for a conventional air-cooled petrol engine, and this is why Thielert has decided to supply his Centurion diesel only for approved installations. Wilksch is already developing installations for popular kitplanes such as the Europa and RV series, with others like the Jodel to follow. Any other installation will need to be quite carefully researched and developed.

With the hurdle of the first customer engines almost out of the way, WAM's larger, four-cylinder 160hp version should be running by January and ready for delivery by March 2004. Then comes certification for the 120 and 160, followed by a family of modular 300 to 500hp-plus Lycoming replacements.

Technology & Development

The introduction of a brand new, clean-sheet-of-paper aircraft engine is significant because it is such a rare occurrence – but an engine which is completely different from the established norm and which will make a huge difference to the cost of flying, is more significant still. It's as if the Chancellor's Budget promised that, from midnight, motor fuel would be a third the current price… By the time you read this and, after a gestation of some 10 years, Mark Wilksch's Wilksch Airmotive Ltd (WAM) will have delivered the first customer versions of the engine in 110hp form with the promised 120hp version to follow as soon as tests are complete.

What it means more than anything to buyers is economical flying; Avtur costs around 35p per litre compared with Avgas at £1 per litre, and diesel engines are far more economical than their petrol counterparts, so the WAM-120 burns a great deal less to produce the same horsepower. The main reason for this is that a diesel has a compression ratio of 20:1 against a petrol engine's 9:1, it also has fewer pumping losses and leaner combustion. The reality is that in 30 minutes of flying the WAM-engined Thorp used less than four litres of fuel – just over a quid's worth. In the same time, the O-200 which took me and my Tailwind to Cranfield used 10.7 litres which adds up to over a tenner. Even allowing for future governmental meddling with fuel tax it's still a compelling argument.

Continental and Lycoming direct-drive petrol engines have been cautiously developed over 50 years and are very reliable, but they are massively inefficient as a means of propulsion. Air cooling is hard to regulate because it depends on outside temperature, airspeed and other variables which the engine manufacturer cannot control. So to keep the cylinder head temperatures safe they run rich mixtures and the extra fuel extracts heat as it vapourises. It's the equivalent of running with the choke out all the time. Add to that the fact that the propellers are bolted directly to the end of the crankshaft, and the traditional aircraft engine needs to displace a lot of litres to produce enough power at revs which props can handle; propellers don't work well at speeds much beyond 2700rpm when the tips get to Mach 0.8 or so, which is decidedly environmentally unfriendly.

A four-litre Continental 0-200 produces about 90hp at 2750rpm, while the twin-overhead camshaft, fuel-injected 1.6-litre petrol engine in a Ford Focus pushes out 99hp at 6000rpm. A Rotax 912, which is a simple 1200cc pushrod petrol engine with two carburettors, churns out 80hp at 5800rpm. It competes with the Continental because it spins faster but needs a reduction gearbox to drive the propeller.

Revolutionary in aviation

What's clever about the Wilksch is that it displaces just 1.8 litres yet drives the propeller directly at a maximum of 2750rpm. Even the most modern electronically injected car diesels such as VW's Pumpe Dusa engine in the latest Golf won't produce anything like 120hp at 2700 – they need 4000rpm to do that.

The Wilksch can match the VW at lower speed simply because it is a two-stroke which fires twice as often for the same rpm. With the exception of the ball-jointed piston/rod connection, the WAM engine uses simple diesel technology which, although revolutionary in aviation (supercharged, turbocharged, two-stroke, compression ignition with piston ported inlet and poppet exhaust operated by a cam in the head running in the wet sump oil reservoir), is 1970s technology when compared with modern car diesels such as the VW/Audi and BMW; the three-litre in the latest 5-series now produces 218bhp and 370lb/ft of torque and yet returns 27mpg in the worst case Urban cycle.

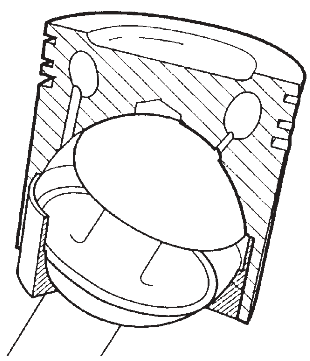
So, if the technology is well established and proven in the automotive world, why has it taken WAM and the rest so long? Some of it is the aforementioned money needed for

FAMEC injector pump - the clever bit is the grey casting on the bottom with the red diaphragm housing – the levers are two of five moving parts

the assembly of the major castings – they all feature metal to metal joints (sealed by 'O' rings or high pressure seals) that require very precise dimensional machining – but the payoff is that the clearances, say in the gear trains, automatically fall into place on assembly. No time consuming shimming or adjustments, no potential for mistakes, and significantly reduced assembly costs.

There have been some real innovations – defined, if you like, by the granting of patents. One is the connection between the piston and conrod. Instead of a conventional gudgeon pin, which can't really cope with the forces involved, the connection is made by a spherical bearing; the male is machined on the end of the rod, while the female is machined into the inside of the piston, with a simple spherical retaining cap circlipped in place.

The other is a clever little interface between the fuel control unit and the pilot. The FCU is based on standard automotive mechanical technology which is tried and tested. However, testing with a real aeroplane and engine



Clever and troublesome to perfect: Piston/rod connection from patent drawing – note piston crown is solid, with cooling chambers

The Thorp is surprisingly small – 577kg MAUW – and although empty weight is 14kg more than original, 20kg less fuel is required to achieve same range

development. People such as Wilksch and his team are cussed, driven individuals who are doing this because they want to, and they could almost certainly make more money doing something else in engineering, but the aviation diesel is their holy grail.

In addition to this, the propeller-driven aviation engine is a strange case. As SMA/Renault discovered to its cost and frustration, the shocks and harmonics of blades thrashing the air, combined with the diesel's high compression and the four-stroke's firing intervals, shattered gearboxes with depressing regularity. These, remember, are the people who beat the best in the world for years in the profligate playground of Grand Prix racing. WAM chose a different route and opted for a two-stroke which fires twice as often with lower firing pressures and, as a result, it is kinder, but employs conventional poppet valves for the exhaust to get around the hot piston problems that have bedevilled others.

Time and resources

Then there is the productionising process. Wilksch admits that producing a working prototype was reasonably easy, but to get it ready for production took far more time and resources. That, as anyone in the car industry will tell you, is now the secret of making money from the production line and when WAM had finished, only one component part was carried over from the prototype to the customer engine. Add to that the need to obtain Quality Assurance and traceability which is essential for aviation components – a requirement complicated by the fact that that suppliers such as VDO (sensors) and Eaton (superchargers) will suddenly refuse to deal with you when they hear their parts will be flying.

The immoral situation in the US which almost killed its GA industry, where a lawyer will go down the list until they find a supplier with enough money to make them worth suing, has seen to that. With this in mind, WAM decided early on that rather than try to write watertight legal

Proven practices and new technology

Continued...

revealed that despite the throttle being shut, the faster you flew, the higher the idle – so much so that test pilot John Brownlow had to use the shut-off control as a crude (but effective) throttle to actually land the thing. Phil Franklin sketched out a mod – referred to, half in jest, as the FAMEC, Full Authority Mechanical Engine Control. It's so simple that a gash prototype was made and fitted in less than a morning and the result was that the engine now behaves quite normally (as far as the pilot is concerned) with the added advantage that during the glide, throttle shut, it is actually not delivering any fuel at all which allows the engine to act as a slight airbrake.

Reducing parts costs and build time is a major goal at this stage, and a great deal of the reason why those who were hoping for an engine six months or a year ago have had to be patient. Building and sorting out a prototype design is one thing – that took just over three years to do – but turning it into a product that was reliable, straightforward to manufacture, and in particular profitable to manufacture, has taken nearly twice as long.

One of the potential shortcuts is to use existing components – not reinventing the wheel – but liability concerns from the manufacturers, delivery schedules that don't fit in with the scheme, and specs that aren't quite right mean that in the end, it's better to do it yourself.

The list is astonishing: a single type of sensor is required for oil, coolant, and air charge temperature monitoring. The standard sensor proved to be rather non-linear in output – you couldn't rely on what it said for accurate information – so you make you own.

Matching a turbocharger to the engine's requirements was a tricky business: the best fit weighed a ton, so why not use some existing components, and make your own hot-side casing?

The injectors, meanwhile, were designed for a car and required deep cutouts in the sump for clearance, and the

Full fuel still allows a useful passenger load – but, even so, delivers as much as nine hours endurance

documents, the company would simply design its own parts, at the same time making them the size and spec it wanted. This has taken a lot of extra work, but Wilksch says it didn't necessarily cost that much more, plus they can control the delivery. "You don't have to order 10,000 and wait until next March…" he says.

They were also able to save a lot of weight. The permanent magnet starter (which will be a Lycoming retrofit) weighs 6lb; the lightest one in the Aircraft Spruce catalogue is 8lb. An off-the-shelf Eaton blower weighs 8kg; the WAM design is 2.5kg and, Wilksch points out, it supplies a bleed for the vacuum instruments so you save the weight and expense of a vacuum pump and drive. The blower, according to Wilksch, is therefore free… There's plenty more, all of it indicative of careful thought by Wilksch, former Cosworth engineering designer Martin Long and Engineering director Phil Franklin who owns the patent for the fuel control on the WAM-designed in-line injection pump.

Liability issues aside, an automotive governor would have been too bulky and heavy for this job, so instead a simple but clever device (five moving parts) reduces the amount of fuel at tickover to make the engine run slowly enough for the approach, but supplies enough at higher rpm to produce the required power. If the throttle cable breaks, a spring sends the pump to full power and you use the engine stop knob to control it. It's another diesel-specific aviation problem which had to be solved and one which both Thielert and SMA both had to tackle, although only Wilksch has done it without a transistor or integrated circuit in sight. The result, says Wilksch, quite easily controllable.

Simple maintenance

WAM has also been very sensible about maintenance. Oil and fuel filters are available from the company at £2 each – it doesn't want to give people excuses not to change them every 50 hours (in addition, careful pilots may get a trend clue from the data logger display that fuel flow is gradually decreasing, showing that the filter may need changing), while the injectors (also WAM designed and made) which currently have to be serviced every 200 hours, are £46 (exchange) each. Glow plugs, essential for starting, are an annual check item, and the cambox which must be removed to check the tappets every 250 hours is accessible via ten screws – or the same time it takes to remove two of four Continental tappet covers. Items such as the low pressure fuel pump should last the life of the engine, according to Wilksch, as should the high pressure injection pump. Both have their own supply of lubrication rather than relying on lubricity of the fuel they pump.

Only time will tell whether Wilksch is right, of course, but on the other hand, things which sound critically difficult – like the design of turbos, superchargers, injectors and fuel pumps – are exactly what the WAM team did before they joined. The harder task is knowing how long the pistons will last when abused by pilots, or whether there are some harmonics somewhere whose effect they hadn't realised.

WAM is confident these would have surfaced during the hours thrashing away on the test bed, and you do get the impression in conversation, that since they were only fitting the wheel to something that hadn't had it before, rather than reinventing it, if a problem does appear, there are places they can look to find the answer. ■

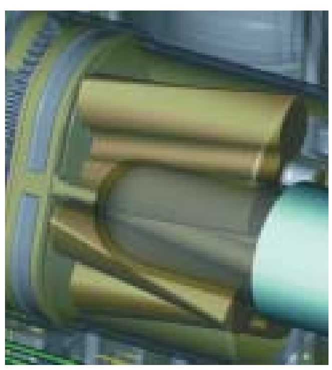
Proven practices and new technology

Continued…

fuel lines were long and complicated to manufacture, so again WAM designed and made its own, saving weight in the bargain.

Ditto with the supercharger internals: they were complex, heavy, expensive and more efficient than required, so it was better for the company to design and make its own much simpler, cheaper, lighter, optimised components – and the engine gained a clean-air pump for the gyro instruments to boot.

All this has been a long, tortuous process, but most of the lessons can be applied to the other engines on the drawing board. This means that the gestation period of the 160hp, four-cylinder engine will be a great deal more abbreviated – and it will probably be the making of the company. No doubt there will be further refinements to the WAM 120 – several are already planned – but meanwhile, welcome to the future. It's arrived.



The old supercharger internals feature a complex twisted shape difficult and costly to machine – they also weigh rather a lot

Engine monitor and data logger displays all the pilot needs to know, and records every moment of of the engine's history for the factory