WREN
Turbines Ltd.

Plans for the MW54 Gas Turbine
2nd edition, Ver.1 - August 2000

Your plan number is: #__________ Dated: __________________
Please quote these numbers in your communications with us.

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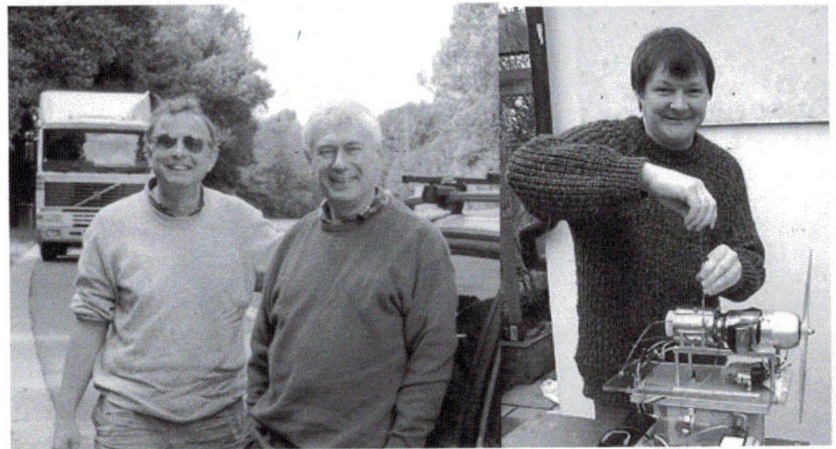
Rotherham
S63 5DE
United Kingdom

Background

Wren Turbines Ltd is a company formed by Roger Parish, John Wright and Mike Murphy.



Roger John Mike

It was formed specifically to launch the MW54 gas turbine design and to manage the design and production of cast turbine wheels and ngv's for the engine. This brief has now been widened to incorporate the production and supply of all MW54 parts and accessories for the turbine enthusiast. Parts available individually and as a complete kit of parts* (*avail Sept 2000). The company will also be providing additional parts to compliment this and future designs in response to demand.

Improvements and enhancements to the design

Since the issue of the 1st edition plan the MW54 design has incorporated a number of refinements and modifications. The majority of these have been to simplify & aid construction, others to extend the engine operating range. These changes have been verified and their effectiveness demonstrated through extensive air testing in a range of aircraft and feedback from you as constructors.

These changes have been issued as an update to current 1st edition plan purchasers as part of our on-going support for our MW54 customers and are now incorporated into the new 2nd Edition of plans and instructions presented here.

In the three months since the release of the MW54 plan many new developments have been completed and tested. The MW54 turbo-prop, mentioned as a development project, has now been completed and running successfully. It has now completed many flights in a Pilatus Turbo-Porter and proved beyond doubt the viability of the design and the practicality of this form of propulsion for modellers. A large demand for plans for this has built up and preparation of these is well under way.

Wren Turbines have undertaken considerable study and practice in turbine wheel design and accumulated considerable expertise in preparation and production of wax moulds and subsequent casting in Inconel 713C and high temperature stainless alloys. This experience has been applied to the production of four new cast items: a 55mm thrust turbine, a matching ngv, a 55mm gas generator turbine and a 72mm power turbine. This experience of investment casting has set us in a healthy position for future projects where the application of such technology can simplify construction and enhance an overall design for the benefit of the home builder and potential commercial production.

Future improvements in MW54 design.

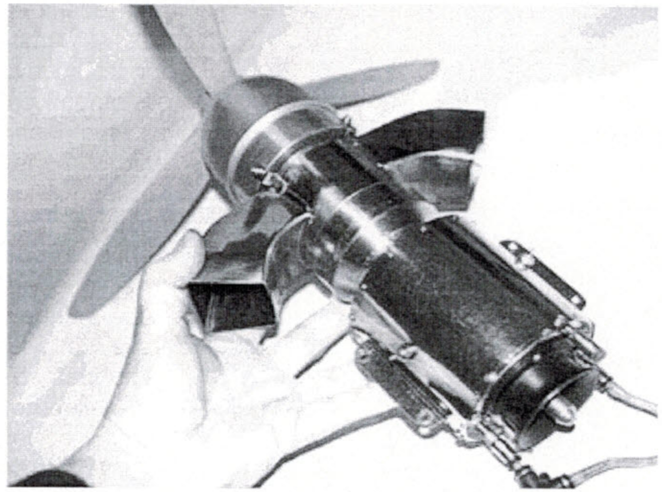
The MW54 is now a proven design and many examples have been built and run successfully without modification. It is always anticipated than further refinements may arise although we feel these are not likely to be significant, but may arise to incorporate the introduction of future commercial parts. All purchasers of the plans will have their names held on file so that we can give them priority notice of any design improvements. A long testing process has, we hope isolated all the critical parts of the design resulted in the maturing of a highly practical power unit. Small changes will be posted on our web site and anything significant will result in a mod sheet being issued. Feedback from customers will always be welcome!

Had your first run of your MW54?

We are always delighted to hear of new additions to the MW54 family. We have a “latest news” section in our web site, so let us know and check for yourself who else has finished and is running.

Check us out on wren-turbines.com!

Turbo-Prop attachment.



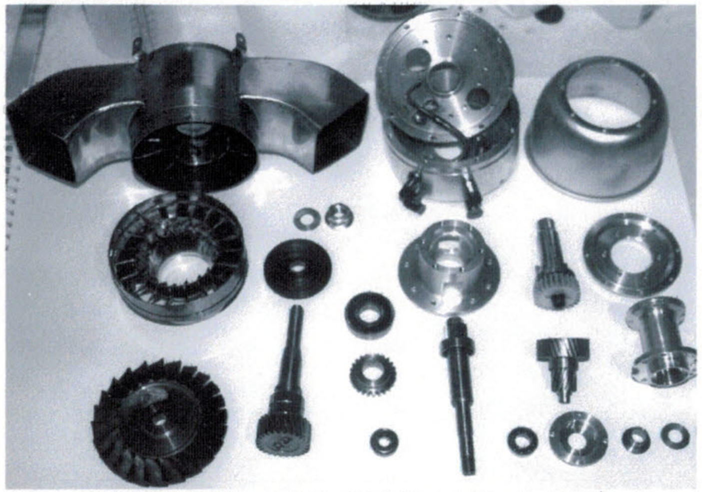
Complete turbo-prop unit with MW54 attached

This unique and exciting new innovation is not a complete engine but a power turbine and gearbox add-on, which can be retrofitted to the engine to convert the thrust to shaft power and drive a propeller to power a model aircraft.

Some small mod’s will be required to the engine but extensive development has enabled this conversion to be easily carried out by the majority of MW54 engine owners.

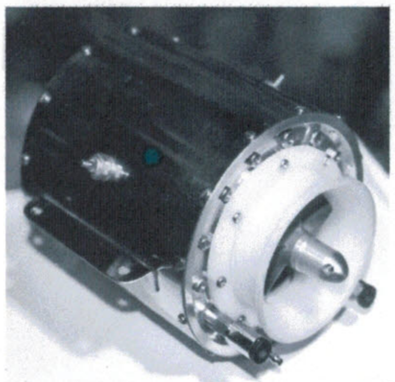
Wren Turbines will carry out this modification for a small charge if required. The turbo-prop drawings are currently being completed and a note will be posted on the Wren site when they are available. Plans will be available separately.

Turbo-prop parts layout.



Layout shows earlier power turbine - now available as a precision casting from Wren Turbines Ltd.

The MW54 Gas Turbine



1st prototype MW54

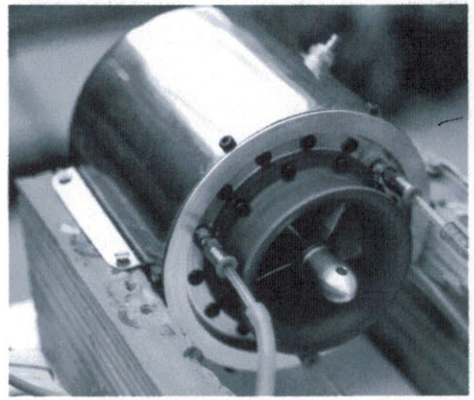
Development

The engine was designed by Mike Murphy, in mid 1999. Mike and John Wright who between them have over twelve year's experience of home-built gas turbines constructed two prototypes.

The engine is the product of over a year of development, which has seen the introduction of many small but important changes aimed at simplifying the construction of the engine for the home--builder, and enhancing its overall performance.

We believe the engine is a significant step forward in refinement of the design of small gas turbine engines, which includes a number of innovative features.

An ambitious target was set to greatly reduce the size and weight from the typical engine currently popular with home-builders and model fliers.



2nd prototype MW54

The small size achieved enables a very short and rigid shaft, a lightweight rotor allowing very fast acceleration and deceleration and overall mass and dimensions hitherto only dreamt of by model fliers.

The engine is unique in that it has been designed with two applications in mind – a compact and highly efficient gas generator for turbo-prop and turbo-shaft applications, and a high power to weight thrust (turbo-jet) engine.

Gas generator for Turbo-Prop

Mike has gained a useful working knowledge of gas generators through his work with his two own-design shaft power units – a 2.5HP turbo-prop and a smaller helicopter turbo-shaft, flown for the public at several venues last year (1999).

This experience prompted a design for a compact and powerful gas generator for the next generation of small turbo-props. The requirement was for a unit providing 3-4 lbs thrust at a case pressure of 1 bar and at a temperature of well under 400 deg C. From Mike's earlier engines it was known this would produce a very capable unit with a shaft power potential exceeding 3kw, (Similar to a good 20cc i/c engine.)

The shaft power unit is now running well and separate plans will be available later in 2000. The prototype turbo-prop version is fitted to a 96" wingspan "Pilatus Turbo-Porter" shown below after it's first flights at the Isle of Man in July 2000.

Turbo-Jet thrust engine

Producing a small thrust engine from the same basic design with as few modifications to the layout as possible has proved challenging. Difficulties in obtaining the compressor map made thrust predictions a problem and a great deal of experimentation has been undertaken to realize the potential of the design to provide a viable alternative to the wide range of current (larger) engine designs.

Initial projections were for just 8Lbs thrust (35N), and exhaust temp' (egt) of around 500'C. This has been comfortably exceeded and we were delighted with the extremely low exhaust temperature achieved for the gas generator configuration (370'C) which showed the potential and demonstrated the effectiveness of the tiny combustion chamber.

Prototypes

The prototype engines both showing extremely good thrust figures with different turbine shapes. The first produced an impressive 12Lbs-thrust (54N - a happy coincidence!) at 1.4 Bar of case pressure and an EGT of 530'C.

The second is being used for the turbo-prop and produces about 5Lbs thrust or 22N, (without nozzle) at 1Bar of case pressure, and 20Lbs thrust from it's 16"x10" (400x250) prop running at over 9,000rpm. Early on, the engines' reluctance to give a low idle due to the limited heating area available from the six vapourisers, necessitated the introduction of the twelve stick combustor which has completely resolved the problem. A sustained idle has been achieved at just 25,000rpm although for secure acceleration we recommend 35-40,000rpm as a practical minimum.

Rotational speed

Due to the small diameter of its rotor assembly, the engine needs to rev at high levels to generate sufficient tip-speed and throughput. The special 688-size, full-compliment ceramic bearings from GRW are rated at 170K and have proved reliable and give good headroom for long operational life.

A modification to the pre-load arrangements to allow a higher rotational speed, sanctioned by the bearing suppliers, has allowed top speed to be raised to 160,000rpm. This revised rating still allows for a healthy margin of safety for the rotating parts and justifies the substantiveness of the turbine hub and shaft design.

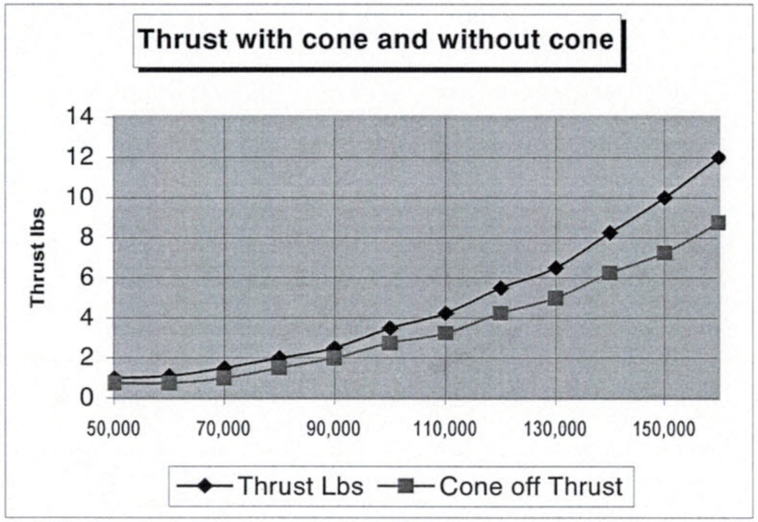
Cast components

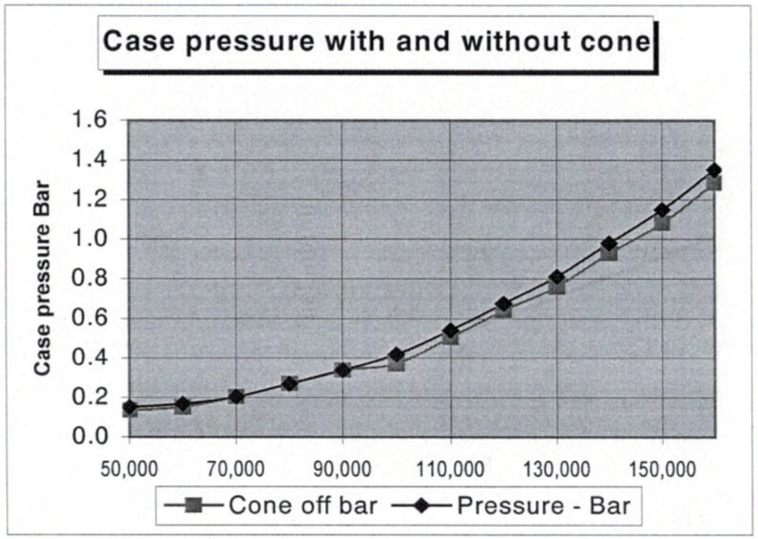
Supplies of cast components are now available. The ngv in particular, has greatly simplified this complex part of the construction for the home builder and removed the requirement for specialist welding, with only spot welding needed to complete the engine. The ngv has proved a good match for the turbine and enabled a reduced turbine tip clearance to be maintained, improving the efficiency of the engine overall.

Installed weight

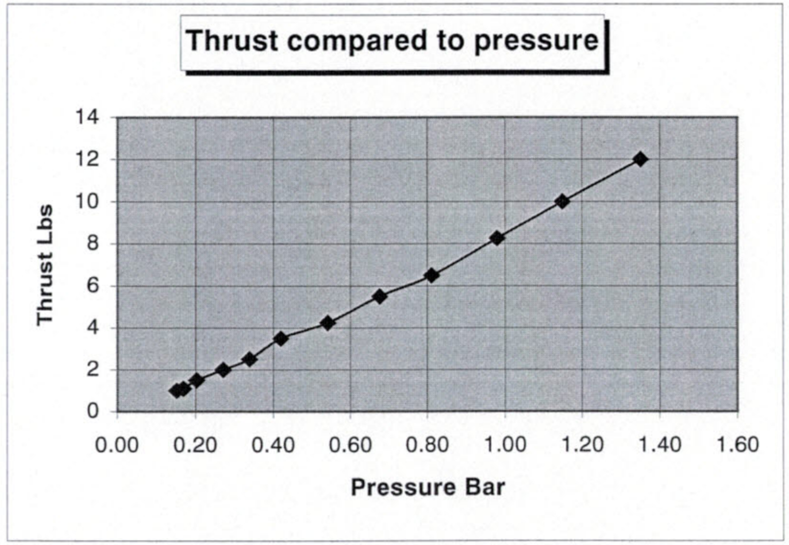
The engine is light in weight, by virtue of the small size and mass of its components. The lighter of the two prototypes weighs only 700gms. By using lightweight receiver and engine controller it will be possible to use much smaller and lighter airframes than have been the case, to date. Fuel consumption for a 'normal' 6-8 minute flight is around 1Ltr, the turbo-prop version, being about the same, depending on the power levels.

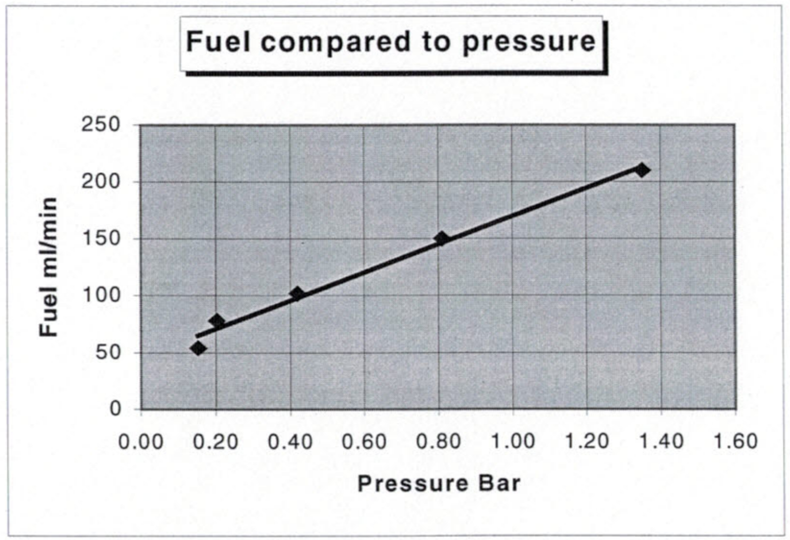
MW54 TESTS
Test runs carried out on John Wright's engine on Sunday 6/8/00
Air temperature 24C and air pressure 1024mb
Engine fitted with thrust turbine and cast ngv





Thrust engine with cone:





Model suitability.

The engine in its thrust form is well suited to the "45" size ducted fan model. For training and demonstration purposes the Winsock Models Turbine Delta or Balsa USA Enforcer kit are well-tested designs proven to fly well.

John and his Winsock Models Turbine Delta & MW54.

The small and lightweight design makes it ideal for twin installations in an airframe that may still fit in the car – another aim for the design satisfied!

Engine Management

The engine is suited to ECU (Electronic Control Unit) control in both the turboprop and turbine forms. A recommended controller is the Orbit ECU. Other makes of controller are being evaluated and the outcome of this testing will be posted on the Wren site. The Orbit is available with a matching speed rating, higher than is normally used for the KJ66 or similar.

MW54 parts availability through Wren Turbines

We have combined our experience in reviewing the construction for the whole range of turbine-builders. In recent years there has been a trend towards ready availability of a wide range of selected and pre-cut materials, part made components and ready made off-the-shelf parts. We know that not all builders have the time to make from scratch and have tried to respond to the likely needs as we see them. Since the release of the 1st Edition MW54 plan we have had many requests for a complete kit of parts requiring no machining and we are working towards this.

The most difficult parts to make are the turbine, ngv and the diffuser. We know that accurate matching of the turbine to the engine can take a long time and require much experience. The design is not tolerant of poor workmanship and for the best chance of good results we would not therefore recommend making ones own turbine wheel. Wren Turbines now stock cast turbine wheels for the engine and these are currently available in thrust form, the gas generator form will be ready very soon (likely Sept 2000), and the quality expected of these critical components is second to none.

The ngv is now available in cast form and has been tested in several engines and gives the highest thrust rating allied to the ability to run exceedingly small tip clearances for low temp and high performance. For those who wish to make their own ngv, laser cut sheet strips will be available which will help ensure accuracy can be maintained and an effective component produced. Both prototype engines had built-up ngv's which performed well. The diffuser can be machined at home although its multi-functional complexity may prompt others to purchase this item ready-made, also now available from stock. The ends of the combustion chamber require spinning to ensure ease of accurate assembly and minimizing air leaks – crucial to its operation, and again some will not wish to make them. These parts are also available.

Other parts such as shafts, ceramic 688 bearings, compressors, intake and exhaust cones, vaporizer sticks, fuel needles and fittings, electric motors for the new electric start system, screws and a host of other sundry fittings are also now available from Wren – see the stock list at wren-turbines.com for latest on parts availability.

MW54 Instruction Manual
and
Plan Set

CONTENTS

1.- Safety

Although this is a small engine it is most definitely not a toy and must be operated with due care both for the operator and any members of the public that may be nearby.

The engine must be operated only in accordance with the GTBA code of practice and the accompanying appendix – obtainable from the GTBA web site http://www.gtba.cnuce.cnr.it New turbine users are recommended to read the information contained therein and to familiarize themselves with turbine operation and special precautions needed.

The rotor in the engine is running at very high speed and if there were a failure of the rotor assembly it could inflict serious injury.

There are some obvious precautions that we would like to take the opportunity to highlight: -

1 NEVER stand or allow anyone else to stand close (within 30 feet or 10mtrs) behind an engine when it is running or be tempted to look at the exhaust. It is always possible that the turbine wheel hub could fail or a blade could fail. If you wish to look at the colour of the exhaust then you can set up a mirror or a video camera to observe it safely.

2 All spectators should stand in front of the engine ideally behind a barrier several metres from the engine, so they are not tempted to point at parts of the engine when it is running. The operator should also stand forward of the engine i.e. in front of the plane of the turbine.

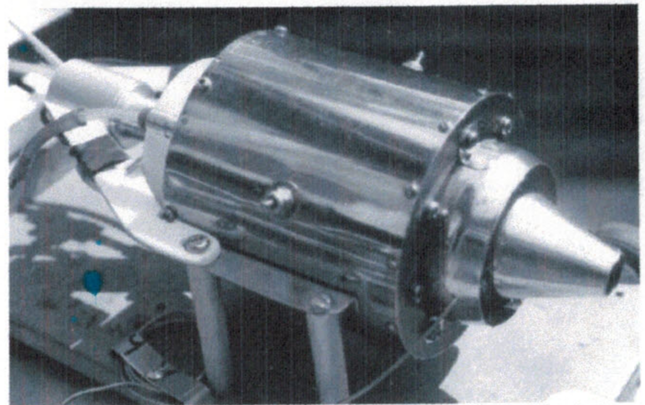
3 All spectators should be briefed before the run on how to behave.

4 Always have a fire extinguisher to hand when running.

5 In the UK it is suggested that you join the BMFA to take advantage of their insurance cover, even if you do not wish to fly the engine.

6 Wear safety glasses when machining and running the engine, and ear defenders when running the engine.

2.0 General Description of MW54



MW54 mounted on thrust-test trolley complete with electric starter

Introduction.

It is not the intention to describe the detail and functioning of gas turbines in general, that would be beyond the scope of this manual. For an excellent body of reading we would strongly recommend the reader to refer to two excellent texts: "Gas Turbines for Model Aircraft" by Kurt Schreckling, and "Model Jet Engines" by Thomas Kamps (shortly to be revised). Both are available from: Traplet Publications Ltd, email general@traplet.co.uk

General arrangement.

The MW54 is a single-shaft turbo-jet of compact design (dims 165x88 o/a). It has a single stage centrifugal compressor, annular combustion chamber and single stage axial flow turbine. The rotor is supported on two cage-less ceramic ball-races, lubricated with oil mixed into the fuel and fed from the main fuel feed. For cooling the bearings an air supply is taken via a special filter ring mounted behind the diffuser and fed through a series of internal drillings to the front of the front bearing. The lubrication supply is also fed into this point and the air pushes the lubrication through the front bearing, down the shaft tunnel, and passes out through the rear bearing. It is then mixed with the outgoing gases passing through the turbine wheel, to atmosphere.

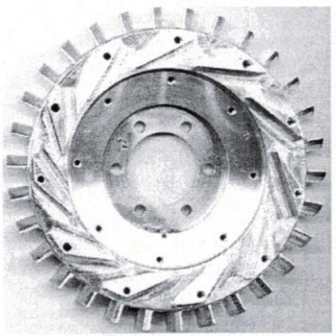
Fuel system and combustion.
The fuel supply is pressurized by a small, external electrically operated gear pump and engine speed is controlled by varying the pump supply voltage using an electronic speed controller or ECU.

Combustion is initiated using a temporary propane gas supply connected to the engine and ignition is obtained by energizing one of the two glow plugs fitted.

The gas is used to provide pre-heating whereupon liquid fuel is then fed in and vapourised in 12 tubes fitted to the combustion chamber. Metering is achieved by the use of hypodermic needles to control fuel flow into the 12 tubes and the single supply for the main bearings.

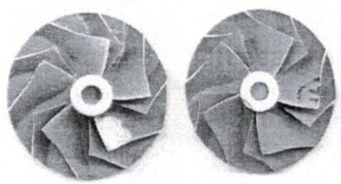
Breakdown of parts.
no.s refer to the parts list and general arrangement drawing at the front of this manual.

3. Diffuser, Part #7



Front

Compressor wheels

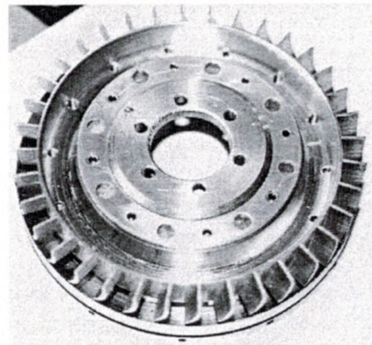


"09" size "10" size

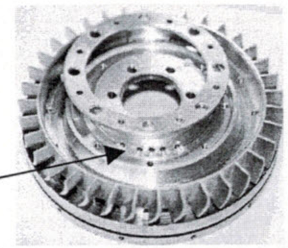
Design.
The diffuser is designed with a system of 11 wedge shaped vanes on the front to direct the diffusion path of the high-speed air coming off the revolving compressor wheel. Around the periphery are a series of 36 curved vanes that act as flow straighteners changing the direction of airflow to lie along the axis of the engine.

Two compressor wheels can be used for the engine. The "09" can be used directly, the "10" size is cheaper but needs trimming before use. Numbers refer to last two no.s of the Garratt part number. See Sect.10 for details.

The wedges on the front of the diffuser face are each drilled with holes, which are tapped to take cover securing screws or engine services. The diffusion path is also gently sloped backwards on the front and periphery to ensure the airflow is continuously expanding for maximum efficiency.

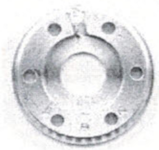


At the rear of the diffuser a plenum chamber is formed that receives air through a fine gauze mesh which is used to filter the air supply to the bearings, improving the bearing life considerably.



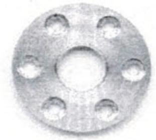
Left shows rear of diffuser with the filter ring raised, and plenum chamber visible below.

Holes (x5 shown - now x3) for air feed to bearings can also be seen in the foreground.



Part #5; shaft seal, rear and front.

At the centre of the front of the diffuser assembly there is an air/oil shaft seal which directs air and lubrication to the front bearing.



This seal also acts as a form of "shaft-saver" in the unlikely event of the front bearing failing.

Diffuser #7 – making.

The diffuser is easy to produce on a 3-axis CNC mill – coordinates can be entered with reference to the drawings to produce a straightforward cutter path for the cutter to follow.

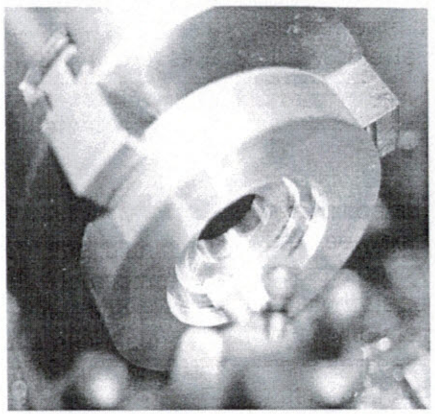
It is also possible to machine it on a lathe using a milling spindle. The wedge angles are particularly sensitive to any layout inaccuracy and care should be taken to get this as accurate as possible. The shaft seal requires careful concentric machining but the rest of the work is reasonably straightforward. The curved wedges are difficult to machine without CNC but there are ways to simplify the process.

Material

The best material for the diffuser is hard, free-cutting aluminium available from good metal stockists. The grades HE15 or HE30 are also suitable but a supply of cutting lubricant (white spirit) will need to be arranged and maintained.

Machining the diffuser

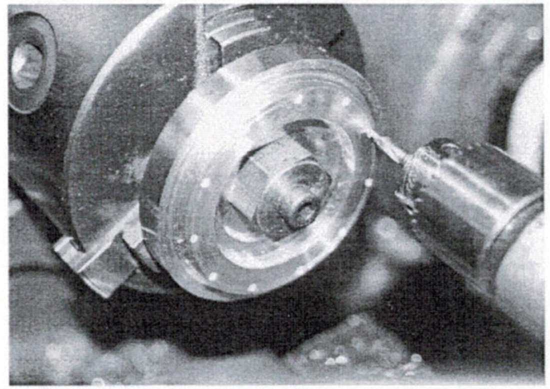
The blank disc is held in the lathe chuck and the rear is faced off and turned first. Carefully machine all the detail shown on the drawing. Do not machine the outside diameter or the 21mm centre-hole yet.



Reverse the blank and machine the recess for the oil seal and the central 21mm hole at the same time, to maintain concentricity. Use a round-nose tool to form the internal radii shown.

Remove the blank and make up a simple mandrel to mount the blank through the centre hole. Mount the blank to the mandrel and tighten securely. The outside diameter can now be machined and the ring machined for the wedges.

The face of the ring should be marked with layout blue ready to scribe the layout marks if you are intending to machine the wedges on your lathe.



Centre-holes for the wedges can now be drilled using a small 1/8 or BSO centre-drill, indexed for the 11 positions using your preferred device. Drill 3 of these to 3mm for service connections (refer to Part #7 drawing for position). The remaining 8 should be drilled out to 2.05mm (tapping size for M2.5) for the cover securing screws.

Wedges

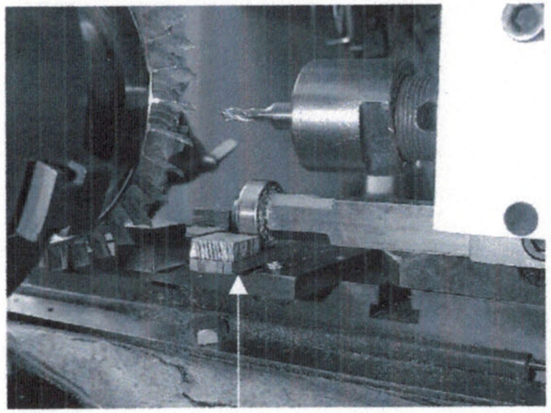
The lathe spindle is indexed for the 11 wedges using the indexing plate. The machining operations may require a more rigid fixing than that offered by the simple detent used for drilling earlier.

Marking out can be done on the lathe with the indexing plate or on a rotary table. The key angle is the underside of the wedge. This line should be extended across the ring marked with layout blue. When the piece is aligned with the milling spindle the cross slide can move the spindle along the whole length of the scribed line to check the alignment for greater accuracy.

The top-side of the wedge will be laid out in the same way. The work will need to be rotated and more than one cut will be needed. A 3 or 4mm end-mill will be adequate to make the main cuts. You should remember that the part between the wedges is tapered back 3.3' to allow for greater gas expansion - see the drawing for details. This taper can be machined easily by angling the rotary table or graduating device (if you have used one) with a sloping wedge or packing piece. You can also mount the cutter on a vertical slide, which is itself mounted on the tool post. This allows the cutter path to be at an angle to the faceplate.

All of the front steps are machined out. This just leaves the flow straighteners on the periphery to machine.

Flow straighteners.
The flow straighteners are tricky to machine. The easiest way to machine them is to construct a small step on the cross slide of the lathe about 3mm high on a piece of scrap metal 6mm or so thick.



The feed screw is removed from the vertical slide and the vertical slide is mounted on the tool post so that the machining is carried out using the top slide feed screw.

The up and down feed is controlled by a 19mm diameter ball race that is secured to the end of a bar. The bar is bolted to the bottom slot of the vertical slide. As the top slide feed screw is moved towards the rear of the lathe the ball race runs down the step and scribes an arc with the cutter. The cutter should be a 3mm-diameter end-mill or 3-flute slot-drill.

You will have to be very careful that the cutter does not snag and that you take small cuts.

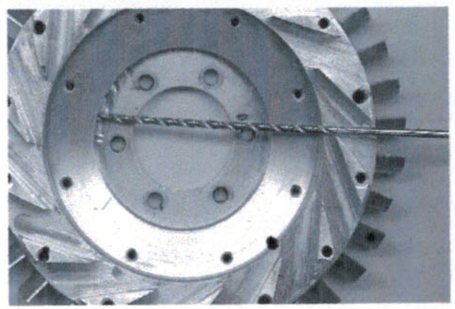
Installing the service connections
The inner side of the 3mm holes will need to be counter-bored to receive the face of the screws that bring the gas, oil, fuel and air pressure services in place. This can be achieved with a pin drill or end mill. Reverse the diffuser onto your mandrel and re-align the rear of the holes with your drilling spindle and dividing device. Counter-bore, using a 6mm dia pin drill or end mill, each of the holes, the aim being to provide a flat face. The inner edge of the periphery of the diffuser may also need relieving to allow the screw head of the pipe connector to slip into place. Mark each hole with a letter to indicate it's function eg "G" for gas – refer to the drawing to confirm which is which.

The diffuser can now be removed and the remaining 7 holes tapped M2.5 for the cover securing screws.

4.0 Air filter

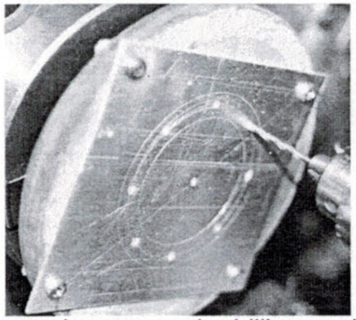
At the rear of the diffuser there is a machined recess which we call a "plenum", on which is fitted a fine filter which helps to ensure the bearings enjoy a plentiful supply of cleaned cooling air, free from grit or contamination and thus prolonging the life considerably. You will need to drill x3 holes of 2mm diameter between the inside of the recess and front oil seal and this air plenum, for the cooling air supply. This is a tricky operation and will require a long (100mm) drill bit as the standard length will be insufficient. If you don't have a long drill, then extend a standard one with a 60mm length of 3mm steel or brass rod drilled dia 2mm, into the end about 10mm. Clean up the drill shank and silver solder in place and keep in a safe place – we shall use it again later!

Drilling the air holes
The drill must be started slightly away from the corner of the oil-seal recess and starting the hole with a small ball-shaped engraving point has helped to keep the drill in the right place. It is also suggested that you slip a short piece of 0.5mm stainless behind the drill to ensure it stays away from the corner. This should ensure that the drill comes out inside the plenum. If you do not do this, the drill will break though where the filter cover is seated.



Refer to sheet 2 of Part #7 for the orientation of the drill, as it needs to pass ***between*** two wedges to end at the right place. See left on early 14 vane diffuser.

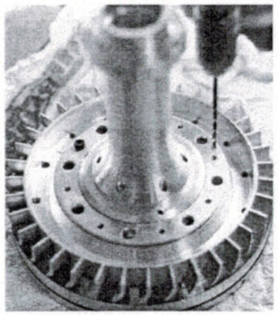
Air filter cover #9



The air filter ring, is simply made from 1mm thick aluminium sheet and this is mounted in the lathe on a ply former and turned - see left.

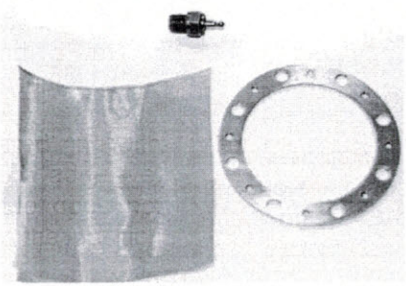
The centre hole should be a nice fit around the shaft tunnel.

Drill the x8 @ 4mm air holes in the positions indicated, using your indexing attachment and drilling spindle. Drill the x8 mounting holes to 2mm dia for the moment. Check the position carefully and mark with a centre-pop to provide a "top" location mark.



Once checked, the ring can be offered up and spotted through to the diffuser, in position, (see above right) using your new extra-long M2 drill! The holes in the diffuser are then tapped M2.5. Finally the 2mm holes in the filter ring are opened up to 2.5mm.

Filter gauze #8

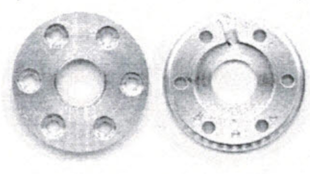


The air filter gauze is very fine 200x200 holes per square inch stainless steel mesh and is readily available from Wren Turbines.

It is stuck onto the prepared ring with cyno' glue or a contact adhesive, making sure that the glue does not spread over the mesh at the position of the air holes.

After it is dry it can be trimmed with a pair of scissors or sharp craft knife.

5.0 Front shaft seal #5



Front Back

This is a simple piece of machining that is turned from a piece of hard turning quality aluminium. The smaller diameter is a close running fit with the front bearing spacer (Part #2). This fit ensures the lubrication and air supply goes down the bearing tube and exits the rear of the engine and should be carefully turned to dia 11.1mm max.

The seal must be turned all in one piece so the centre-hole and outer diameters are concentric and finely finished. The air holes from the diffuser plenum meet the wedge shaped recess at the rear of the seal and are directed into the gap between the compressor and the bearing. Make sure the outside diameter is a snug fit to the diffuser.

The slotted grooves for the oil and air, can be made by milling with a 2mm ball-nose milling cutter whilst the piece is still in the lathe before parting off. Be careful to get the orientation right. Alternatively the grooves can be made using a 2mm dia ball-end engraving cutter in the "Dremel" and carefully "stroking" the groove in free-hand. The 0.5mmx21mm recess is to retain the front bearing and needs to be done carefully to size.

Use a six-step indexing device to accurately centre and drill the six 3mm dia holes for the securing screws – noting the orientation. These screws also retain the shaft tunnel (Part #11) so need to be accurate.

Mark the "Top" with a centre-pop to aid location later. If you find the shaft seal difficult to remove (to get to the bearing for example) then two of the holes (diagonally opposite) in the shaft seal can be tapped 4BA. Two longish 4BA screws can then be used as an extractor to gently ease it out without damage to the delicate sealing ring in the centre.

Front spacer #2

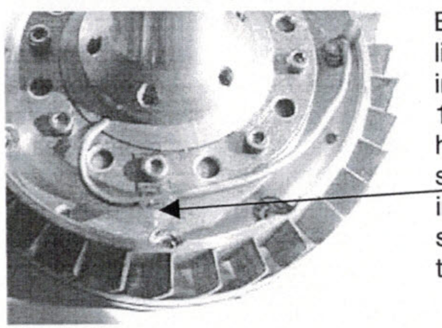
The centre spacer between the compressor and front bearing is a close running fit with the shaft seal and needs to be well polished and dead parallel across the ends and the outside diameter concentric with the bore. If it is slightly out of parallel it will bend the shaft as the compressor wheel is tightened onto the shaft. This will cause the end of the shaft to distort when running and may permanently bend the shaft and ruin the bearing.

Machine from mild or high carbon steel (do not use stainless) in one setting and carefully part off and check for parallel with the vernier or dial caliper. Stroke onto fine emery paper on glass plate to adjust if required. This item can be left slightly overlong, or made after assembling the motor, so its length can be 'adjusted' to give the correct compressor position relative to the diffuser. If adjustment needed a mandrel must be made to fit the spacer onto to maintain accuracy, and the part skimmed from the narrow end. Check as above afterwards for parallelism.

6.0 Lubrication and Gas Supply

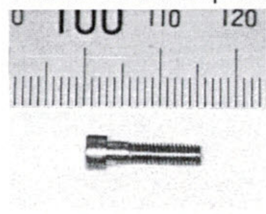
Lubrication
The bearings are lubricated with oil mixed with the fuel to the ratio of 6% oil to 100% fuel. Feed is via a simple pressure feed from a tee in the main fuel line. Metering is achieved using a 0.6mm hypodermic needle as a restrictor fitted in a short length of brass inserted in the pipe that leads to the lubrication fitting. This restriction is probably supplying a little too much lubrication but as it has worked well during tests is what we recommend.

Lubrication supply #33



Before attempting to fit the lubrication line, the filter cover plate must be fully installed. The lube line is made from 1.6mm o/d (0.8mm i/d) brass tube and has a small tab from brass or steel shim soldered to the tube when it is installed in position. The tab is subsequently anchored using one of the filter plate fixing screws – see left.

The oil line curves around from the bearing tube entering through the service access hole in the diffuser. To ease the forming of the bend, anneal the brass tube by heating to red hot and quenching in water. An angled 1.6mm hole will be required for the tube to feed lubricant directly to the front of the front bearing – see #33 drawing for details. The tube should be pushed through until it just appears through the diffuser face. It is then sealed in place with a smear of silicone sealant – be careful not to get any down the tube itself!



Service connection – lubrication

The connection through to the outside of the engine is achieved using a Part #36 tube-end fitting silver-soldered to the end of the tube. This allows an M3 female 'Festo' type push-in fitting to be used to secure and provide connection.

Propane supply #34

The space between the rear of the diffuser and the combustion chamber is small and we have kept the pipe sizes small to reduce affect on the airflow. We use a small brass feed-pipe made up into a "tee", with fine stainless tubes, silver-soldered in the ends of the tee. If brass were to be used at the ends they would surely melt in the heat of the combustion chamber.

A 16mm length of 2.4mm brass tube (1.6mm i/d) has a 1.6mm hole drilled in the side and a 10mm length of 1.6mm (0.8mm i/d) pipe is silver-soldered into this hole. Two lengths of 40mm long, 1.6mm brass tube are then silver-soldered to the ends of the 2.4mm tube to form a tee. Finally each end of the arm of the tee has a 25mm length of 0.8mm hypodermic needle or fine stainless tube silver-soldered to it. A Part #36 fitting is then silver-soldered to the feed end to provide the gas connection through the diffuser. The seat of the fitting should be exactly 13mm to the back of the 2.4mm tube – see drawing for detail.

The propane supply is fed through two small 1mm dia holes of its own at the forward end of the outer wrapper of the combustion chamber. The ends of the tee should be bent to the shape shown in drawing #34 and the ends inserted into the chamber. To ease the bending, anneal the brass tube as for the oil pipe. No fixing is required but if desired a couple of small stainless tabs can be spot welded on to the chamber to secure the gas pipe assembly. This completes your gas supply.

7.0 Front cover #6

The front cover is a simple piece of turning that is made from hard free-cutting aluminium. The machining will be easier if you can make an arbor to hold the cover when turning the outside diameter and o-ring groove.

Face off both sides and drill a hole to the arbor size. Secure the work on the arbor and turn the diameter down to 88mm o/d and at the same time make the recess for the 1.6mm sealing ring (or 1.5mm ring if you are using this size). The ring must be slightly proud of the adjacent surface but not so proud that it is impossible to push the case on over it, about 0.1mm proud has been found to work well. When fitting parts onto o-rings remember to use a smear of silicon grease over the ring so the parts are easier to disassemble, use steady pressure and ease it out in a controlled manner. Set up your drilling spindle and 11-way indexing setup and centre-drill and drill the mounting holes, 7 @ 2.05mm (to tap M2.5) and 4 @ 3mm. Take care to get the pcd to exactly 69mm.

The work can then be removed from the arbor and the inside and outside dimensions turned. The curve on the inside of the front cover can be hand turned after roughing out using a ground off end of a file and a rest. This will produce s smooth finish that will not need further treatment. The tapped holes for the plastic intake #4 are not drilled until it has been made and offered up.

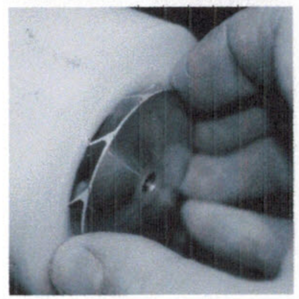
8.0 Inlet cone #4

This is machined from white or black nylon rod – Nylon 6 or 66 has been found to be especially suitable. Most grades are acceptable, as it does not get very hot or subject to significant forces. If you are using the larger "10" size compressor then trim this to size first (see Sect.10) and make your cone to match this.

A length is cut off with a hacksaw or wood saw and is held in the chuck in the lathe. It is important that all turning needed for the rear of the insert is completed without removing it from the chuck. First face off and bore the hole out to a snug fit on the compressor. Then by manipulating both feed screws and a boring tool rough out the inside curve for the compressor. The compressor should be offered up regularly to check progress.

The final turning is done by hand using the end of a file, which has been ground off to a gentle curve and a tool rest (using a bar in the tool post). It is easy and quick to turn the material and simple to get a good fit (see left).

Final fitting is by rubbing some pencil lead or a permanent marker pen on the vanes of the compressor and twisting the compressor in the turned surface. Alternatively marking blue can be wiped onto the plastic cone and the compressor twisted in its recess where it will scrape through the coating where it touches. This will leave a mark on the area that needs to be eased out with the file as before.



Don't fuss trying to get a perfect fit, as there must be a clearance for the compressor wheel of around 0.1mm. Once the recess for the compressor is completed, the 55mm stepped recess for the front cover can be turned. Use a nice sharp parting tool to get in tight into the corner here. Finally the outside of the cone is machined as far as can be accessed and the flange for the securing screws can now be formed. Make sure to leave at least 3mm of the intake end unmachined. This is important as if you need to make a small machining clearance later the part can be inserted in the chuck and careful light cuts can be taken with the ground off file.

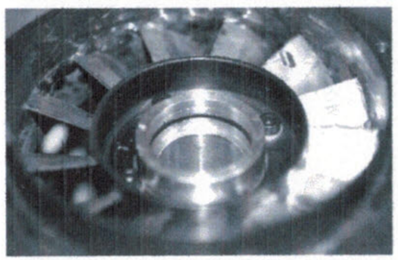
The drilling spindle should now be set up and your 6-step indexing device attached. The holes for the securing screws can be centre-drilled and drilled to 2.5mm dia. Be careful when drilling out holes in nylon – it has a nasty habit of trying to wind the part up the drill bit spiral, rather than make a hole in it!

If your chuck is known to centre fairly accurately with outside jaws, fit these to your chuck and clamp the front cover in place and using the same drilling set-up and indexing jig, centre-drill the six holes and drill out to 2mm diameter. The 2mm holes can now be tapped to M2.5 for the inlet cone. The drilling and indexing kit can now be removed.

The cone is now refitted to the chuck holding in reverse by the securing flange, and the outside profile is carefully produced. You will need to machine the profile carefully, taking light cuts because the work will not be held very securely and is flexible at this later stage. The intake bell mouth is formed in the same way as the compressor seating and the outside is turned to make a smooth curve matching the intake side. The wall thickness is not critical and can be left a reasonable thickness unless an especially lightweight engine is being constructed – be careful not to overdo it however and go through the side!

9.0 Shaft Tunnel #11

To ensure that the ball races do not revolve at high rpm, the outer ring of the ball-races are seated in O-rings fitted in machined grooves in the bearing area of the shaft tunnel. These provide a friction yet allow some element of give to allow the bearing to take up its optimum operating position without movement.



The O-ring grooves are made with a small internal boring bar hand ground to shape or alternatively an old slot drill can have its flutes ground away to leave a single "tooth" of 1.5mm wide and at least 1.5mm long (for 1.5mm o-ring).

The bearing tube is made from hard aluminium (HE30) and the first operation is to cut to length and face both ends. Drill the hole through and bore out to 14mm all the way through. Next carefully bore the 16mm hole for the turbine end, to a length of 41mm. Use a 688 bearing as a plug gauge – you need to make it a sliding fit, not too loose, not too tight!

Then using your made-up tool, machine the o-ring groove. Make small adjustments to allow the ring to just protrude enough to lightly grip the bearing and yet still allow it to slide. The bearing has to be able to move with the pre-load spring so should not be too tight. When happy with the fit, machine the outside profile to that shown on the drawing Part #11 to about half way along the outside.

For built-up ngv's – note the small step on the end to seat Part #24. Use a rounded tool to form the 3mm radii which is non critical. Do not drill the 4x2.5 tapped holes at this stage.

For cast ngv - follow the lower drawing to suit Part #35.

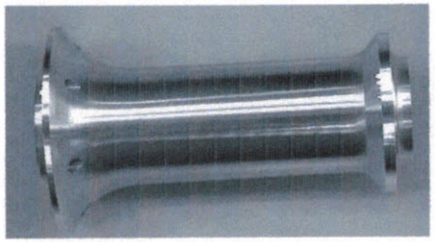
When completed, remove the shaft tunnel from the chuck.

Next we need to make up a mandrel. Cut a 70mm minimum length of mild steel of around 19mm in diameter and holding in the chuck, protruding at least 45mm, turn it down till the shaft tunnel will just push-fit onto this. Make sure it is a good finish before you try this – it might get stuck! (heat it if it does jam and ease it off gently).

Push the shaft tunnel onto the mandrel and turn the front bearing housing and O-ring groove as before. Take special care to ensure the back of the housing is absolutely square to the front face. The bearing surfaces must not be a loose fit but it should be possible to gently slide the bearing into its housing with only very light pressure – this is no place for a press or interference-fit! The front bearing has to be able to be extracted without force or there is a danger of the balls in the ball race falling out when the shaft is removed!

We have specified use of 1.5mm x 16mm O-rings. An alternative is to use 1.5mm O-ring cord cut to length and inserted into the groove which also worked well. I have found a cord length of 55mm works well. Do not cyno-glue the cord or you will get a hard spot on the ring. When assembling the engine, make sure to use a smear of silicone grease every time, to make disassembly easier and less strain on those precious bearings.

The grooves are machined so the O-ring is just proud of the machined aluminium. This needs careful checking and testing with a spare 688-size ball-race. The race should slip in with a squeeze of the fingers – don't forget the silicon grease! The ring can be made thicker when using cord, by leaving it slightly over-long to help where the groove is a little over-size. The material is cheap so a number of spares can be made up.

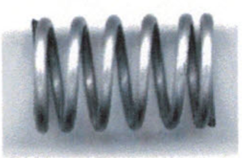


The outside profile for this end of the shaft tunnel can be turned whilst still on the mandrel. Rough out the curve out by jiggling the feeds and finish using the ground-off file and rest and easing the curve gently to shape by hand and eye to a blended 8mm radii.

Pre-load Tube #38

This is a new item and is used to even out the inevitable side loading imposed on the bearings due to asymmetrical thrust from the pre-load spring and provide even contact around the bearing ring. It is turned from the steel mandrel previously used for the machining the shaft tunnel. Drill and bore the steel to 14mm i/d and turn the outside to 15.9mm to ensure it is a nice sliding fit into the shaft tunnel. Carefully face off the end and de-burr and polish the outside and end to a nice finish with fine emery and oil. Part off carefully to 20mm long and remove any burrs. Make a second tube in the same way except 21mm long, while you have the material in the chuck. Keep this for a spare in case you need to change the pre-load.

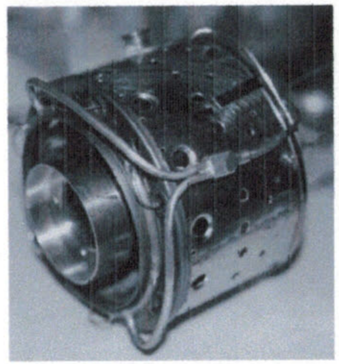
Pre-load spring #10



The pre-load spring is available at low cost from Wren Turbines. It can also be made from a 15.75mm dia spring cut to the appropriate length and ground flush and square. If the spring wire is too thick it will bind on the shaft. If it is to thin it will not have sufficient compressive strength. We have found that 1.6mm (16g) is a suitable diameter to aim for. You should load the bearing to 10lb. (4.5Kg) pre-load and the spring size shown should reach this point at 15mm compression from 20mm free length. A popular alternative for other applications – "Smalley" washers, are now available in the 688 size but the inner diameter unfortunately fouls the shaft thus cannot be used here.

10.0 Combustion Chamber #13

Design



Chamber above showing early fuel pipe arrangement

The chamber is a major step forward in reducing the volume required for complete combustion. This is made possible by the use of z shaped sticks that provide a longer length for vaporization than with the more usual straight sticks.

Swirl jets facing directly into the primary zone promote an aggressive mixing of fuel/air at the point of combustion and help retain the correct mixture ratio.

Introducing the main air dilution holes almost at the back of the chamber has reduced the overall length of the chamber. It has been found by our experiments that despite this small size of chamber the penetration and mixing of the cooling air is so good that there is no loss off efficiency of burning compared with larger engines. The fuel consumption of the engine is comparable to that achieved by larger engines. In gas generator form the engine is exceptionally cool running at 350 Deg C.

Workmanship

The home builder will find that a small engine is less tolerant of poor workmanship. This particularly applies to the combustion chamber.

The front and rear covers for the chamber must be accurately spun and fitted with minimal gaps. Extra air entering through gaps, particularly at the front joints, spoil combustion and cause combustion to continue into the ngv section making the engine run hot. Large gaps at the rear will rob the front holes of air and may be sufficient to stop the engine from running or from reaching its full power.

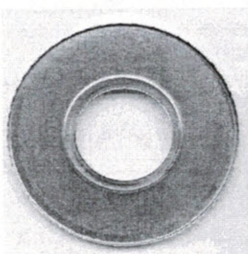
Materials

The chamber is made from stainless sheet. It has been found in practice that 0.4mm is an ideal and readily available thickness. We have used both 316 and 304 grades; both have proved eminently suitable. If using 316 the ends will need to be annealed before they are spun, by heating to red heat and allowing the material to cool down slowly. If using 304 this has not been required. This thickness also has the merit of being easily cut with good quality tin snips. 0.5mm stainless has been used for the rear of the combustion chamber and has shown to be a stiffer support for the vapouriser sticks, if available.

The vaporizer tubes are made from stainless steel 316 or similar with an outside diameter of 5mm and wall thickness of 0.3mm. A better material for the tubes would be Inconel but this is not as readily available.

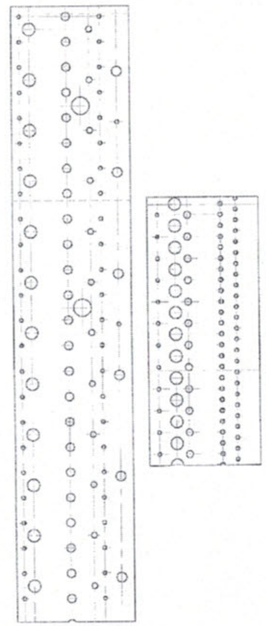
Making the combustion chamber ends #14&19

The inner and outer wrappers of the chamber are fitted inside the turned down flanges of the combustion chamber ends. A combustion chamber front can be seen at left. They must be made first so that the wrappers can be made a snug fit in this recess. If the correct grade of stainless is selected and properly annealed it is a straightforward matter to spin the ends onto aluminium formers of the size shown on the drawings. If the builder is not proficient at spinning the options are to either hand beat to shape over a former or to buy the shapes ready spun. When the ends are completed do not drill any holes at this stage.



Marking out the chamber inner and outer #16&17

These can be marked out by carefully scribing lines out on the metal to the dimensions shown on the drawings – don't forget the "TOP" marks.
The hole centres are gently centre punched to stop the drill wandering when drilling the hole. You can also use the spare drawing of the chamber included in the plans and to glue it to the metal with "Scotch" spray mounting adhesive or a solid adhesive such as "Pritt-Stick", and use as a template. If using the template, the centres of the holes are also centre punched. These adhesives are hard to clean off except with pure turpentine although a good soak in turbine fuel also works!



When all the holes have been punched the sheet will be deformed by the punching. Do not flatten it at this stage.

Drilling the holes

Before starting to drill, fix the items to be drilled to a scrap piece of MDF or plywood using some drawing pins. Do not try to hold with the fingers – if the drill grabs you could get hurt – you have been warned! The hole sizes are important and it is worth buying a new drill of each size to ensure you have the correct size to hand. Holes can be drilled with a sharp high-speed-steel (hss) drill and cutting oil should be used to cool and lubricate the drill.

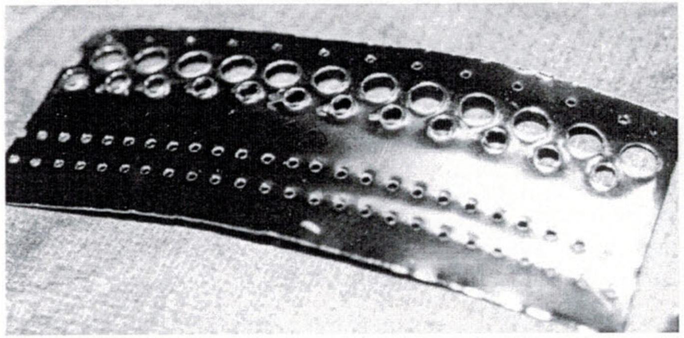
Start with the smallest size of hole and drill out all the holes with this drill. The larger holes can be increased in diameter to the specified sizes. Be careful to leave the large countersunk holes at the specified diameters, as they will be expanded when punched out. It is important to use a drill of the exact specified diameter. The hole sizes, particularly of the smaller holes is critical. The drill tends to pick up a cap over the end as it breaks through the material – the cutting oil helps to minimize this. Be careful to clear it from the drill before drilling the next hole.

An alternative to drilling the holes is to make a punch similar to the design that Terry Lee of the GTBA (Gas Turbine Builders Association) published in the GTBA newsletter. This can make the holes more cleanly and with less distortion than drilling.

Cleaning up the burr from the underside of the holes.

The metal is turned over and it is filed or sanded using a small drum sander in the faithful "Dremel" drill, to remove the burrs.

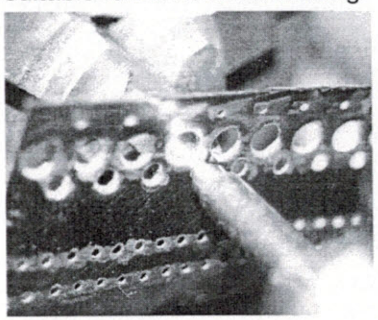
The slightly distorted shape will aid the job of removing all the burrs.



When complete the strips can be gently beaten flat ready for rolling to shape.

Forming the countersinks before bending.

If you don't have a set of bending rolls then the required countersinks in the chamber inner and outer can be performed while they are still flat, using a simple punch tool ground off to 60' and forming into a 60' recess made using a centre drill. They can then be rolled by hand around a suitable former before welding.

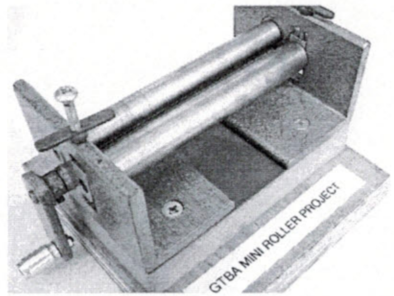


To keep the accuracy of the forming and stopping the countersink sloping off to one side, the die can alternatively be held in the 3-jaw chuck and the punch held in the tail-stock. Forming can then be smoothly and accurately achieved by simply winding in the tail-stock with the metal held in the tool.

The inner and outer can then be easily wrapped around a suitable former to curve into a neat tube.

Rolling to shape before countersinking

If you have access to a set of bending rolls and prefer to form into a tube first and then countersink, this is also straightforward. Terry Lee's design



(left) for a small bending roll, shown in the GTBA newsletter, is ideal for our task:

The chamber inner and outer are fed in between the rollers and the adjusting screws tightened until they are bent to the correct radius. This will make nice smooth curves and will be good practice for making the outside of the engine. When rolled they can be tried for fit in the end caps.

Spot welding thin stainless sheet

Welding of the chamber is carried out with a simple spot welder. The GTBA spot welder is ideal for stainless up to 2 layers of 1mm thick. The welder is best fitted with a timer because it is easy to blow holes in the thinner materials if the weld time is too long. Stainless steel should be cleaned in the area to be welded with a light touch of the "Dremel" grinder along the seam line. This will ensure a strong and effective weld.

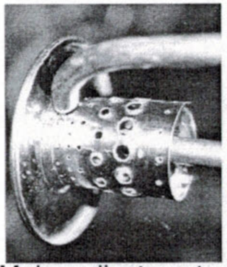
Forming the countersunk holes after forming into a tube.

The chamber inner and outer can be rolled into a tube that is a snug fit onto the chamber front (and rear in the case of the outer). The countersinks in the outer wrapper can be formed with the use of a 60' cone-shaped punch and a die in the form of a piece of steel bar with matching hole to punch into. The die is inserted inside. If the hole is punched a little smaller than the required size it can be drilled out to exactly the correct diameter.

Inner wrapper #16

The inner wrapper needs a slightly different approach if you have opted for forming the countersinks after rolling. You will need a short punch inserted crosswise in a length of 20mm diameter mild steel rod or similar. You will also need a steel rod drilled out at the end and shaped for the countersink using a 60' centre drill. The drilled hole in the inner wrapper is located on the short punch and the rod is hammered onto the punch. Again finish to exact size by drilling out the holes if required.

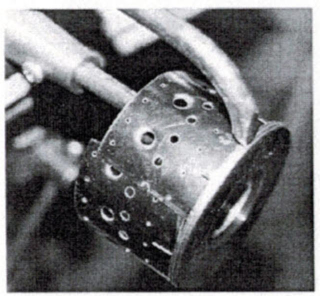
Welding the combustion chamber inner to the chamber front.



The chamber inner fits over the inner flange on the front cap. You should slip the chamber inner over the small flange and tack the seam with one spot and check the fit. When satisfied tack the other end to form into a tube. Tack the tube to the chamber front with a spot at one edge of the joint and check the fit. Left shows a chamber inner already countersunk, being welded to the chamber front.

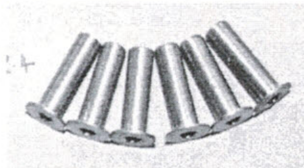
Make adjustments to get the chamber inner exactly at 90' to the chamber front, and place an opposite tack to hold in place. Then weld two more tacks at the 90' points and check all is square – any problems can be cured easily at this point if required. A series of spot welds can then be placed around the edge to seal the gaps. The seam along the chamber inner can now be spot welded all the way along.

Welding the combustion chamber outer #17



The chamber outer is spot welded into a tube which is a snug fit into the chamber front - use a couple of tacks and when satisfied with the fit weld along the seam. The chamber outer should then be aligned so that the large countersunk holes exactly intersect between the countersunk holes in the chamber inner. This can then be carefully spot welded to a close fit with the chamber front be careful to eliminate any air leaks as it should not be necessary to take apart again. When satisfied with the fit, weld along the seam. If the chamber inner and outer turns out slightly non-concentric a small adjustment can be made by inserting a bar into the inner and bending in the required direction. This flexes the chamber front so should be done carefully.

Swirl Jets, Part #39

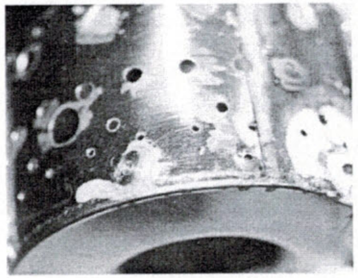


These are an important part of the chamber design and are the key to the combustion chamber working well at high airflow rates. They consist of a hollow stainless turning. The size of the hole in this part is the only real "tuning" that can be done with the engine.

The jets replace an earlier version of the chamber which had small slits which provided a flow of air into the front of the chamber – if the slits are on your plan then replace them with a 3.8mm drilled hole. The jets replace these slits and are installed at the same location. The jets are simply turned from stainless to the shape shown or alternatively can be made from a piece of stainless tube 2.4mm bore x 15.5mm long tube with one end belled out slightly. If your tube outside diameter is different from 3.8mm, adjust the holes in the combustion chamber outer to suit.

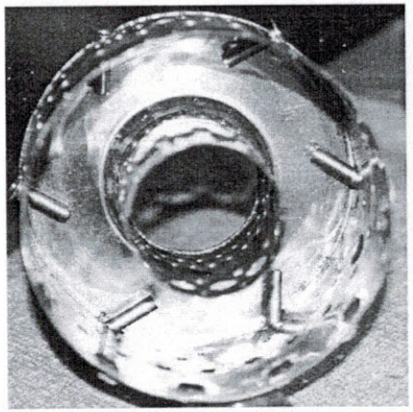
To fix to the chamber, one edge of the jet is bent to an angle of about 45' and after cleaning around the hole, is inserted into the chamber wall. A length of 2.4mm dia steel rod or piano wire of 13swg is inserted through the jet to a total depth of 30mm, whereupon the end (inside the chamber) should be positioned 10mm away from the edge of the chamber inner. The rod and jet should then be angled forward until the rod touches the front wall of the chamber. This is the correct position of the jet and a spot weld should be placed between the angled flange and the chamber outer to hold it into place.

When completed check the orientation and when satisfied do the same for the remaining five jets.



The jets should now all be silver soldered into place using a high temperature silver solder such as Easy-Flow 24. Use plenty of the appropriate flux and heat quickly. When cool, the rod can be inserted and small adjustments made to the jet angles if required.

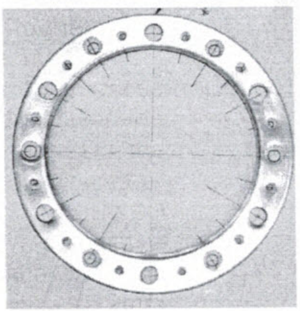
The outer ends of the jets can now be linished or filed into a neat and tidy shape.



The angle and position can be seen here at left viewed from the turbine end.

The inner ends of the jets should end up about 4mm away from the ends of the vaporizer tubes and slope 5-10' towards the front.

Combustion chamber rear #19

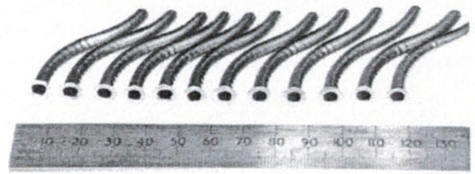


The chamber rear should be spun to the shape shown on the plan and can be marked out carefully and centre-punched for the various holes. I found it easiest to do this directly on top of the plan and mark with a felt pen. Do the vaporizer holes first.

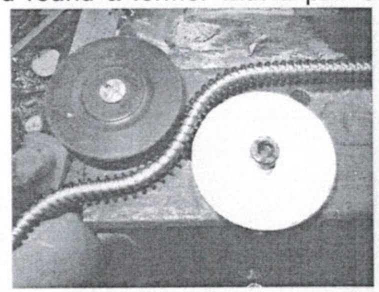
Drill with a centre drill and follow up with a 4.8mm drill - use low speed and be careful it doesn't snatch. Finally drill out with a 5.2mm drill to size. Deburr the holes and then repeat the process for the air holes, drilling out to 2mm. After drilling the holes should be carefully de-burred.

Vapouriser tubes #18

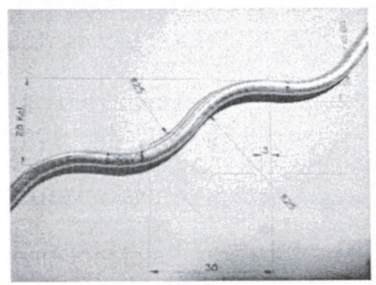
The vaporiser tubes are made from thin walled stainless tubing that provide a heating surface for the fuel to flow over and vapourise - hence their name.



They should be bent whilst still in a long length as it is impossible to grip if already to size. Bend round a former with a pair of 6mm thick, 40mm diameter disks from aluminium or steel (40mm as the tube "springs" out after bending).



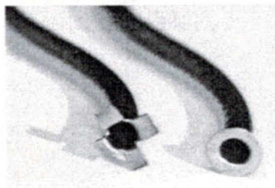
Bend to the shape shown left, using a length of steel spring slipped over the tube. This should be a good fit or the tube will readily kink. I found spring sold for model loco springs to be ideal. An alternative is to use "Woods" metal, a very low melting point alloy. Fill the tube completely, make the bends and then melt it out in boiling water afterwards. You will need about 1mtr altogether for the 12 sticks.



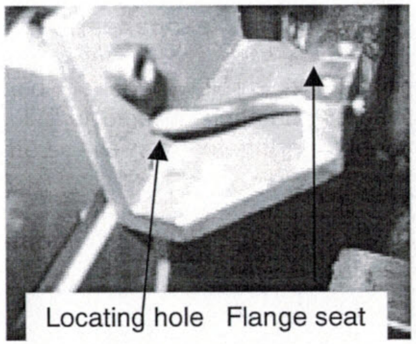
Bend the whole length into a series of alternating "s" shapes so you can get a good hold of it and get the desired shape. Then lay it over the plan at the point where the length fits best, and mark the ends at the dotted lines with a felt marker for the cuts. This allows a little extension on each end to allow you to form the flange and some adjustment for total length in the chamber later.

The tube can be easily cut with a small hacksaw - an old blade is best, as it doesn't stick so easily. Use pull strokes after starting as the teeth will jam otherwise, don't use cutting oil as it is hard to clean off completely afterwoods and will prevent the spot welding working. When you have cut all the sticks out deburr the ends on your linisher or belt sander gently, and clean up the inside of the ends - a centre drill works well here, a small file would probably also work.

Forming the flange on the vaporizer stick.



The flange can be made by slitting the end of the tube into 4 petal shapes with pointed snips or a jig can be made to form a neat flange.



Flanging jig.

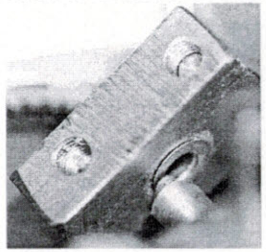
We have to hold the end of the stick at the right angle leaving the end protruding about 2mm. I used a piece of angle iron attached to the faceplate. The seat of the flange was formed with a piece of steel 19x13x25mm long and attached with two M5 cap screws.

The flange seat is attached and the whole assembly adjusted on the faceplate until the middle point is centred on the tail-stock centre. A 5.1mm hole is then drilled through from the tail-stock end. The end is then faced off to ensure it is dead square.

The flange seat is then removed and the rear of the hole is relieved with a 6.5mm drill to leave the 5.1mm hole at a depth of 4mm from the flange end. This gives the curved tube clearance to enable it to be withdrawn after the flange is formed. To locate the other end of the stick a 5.1mm hole is drilled in the angle iron (see the arrow above). The position is such that it allows the stick to protrude the 2mm required.

Using the flanging jig

A stick is inserted into the jig by removing one of the M5 screws and the stick end located into the locating hole to lock it into place.



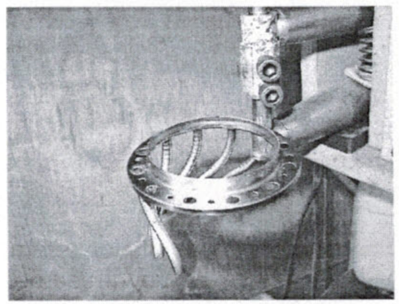
After replacing and tightening the M5 screws, the end of the tube is spun over with a small brass stub held in the toolholder. With a little practice this can be easily achieved and done in one pass.

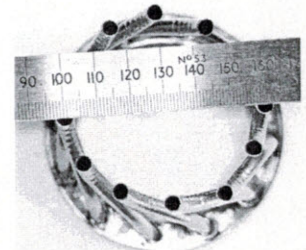
Gently tap the flange with a small hammer afterwards to fully flatten it down square. Repeat the process for the other 11 sticks.

Securing the vapouriser sticks

The tubes should be spot welded into position – securing by silver soldering is popular for other designs but we have found it has a tendency to crack over time so we recommend the added security and simplicity of spot welding.

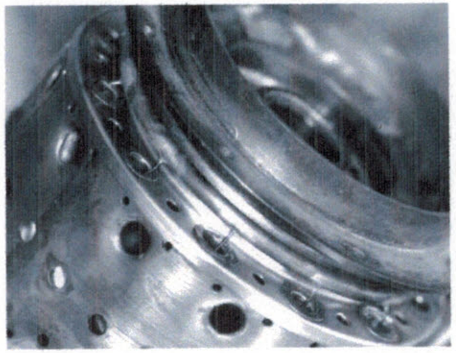
Welding in position





The tubes should be welded to the chamber end in a position that enables the centre of the tube ends to lie on a 54mm diameter circle. Ideally four spots should be used if you can get in ok. There is a layout for the combustion chamber sub-assembly #13 in the plan.

Once the sticks have been welded in place the chamber end can be offered up to the chamber outer and the position adjusted until the "TOP" marks are aligned and uppermost.



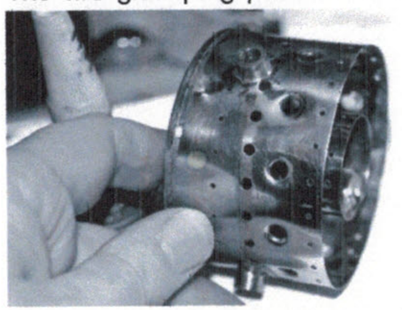
The vaporizer tubes should pass neatly *between* the large countersunk holes in the chamber outer. The tube ends should end up 4mm away from the swirl jets and in line with the jet of air that they produce.

The completed assembly should look as shown left.

You can weld some tabs to secure the back of the chamber to the rest of the chamber assembly. Alternatively some stainless wire can be used to wire-lock the end on. It has been found in the prototypes that the two glowplug locations provide a positive location preventing parts coming apart. This has the added advantage that you can easily take them apart for observation or cleaning if required. In addition the glowplug attachments locate the combuster inside the outer case negating any further fiddly fixtures.

Glow-plug boss's Part #15

The two glow plug positions are shown on the drawing and you should keep to these and work accurately. You should make and fit the two boss's even if you do not wish to use a glowplug as they provide the location and fixing for the combustion chamber.



If you do not intend using a glowplug then a pair of blanks should be made to enable the fixing to still work.

The short length of stainless rod for the glow plug should be drilled and tapped ¼"x32TPI which is the standard thread for glowplugs. They will need to be silver soldered in position.

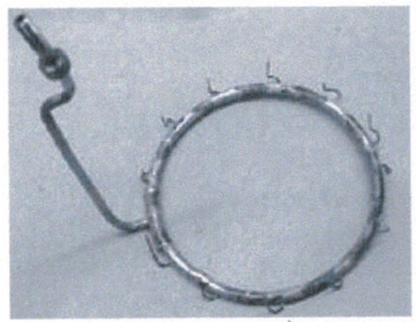
If you are making the gas generator version of the engine for a turbo-prop or turbo-shaft you should fit both glow plugs. It will be impossible to start the engine without using plug ignition and having two allows some redundancy in the annoying event of blowing one!

The crest of the glowplug boss should be gently rounded to match the curvature of the outer can of the engine. This can be achieved by judicious use of a fine file or the linisher.

Fit to the NGV

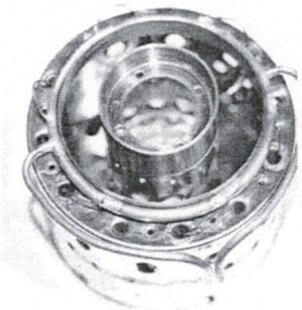
The combustion chamber inner must be a snug fit into the inner core (#24) of the NGV rather than loose. The chamber outer that slides over the outside of the NGV (#23) must also fit well but should not be too tight a fit otherwise assembly will be difficult. Heat expansion can cause splitting if it is too tight. The NGV may need to be turned down slightly to fit the inner diameter of the combustion chamber rear (#19).

11.0 Fuel supply



The main fuel pipe is made from standard brass 2.4mm outside diameter tube as found in model shops. Be careful to get the drawn seamless variety so you don't get leaks and anneal it all along by gently heating to red heat and allowing to cool. The pipework is silver soldered together. The 12 injector needles are 0.50mm o/d hypodermic needles. For the thrust engine you can use 0.60mm o/d ones if your pump is not very good and you cannot reach maximum rev's. This gives a less controlled start but runs well.

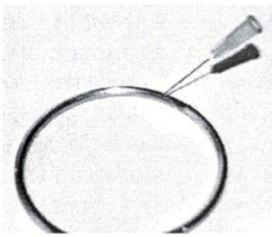
Ensure your problem is not mechanical first!



The fuel distribution ring simply slips onto the chamber rear. This method does introduce an element of fuel pre-heating and this is felt to be desirable.

Left shows earlier ring with two feed, now simplified to just one.

A fuel distributor ring is made to the dimensions shown on the drawing from 3mm or 1/8" brass tube.

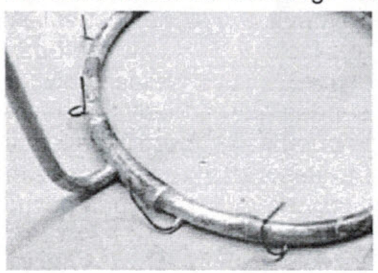


The holes for the needles are drilled before the stalk is soldered in place and a good technique is to drill until the drill bit is just about to break through and then use the needle or a sharp scriber to punch through the last little bit. This will ensure the needle is gripped in a tight fitting hole that will prevent any soldering flux getting in.

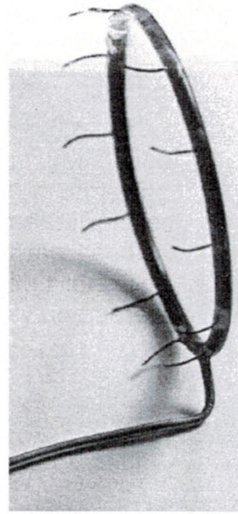
The needles are silver soldered in place being careful to supply only just enough heat to melt the solder and get it to run around the needle.

Fuel pipe assembly #20

The ring is joined by a piece of slightly larger diameter tube that fits over the tube used for the ring. When silver soldering these small parts it is worth obtaining some 0.5mm silver solder as it melts very quickly and together with a supply of freshly mixed flux will ensure success. Be careful not to overheat the brass pipe as it can be easily melted. The fuel supply pipe is simply silver-soldered to one edge of the fuel distribution ring.



The ideal position is that of the joiner (see above).



Once the needles are soldered in place and the ring is joined, the assembly can be tested using gas to ensure that there are no leaks and that none of the needles are blocked.

There should be an even height flame from each needle. Thin fuse wire may be useful in removing small obstructions to even out the flame but easier still, if you have a problem with any of the needles they can be re-heated and pulled out with pliers. The resulting hole left will fit the needle nicely and a new one can be inserted and soldered.

Service connector Part #36

For connecting the fuel pipe to the outside world and for use with the other service connections for lubrication and gas, a special screw connector is used. This is a simple steel turning which is threaded M3 and is drilled and silver soldered to suit the various pipe sizes. You need to apply pressure between the pipe and the screw to avoid the silver solder running into the tube. If you are unlucky and the tube is blocked after soldering do not worry. Simply drill through the hole in the screw until it penetrates the obstruction. When drilling, the screw should be kept horizontal so any swarf will not drop into the pipe. With care it is possible to drill out the blockage and have still have a usable pipe.

The head of the connector is seated on the service connector holes through the diffuser vanes. It is drilled out with a 3mm-clearance hole. The base of the rear of the hole is faced square with a pin drill or end mill as previously described in the diffuser section.

Adapter Part #32

The threaded fittings, part#36 are fixed with brass adapters which retain them and provide easy access around the inlet cone mounting flange, to screw in a 3mm 'Festo' type or similar push-fit male fittings. If preferred the adapters can be omitted and 3mm "Festo" female type fittings can be screwed on to Part#36 directly, but a relief will have to be trimmed from the edge of the inlet cone mounting flange to clear them.

12.0 The shaft #12

Design

The shaft is exceptionally short and this has enabled the engine to run safely to high speeds without distortion. The early prototype engines had the compressor mounting hole slightly enlarged from 6mm to 6.35mm or ¼", achieved by the use of a machine reamer. This gave a stiffer shaft overhang. In tests this has been found unnecessary and we have reverted to the 6mm o/d mounting for the compressor. The compressor and the turbine are secured with a 6mm left-hand thread. Right hand threads cannot be substituted here as the torque from the turbine will unscrew the nut and release either the compressor or turbine with disastrous consequences.

Workmanship

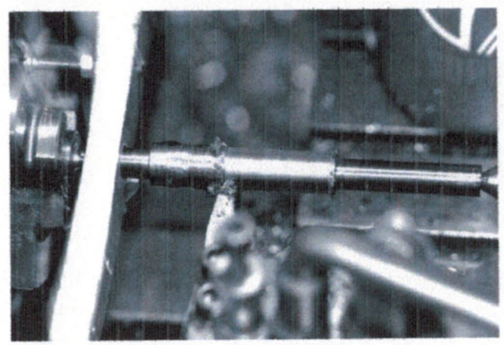
Shafts appear simple to make, but they demand exceptional care with turning even when turned between centres. Cylindrical surface grinding will give the best results and allow a better fit for the bearings if this is available. Bearings should not be a tight fit and require the use of an extractor. They should be a gentle sliding fit that can be removed with the fingers. The special 688 size ceramic cageless bearings are assembled in one direction and can come apart if disassembling the engine without care. Screw-cut threads generally produce a better finish than a die and are less likely to distort the shaft.

Material

The shaft for this engine will not need hardening. We recommend using En24T grade steel in its supplied form. The prototypes have run to high rpm with this material without any problems.

Machining the shaft

If you are to attempt making the shaft on a lathe you must have sharp tools preferably with indexed tips. En24T is tough but straightforward to machine. A supply of cutting fluid is preferable but if possible use a high sulphur oil to dissipate the heat, paying special regard to adequate ventilation to avoid build-up of fumes. The first task is to cut the blank to length and face the ends. Both ends need centre drilling and all turning must be carried out between centres, preferably without removing the shaft until completion. The shoulder of each diameter should be formed with a small radii to avoid stress points.



Turn the outside to +0.5mm oversize; (this will enable a final finishing cut to be taken after the bearing surfaces have been machined). The bearing shoulders are turned leaving the bearing surface +0.25mm oversize. Turn the shoulder for the compressor at the right hand end and finish to size. You will find it easier to get a close fit for the hole by turning almost to size and then using a fine cut file to smooth out the machining marks and the last few 0.001mm. You could purchase a clockmakers pivot file, which can be used to obtain a high polish to the surface.

Bearing surfaces.

The bearing surface can be turned next in a similar fashion. Be careful about marking the surface of the finished sections with the lathe dog - always use a scrap of brass or soft aluminium to protect them.

The bearing should be a sliding fit and should not be loose. However it must not need force to push it on or off the spindle. We recommend that you have some standard (cheap!) 688 bearings to use to check bearing fit. The ceramic bearings should be kept as clean as possible before installation and you wouldn't want to have to retrieve a load of tiny ceramic balls that have dropped out of a bearing push-fitted too tightly!

Ease the diameter down to a nice fit with oiled 1200 grade emery paper wrapped round a flat piece of metal. Do not wrap the paper round the shaft - it will grab and take your fingers round with it!

The threaded portion

The step down for the M6 thread can be turned to size now. Cut a small lead at the front of the shaft to help the thread start. Using a fine round-nose tool, cut a small run-off for the thread about 1mm wide and 0.5mm deep. Don't cut the actual thread until the other end of the shaft is ready. The tapered shoulder is turned next - simply set your top-slide over to the correct angle and take small cuts.

Turbine end

The shaft can now be reversed and the turbine end machined. The turbine wheel seat should be turned to size in the same way as the compressor. You may find that drilling and reaming a hole in a piece of scrap steel, with the same reamer you plan to use for your turbine, will be an accurate way of gauging the correct diameter for the hole in the wheel. Alternatively - make good use of your micrometer. The seat should be nicely polished. Finally, turn the 6mm diameter for the turbine nut with a small sloping lead as before. Finally turn the tapered shoulder as before and we are ready for threading.

Screw cutting the left hand thread

The threads at each end are best screw-cut in the lathe if you can. Set up the change wheels for the thread and be sure to check that the travel is for left hand. Old Myford lathes can cut metric threads with 42 and 21 tooth change wheels. See Myford handbook for details. Using a high speed steel threading tool ground to 60' for the metric thread engage the feed screw ready to cut the thread. Always use a handle or some means to turn the lathe spindle by hand to avoid damaging the work. This method will cut the screw with the minimum of force on the shaft. Reverse the shaft again and thread the compressor end. If you have to use a die, then hold off finishing the centre body of the shaft for the moment.

Finishing the centre body

The centre body of the shaft is given a skim down to size after making sure with a dial indicator that the bearing surfaces are truly concentric with the centres. You can finish with a fine cut file or a piece of flat steel wrapped with 1200 grade emery and oiled, to get a polished finish.

Threading with a die

If you have to use a die for threading then remove your centre from the chuck or head-stock and hold the shaft as accurate as you can in your chuck. Lock the chuck using whatever means you have. Use a hand die-stock, held square by gentle pressure from the tail-stock. Apply cutting fluid and start the thread (don't forget it's a left hand thread!!). By rotating the die as opposed to turning the shaft any inaccuracies tend to be minimized. Finish the thread up to the shoulders. Finally set up your centre at the head-stock end again and skim the centre body of the shaft down to size - see above for details.

Once complete you will find that however you have made the shaft that it will be very slightly out of balance. It is only possible to detect the forces at each end of the shaft using a very sensitive balancer of the type that Tom Wilkinson describes in the GTBA newsletter.

Making the compressor spinner #1

This is made from a nice hard aluminium in one operation. The cross-hole is drilled first after accurately setting up in a drill machine. The rod is then held in the lathe and the end of the rod is faced off and drilled to take the tap to cut the thread inside it. The M6 left hand thread is cut using cutting compound and it is necessary to use a plug as well as a 2nd or taper tap to get the thread right to the end.

The outside of the spinner is turned to shape to suit the diameter of the boss on the compressor. It is tapered and rounded and parted off carefully ensuring the seat is dead square and with the smallest pip possible. The spinner can be mounted on a previously threaded rod to complete the rounding of the end using a fine file. Use fine emery paper and white spirit to polish to a nice smooth finish. The spinner must run dead true or the engine will howl as a result of imbalance and the front bearing will suffer. If it runs out don't mess with it, make another!

Making the turbine nut #27

This is made from hexagonal stainless 316 bar and is simply faced, drilled and threaded as for the spinner (don't forget it's a left hand thread!) and parted off.

The rear spacer #26

The rear spacer is between the rear bearing and the turbine. This part, as for Part#2, needs to be made with accurately machined faces that are exactly parallel.

The material can be any easy to machine steel such as mild or silver steel. The spacer is machined for the outside and drilled and bored to the final finished size. It is then parted off and then checked between the calipers of the vernier gauge or micrometer. It should just slip though and not bind at any point. If it does then it will need to be rubbed down by hand on a hard flat stone such as an Arkansas stone or on a piece of fine cut wet and dry emery paper glued onto a flat surface. By applying pressure on the side of the spacer that binds it is easy to remove just enough material to make the spacer exactly parallel.

Making the ngv inner #24 (fabricated ngv's only)

The ngv inner is a simple turning from stainless steel. The ideal grade is 310 but any similar grades are ok. Start with a block 38mm diameter and about 30mm long. Chuck the block, face off, and turn the inside end first to retain concentricity. Centre the end and bore out to 22mm i/d for a depth of 20mm. Then turn the recess to a depth of 6.5mm and i/d of 32.8mm to fit over the combustion chamber inner (#16). Turn the 30' chamfer inside and outside and the lighted portion to the shape on the plan.

Next set up your drilling spindle and a 4-way indexing device. The mounting holes can now be centred and drilled to 2.5mm on a 26mm pcd. Part the component off to a length of 17.5mm and reverse in the chuck. Face off to 17mm long o/a and bore the 35mm i/d recess to a length of 9mm. The completed part is now slipped over the shaft tunnel and the mounting holes spotted through and finally drilled 2.05 and tapped M2.5.

Bearings #43

We have specified the D688/602 976, full complement ceramic bearings from GRW.

These are the only bearings that we know of that are suitable for prolonged running at 160,000rpm.

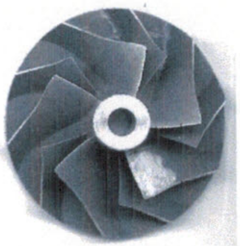
The prototype engines have been run for many hours up to high speeds free of bearing problems. When testing the first prototype we did have a failure when using a standard caged 688 steel bearing. The bearing was being adequately lubricated but the cage simply opened up and released the balls.

We strongly urge the builder not to attempt to run with standard bearings even though the low cost of the standard bearings may be attractive, you will barely get about idle speed before certain failure. When our early bearing failed the shaft seal acted as a shaft saver and damage was minimal apart from having to remake the shaft seal.

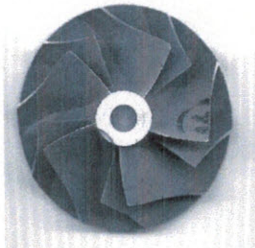
13.0 The Compressor #3

The aim of the design was to utilise the largest amount of air that could be delivered from the smallest compressor.

This has proved an ambitious aim, as the high throughput wheel is very intolerant of the turbine wheel, NGV and diffuser angles.



Garrat 446335-09



Garrat 446335-10

The Garrett 446335-09 T25 compressor chosen (see above left) has an inlet diameter of 38.6mm compared to the overall diameter of 54mm ("54" is where the engine gets it's MW54 name). The prototypes have been tested with this wheel, a larger inlet variant of the Garrett wheel (446335-10) and a compressor wheel from KKK.

The design has been optimized for the Garrett "09" size wheel and that is the wheel we suggest. The Garrett compressor needs no other modifications but may need accurate electronic balancing. As this "09" is an expensive wheel we have used the larger "10" size trimmed down for the prototype engines and this was found very successful - in fact this is how manufacturers make their smaller sizes. For some reason the larger size is a lot cheaper!.

Re-profiling the "10" size compressor

If you obtain the "10" size you will need to trim it to size. Remember to do this before making the inlet cone so it can then be made to match your profile. First mount a length of steel rod in the lathe and turn it to be a nice firm fit for the compressor. The compressor can be gently pressed on and we are ready to trim.

Make up a plastic template of the profile required, using the plan. Set up a turning rest on your toolpost, positioned as close as you can to the wheel.

Wear your safety glasses for the next part, as a lot of little bits are spread around! Select a flat file that has had a nose radius of about 8mm ground onto it with a touch of clearance angle. Using the file and with the lathe running nice and fast, gently trim the compressor to the new profile. Take very small scraping cuts so you don't bend the blades, and aim for a nice smooth finish. The template should be offered up to the wheel from time to time. Note, it needs to be turning for the true profile to be seen, so watch your fingers while you're doing this!

Once you are happy with the shape the wheel can be removed from the mandrel. At this point it is most likely out of balance and this will need to be done before it can be used in running in the engine.

14.0 The outer case #21

The design is aimed at allowing the home builder to make more of the engine if he chooses and to retain the compact dimensions of the unit overall.

The case is made from 0.4-mm thick, stainless steel, rolled into shape and the seam spot welded. You MUST be able to produce a good quality spot weld, as this is a pressure vessel. It has to be able to stand at least 1.5 bar above atmosphere. We have specified two rows in order to incorporate plenty of strength into this important component.

An alternative to the wrap around case made from sheet is to find a vessel of the correct diameter and length in the Cookware Dept. of a local hardware store. We have not carried out an exhaustive check of oil filters but there may be one that has a casing that is close to the required diameter. If you use a case that is too large then the effect of the cooling holes in the combustion chamber may be changed so it not advised at this stage.

Making the outer case

The sheet for the outer case is carefully marked out first, not forgetting the glowplug positions and cut out with tin snips. It is ideally and effortlessly rolled into shape using the GTBA rolls or similar. The case needs to be made a tight fit over the front cover and rear case of the engine. When ready, the area of the weld should be thoroughly cleaned with a green kitchen scourer.

Welding

One spot weld at each end is then made to check the accuracy of the fits. The fit at the front can be looser than at the back as the O-ring is intended to seal the case here. When satisfied with the fit, the case can be spot-welded along the seam by running a line of large spaced spots about 20mm apart and then going back and welding the space in between. This will help to minimize distortion.

The joint must have two rows of closely spaced spot welds along the length. If the joint is placed towards the underside of the engine it will not be noticeable. A thin smear of car exhaust gum such "Holts Firegum" (available from Halfords and other motorists stores) along the seam will help ensure the seam remains gas tight. Silicon can be used but the tail end of the engine can get very hot under certain circumstances and the seal might de-compose and start leaking.

Case rear #22

The rear case for the engine is turned from either a piece of 6mm thick mild steel plate or stainless and the centre hole should be bored for a snug fit to the NGV. The steps can be machined out with a boring bar. The outer diameter can be turned to allow the case to be a tight fit. Before removing from the lathe the 3mm holes for the eight NGV screws can be drilled using a dividing attachment and a drilling spindle. The rear case can be removed from the chuck and eased into the outer case, aligning carefully with the end. There is no need for the end to be removed from now on so a tight fit is ok.

Assembly to the case – marking fixing holes

Using a compass, draw a circle of 90mm diameter on a sheet of paper. Then with a protractor, mark out on the circle, lines at 60' to each other and passing through the centre point and extending out about 10mm beyond the periphery.

The case can then be carefully positioned over the circle and index marks placed with a scriber in line with the lines on the paper. A pair of dividers can then be used to accurately mark the distance in from the end. The crossed marks can then be gently centre punched.

Drilling for fixings

It is best to drill the two parts together by drilling the tapping size drill right through. The holes can now be tapped for the securing screws – use cutting compound. Finally a clearance drill can carefully be used to open out the holes in the out case. The fixing screws can be smeared with thread-lock and screwed in firmly. They will not need removing again.

Sealing

An air and oil tight seal can be obtained by smearing high temperature silicon sealer or exhaust sealing gum around the inside of the rear case connection to the outer case. This goes off quickly so once on do not "play" with it Only a small amount should be used as it expands when heated. This has been used as the method of sealing the prototypes and has been very successful.

The front cover is made as part of the diffuser assembly and can be marked using the same system as for the end. The case is drilled 2.5mm clearance size after careful measurement of the main engine assembly. The assembly is fitted into the case, orientated carefully, and then the drill is used to "spot" the fixing screw positions. The engine assembly is then removed and the front cover removed and drilled for the tapping size for the fixing screws. It is useful at each stage of assembly, to have marks to show orientation as although parts should be able to be rotated and still fit – sod's law will intervene to ensure this is not the case!

15.0 The turbine wheel #25

This is available as a cast item and we have spent much time developing the profile and optimizing the engine to match the wheel. The material is Inconel 713c and is extremely tough to withstand this exacting duty.
We have tested our cast wheels to higher speeds than anticipated to be used on the engine, without any problems. It is important that the top speed of 160K is not exceeded. As usual the wheels are cast to aerospace standards with full x-ray testing.

The wheel can be obtained from Wren Turbines with the hole reamed to 1/4". Wheels can also be obtained with the hole bored if you wish to do this yourself.

Making the turning fixture

To bore your turbine wheel, you will need a fixture to hold the wheel securely and perfectly square. This can be made from an aluminium blank of 75mm x 10mm thick and a ring of 75mmx6mmx33mm i/d.

Hold the ring in the chuck and face off. Using the drilling spindle and dividing attachment drill 4 holes at 5mm dia on a 64mm PCD. Remove from the chuck and hold the thicker blank in the chuck and using the same drilling and dividing setup, drill 4 holes at 4.2mm diameter to 8mm deep, on the same PCD. The drilling and dividing setup can now be removed.

The 4.2mm holes should now be tapped M5. A hole of 30mm diameter should now be bored right through - be careful you don't run into your chuck! Then turn a recess of 5mm deep to the outside diameter of the wheel. The wheel should be a sliding fit into this recess, so keep checking the fit as you get to size. The wheel is fitted with the inside face facing out.

The wheel is eased into the hole in the blank until the rim at the root of the blades rests against the back of the recess. The ring can now be attached used 4 M5x12mm long screws and gently nipped up squarely. The wheel should now be held firmly for the inside face of the hub to be machined square.

Machining the turbine wheel

Use a new tip in your tipped tool and running the lathe at around 250rpm, carefully face off the hub. Using a new BS2 or 6mm centre drill, carefully drill the centre. Technically, using cutting oil ought to make it easier to cut but this is not always true in practice with these difficult and tough metals - it can make the drill slide instead of cut. When the hole has been centred you need to drill ready for final boring to size.

Drilling and reaming the centre hole

The hole must be square to the wheel, perfectly centred and exactly 1/4" in diameter, a tough task. It is usual to finish the hole to size with a reamer after running through with a small boring tool to ensure perfect centering.

Drilling must be done using a tough drill bit - ordinary high-speed-steel is not up to it and the drill edges will wear off before it has gone halfway in the hole and will jam. Ideally a solid carbide or cobalt stub drill, preferably without twist, is the answer. Having obtained your drill (one size down from the finished size) fit it to the tail-stock firmly and running nice and slow drill the hole. Keep the pressure up throughout the cut. If you ease off the material work-hardens and that will be the end of your expensive drill-bit!

If you are lucky the hole will be dead centre and only need reaming to final size. If so then use some cutting compound and running the lathe dead slow run the reamer through. If you are unlucky the hole will have gone off centre due to the drill bending. If so you will have to bore the hole until it is square and then ream to size. The turbine can now be removed.

Facing off the rear face of the turbine

The turbine needs the outside hub face squaring off and trimming to length. Make up a steel stub mandrel to hold the wheel making it a snug fit and face off as before using the tipped tool. Machine enough to get the length down to 12mm front to back. The turbine should be running straight with little or no wobble. It will need balancing however and we will tackle this later. There should be no need to skim the outer diameter until we are able to assemble the engine. We will then have the turbine on the shaft and it can be held between centres for trimming then.

16.0 Nozzle Guide Vane

Built-up version

The ngv can be made up using fabrication techniques although it's small size and need for specialized TIG or Plasma welding equipment make this prospect of limited interest to many turbine builders in our experience. One of the most difficult elements is the accurate cutting of the tight curves for the vanes in the ngv outer. To help support the builder keen on this element of construction we are arranging for pre-cut components to be made available soon which will only require assembly and welding for completion. The plan contains a pattern for the cutting out of the ngv vane which can be used to stick onto your sheet material. We have found 310 stainless to work well for this component and it is relatively easy to work with.

Turbine shroud

Start by cutting the sheet to the size shown on the plan - don't stick the template on just yet. I found it best to make it a touch longer and trim it to a perfect fit. Use 2mm sheet and cut out using a bench shear if you have access to one, or a hacksaw if you don't. Using a set of bending rolls, form the strip into a neat ring and check the internal size. We want to get the internal diameter to just over 55mm, so file the end until you reach this dimension.

Once satisfied the ring can be welded along the seam.

Welding the seam

Use a TIG (or Plasma if you have one!) welder with a 0.6mm stainless welding rod and 1.6mm tip. Back the inside of the ring with a steel tube or bar to allow the shielding gas to collect and protect the inside face from oxidation. Make tack at each end of the seam first and then weld from the outer edge inwards. When cool, clean up as required and check for circularity. If required pop the ring in the lathe and true up the turbine end dead square.

Cutting the ngv slots

The paper strip can now be stuck to the outside and the curved slots cut. These are the hardest part although it is possible to do them with the "Dremel" and a 20mm disk cutter. Carefully grind out the profile and clean up any burrs that occur.

Guide vanes

Next the vanes themselves can be tackled. Make a master vane from 0.8mm 310 stainless sheet, mark it with marking blue for identification. Make the vane about 3mm deeper than the drawing to allow for the inner diameter to be ground to size when they are welded in place and to allow the outer edge to protrude about 1mm to weld down onto. The 13 vanes can now be scribed onto a strip of material and cut out using snips. Check each with your master and trim/grind to shape as required.

A jig is required to aid the location of the vanes in the shroud. This is simply made from a block of aluminium 60mm dia x 30mm long. Hold in the chuck so 24mm is protruding. Turn the outside diameter to a snug fit in your turbine shroud to a length of 23mm. Then turn a step of diameter 35mm to a length of 15mm. This will form the seat for the vanes to rest upon when being welded. A tapped hole of about M5 can now be put into the centre of the blank. A steel disk of 57 diameter mm by about 2mm thick with a 5mm hole in the centre, should be made which will hold the turbine shroud onto the aluminium former.

Shielding/backing gas

A small hole should be drilled into the disk to which shielding gas should be fed to protect the inside of the ngv's whilst they are being welded. If this is not done severe oxidation occurs, and the metal bubbles up in and around the vane roots.

Ngv flange

Take the opportunity to make the ngv flange now. This is made form 2.5mm mild steel. Obtain this in the form of a square plate about 100mm square, which can have four holes drilled to each corner and simply screwed to a plywood back-plate mounted on the lathe faceplate. Make this back-plate at least 18mm thick as we can use it to machine the ngv assembly later. The inner diameter for the turbine shroud can be bored out, making it a snug fit as it will help to keep the turbine shroud circular. Leave the rest of the plate square for now as when welding it helps to stop distortion creeping in.

Welding the vanes

The aluminium former can be slotted in and the vanes can now be offered up to the slots, cut in the ngv shroud. The slots may need opening up in places to enable them to be inserted fully. The former will show when they have been inserted far enough. Remember we want about 1mm protruding out.

When ready, turn on your inert backing gas supply. This should be 100% Argon (same as on your TIG welder) and only a gentle flow is needed, just enough to be felt emitting from around the vanes. Use a screw-down valve or similar to control flow. Set up the complete assembly in a vice and using your TIG torch and 0.6mm stainless welding wire, place a spot weld at the beginning and end of each vane. When done, remove the steel disk to reveal inspect the vanes inside. Most likely a few will have moved out of alignment, these can easily be bent back into place.

When you are happy they are all aligned as best as you can, the steel end cap can be replaced, and the vanes welded up fully. Weld from the outside edge towards the centre to minimize distortion - don't forget the backing gas. Aim to just melt down the protrusion so it sits reasonably, don't keep heating as you will cause it to sag on the inside. When cool remove from the aluminium former and inspect. To remove you sometimes have to almost "unscrew" the assembly as the vanes stick on the centre step. Hopefully your ngv will look good and there will be no blowholes! The aluminium former should now have the centre step turned down a couple of mm to enable it to slide on and off without sticking on the vanes, as we need it again next.

Welding the flange

The flange now needs to be welded to the turbine shroud. We still need the inert backing gas so the shroud can be replaced onto the former and the end cap attached and gas supply rigged up. The ngv flange can be offered up into place, any ngv welds protruding too much can be carefully filed down flush. When the flange can be eased into the position shown on the plan, we can get ready for welding.

The flange should only be welded on the ngv vane side. Turn on your backing gas and position the flange in place, and using a 0.8mm ***mild steel*** welding rod or MIG wire, place a spot-weld to hold it. Check carefully to ensure it is square and tack the opposite side in the same way. Check again for correct alignment and do two more tacks in between the other two so it is now tacked on all four "corners". Welds should now be positioned in between the previous tacks. When done the flange can now be welded fully.

Use of a mild steel welding rod is unusual but allows the weld to be achieved at much lower temperature than the stainless and therefore causes much less distortion of the flange and the turbine shroud. When the flange has been welded fully and cooled it can be removed from the former.

Machining the ngv assembly

To ensure concentricity, the ngv assembly should all be machined in one setting. Use the plywood faced faceplate used earlier and bore a hole to a snug fit with the welded vane side of the ngv. Hopefully you will find your original attaching screw holes still line up and the turbine shroud will run true. If not, your objective is to make the turbine shroud run as true as you can!

When done and held secure, the turbine shroud should be skimmed out to 55.2mm maximum internal diameter, and the outside turned down to 58mm. Now using a nice sharp boring tool we can gingerly bore out the vanes to 37mm i/d. This is quite easily achieved and only requires that you are patient and don't take off too much at a time (0.1mm or so). Use the power feed and aim for a few dozen cuts!

Keep offering up the ngv inner Part #24 to check progress and aim for a gentle sliding fit. I finish the hole by putting a very slight, one degree taper opening out towards the combustion chamber. This helps to stop the ngv's gripping the inner part tightly and distorting the turbine shroud. As the gas entering the ngv is always hotter (and therefore greater expansion of the vanes) than that exiting this seems to make sense, anyway it works in practice!

The flange can now be squared off and trepanned out using a parting tool. Cut in 1mm or so first and keep checking on the diameter as we want this to be a nice fit into the recess in Part #22. When you have cut right through the outside diameter will be very sharp. Clean this up gently on your linisher.

The turbine shroud can now be gently gripped in the chuck and the rear face of the flange skimmed flat and a cleaned up. If you are concerned about weight the flange can be thinned down to about 1.5mm thickness now if required. All that now remains is to skim the outside diameter down to match your combustion chamber end - it should be 58mm, check to see and turn to fit. Any trimming should only extend far enough to enable the edge of the ngv to align with the inner face of the chamber end.

Leave an abutment to stop the chamber being pushed on too far. Finally turn a neat 45' chamfer to aid gas flow.

Drilling for the fixing screws

The ngv can now be offered up to the rear case from the inside, and the fixing screws positions carefully marked through from the outside. After centre drilling using a small point centre drill, the 2.5mm tapping size drill can be run through and the holes tapped for the M3 fixing screws. And that's the ngv done!

The Cast NGV

For many builders the cast ngv will be the main route to completion of this component. The casting may be turned at a slow speed using a nice sharp tipped tool.

Machining the casting - rear face

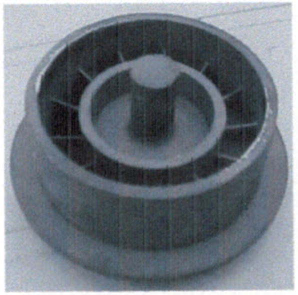
The casting should be held gently in the chuck with the turbine shroud facing outward. Check that the mounting flange is running reasonably true and adjust if necessary. The centre hole can be bored first to 20mm diameter to match the shaft tunnel, and the area around the centre machined to the profile shown.

The merest trace of material should be skimmed off the inside of the turbine shroud to make it circular. Aim for no more than 55.2mm i/d.

Carefully face off the rear face of the mounting flange and turn the outside diameter to 76mm to match the recess turned in the case rear (#22).

The turbine shroud outside diameter will then require truing up to ensure concentricity with the inner and to get the diameter down to 58mm.

Machining the casting – front face



The ngv can be reversed and **gently** gripped on the mounting flange and the inside can be cleaned up. Check the centering and turn the combustion chamber seating to the correct length and diameter.

Offer the chamber end up to check the fit - the object being to enable a smooth transition between the inside of the chamber and the ngv.

When satisfied machine the 30' sloping lead-in, both inside and out. Then machine out the recess shown to lighten up the centre section.

Drilling for the fixing screws

The ngv can now be offered up to the rear case from the inside, and the fixing screws positions carefully marked through from the outside.

You've worked hard so here's a picture of Terry Lee (our draftsman) starting his MW54 & plane!

After centre drilling using a small point centre drill, the 2.5mm tapping size drill can be run through and the holes tapped for the M3 fixing screws.

That's the cast ngv done!

17.0 Assembling the Engine

The sequence of assembling a gas turbine is a varied as there are days in the week, but for those building their first engine we offer our version.

Firstly it is vitally important that all parts are spotlessly clean before assembly. There is no point having a neat system of filtering air for the bearings if the tunnel is full of muck before you even start! Gasoline is useful here as it will evaporate easily and is a good degreaser - watch out though it's very inflammable! Lay all the turbine parts on clean sheets of kitchen roll and clean each piece methodically. Right let's start!

Start by fitting the filter cover #9 to the rear of the diffuser (#7), don't forget the small tab to secure the lube line (leave this loose for the moment). The lubrication line and it's tube end fitting (#36), can now be fitted and the small tab for securing it can be soldered to the pipe with soft solder, using a high wattage iron. The filter screws (#42) can all now be fitted, use a spot of screw locking compound on the screw threads to stop them coming undone.

The front O-ring (#45) can now be fitted to the shaft tunnel (#11) - use a good smear of silicon grease here. The front bearing (#40) may now be fitted. Look for the narrow face on the inner race, this should face inwards towards the turbine end. Lubricate the outer race with a smear of silicon grease and slide in the ball-race gently.

A small smear of liquid gasket sealing compound can now be put on the shaft tunnel/diffuser mating face and the two parts brought together. Fit the shaft seal (#5) into place and carefully align with mating marks. Secure the three items together with the six fixing screws (#44) and tighten evenly.

The pre-load spring (#10) can now be fitted, use the usual smear of grease. Fit the rear O-ring (#45) and then slide in the greased pre-load tube carefully over the O-ring.

The turbine bearing (#40) can be fitted with the narrow part of the inner race facing inwards. The rear spacer (#26) (slope facing inwards) and turbine wheel (#25) can now be fitted to the shaft (#12). Grip the shaft gently in a vice lined with soft jaws or soft aluminium and using a tommy-bar gently tighten the turbine nut (#27). Don't overdo this, it's not a lorry wheel nut!

Apply a smear of silicon grease to the bearing and gently slide the shaft into the shaft tunnel. Slide on the front spacer (#2) on the front end of the shaft followed by the compressor (#3) and finally the compressor nut (#1). Gently do up the nut being careful that all the parts gently align themselves without jamming.

Check the height of the front face of the compressor with the diffuser and ensure it is either level or very slightly proud above the diffuser. If it is more than about 0.2mm then carefully measure the protrusion and you will have to machine this off the front spacer to get it level. This must be done on a freshly made mandrel and accurately squared off - see Sect 5.

When happy with the clearance the opportunity should be taken to check the clearance behind the turbine wheel and ngv inner. If you have made a fabricated ngv the turbine and shaft can be removed and the ngv inner (#24) fitted to the shaft tunnel and held with a couple of fixing screws (#41). Re-fit the turbine and shaft and all the front end components (compressor etc) and check the running clearance - ideally it should be between 0.5 and 1mm. If it is too small then trim the ngv inner, if it is too big, make a washer from shim to fit over the shaft tunnel/ngv inner interface to reduce the gap, or reduce the length of the rear spacer (#26). For cast ngv's the gap can only be adjusted by making the rear spacer (#26) longer or shorter. This can only be checked at final assembly as it depends on the case fit etc.

Remove the shaft (and ngv inner) and store away from dust. The front cover (#6) can now be fitted. Screw in the seven fixing screws (#49), making sure to miss out the holes for the services. The fitting for the air pressure connection can be fitted now, together with it's adapter, (note this is not shown on the drawing).

The combustion chamber can now be assembled. The chamber rear complete with vaporizer sticks attached (#19&18) should be offered up the combustion chamber assembly (#14,16 & 17). Orientation should be such that the sticks ends should align with the outlet of the swirl jets (#39) about 4mm away. Mark the "TOP" location with a suitable mark using an engraver or cutting disk in the trusty "Dremel". If any adjustments are needed to any sticks they can be gently bent into position using a length of steel rod inserted into each end of the stick and bent in the appropriate direction. Aim for the centre of the sticks to be on a circle of 54mm, small variations of 1mm or so are not critical. The sticks should end up 8-9mm from the front inner face of the combustion chamber.

When satisfied, assemble the gas pipe (#34) onto the front of the chamber. If the ends are bent to the plan the doubled back section can be slotted in and the straighter section at the other end manipulated into place. Once done it should hold itself in the right position. Gently bend the appropriate part to get the exact position as required. The fuel pipe assembly (#20) can now be slid over the combustion chamber rear, each needle being carefully eased into the stick ends - see the drawing for the orientation.

The ngv (#23 fabricated, or #35 cast) can now be eased onto the end of the chamber. A screwdriver may need to be inserted to help align the chamber inner into the recess in the inner part of the cast ngv. The whole assembly can now be slipped into the case. A couple of fixing screws (#43) can be screwed into the ngv flange to locate this section and the glow-plug bosses lined up and plugs inserted to hold the combustion chamber in place, don't forget their copper washers. When happy with the alignment the remaining six fixing screws can be screwed in to the ngv.

The O-ring cord (#50) can now be cut to length and fitted to the front cover. It should be cut long enough to still protrude about 0.1mm to ensure it properly seals the case and prevent loss of pressure from the engine, start with a 268mm length.

When you are happy with the fit (offer the case up to check) liberally silicon grease the cord. Align the gas and fuel pipes with the diffuser back and slide the case over up to the front being careful to get the fixing screw holes aligned. The 3 tube ends (#36) (oil, fuel & gas) should be protruding now and sealing washers (#47) and adapters (#32) can be screwed on and gently tightened. Don't overdo this or you will break the fittings.

18.0 Balancing

Once the ideal tip clearance is reached we need to attend to the balancing of the rotor. If the engine is out of balance it can fail to spool up at all, or it can make the most awful din! It is in your interest to ensure it is well balanced.

The engine can ideally be balanced on an electronic dynamic balancer. If this is not available do not worry, it can still be statically balanced well at home.

Order of balancing

1) Compressor on shaft
2) Turbine on shaft
3) Compressor and turbine on shaft

The following procedure works well:

Balancing the compressor

The turbine is carefully removed and the bearing re-fitted to the compressor end, along with the front spacer (#2), compressor, and compressor nut. Tighten with a small tommy-bar inserted through the nut and try to remember the feel of how much you tighten it for the future. Very gently make a couple of very small indentations in the edge of the compressor nut, and beside it in the end of the compressor nose, to provide location marks for the future. Use a 1or 2mm round nose engraving tip held in the "Dremel" for this. If you have to remove the shaft in the future, replace with these two marks lined up as they are now.

Remove the front bearing from the shaft tunnel and slip it onto the turbine end and give both bearings a few drops of gasoline. The gasoline makes the bearings extremely free running. The rotor is then inserted into a clean seamless tube of about 25mm i/d and 70mm long and place on a flat and level surface with the compressor overhanging.

The tube can now be rolled in short movements back and forth a few mm each way and you will see if the compressor assembly is out of balance clearly, as the heavier section will move to the bottom. Mark the heavy point with a fine felt tip and repeat. If the same point moves to the bottom again you can confirm it is heavy here. Using a fine needle file on the back of the compressor at the edge where the felt-tip mark indicates, make a half dozen strokes, evenly, to ensure no scratches are concentrated that might become weak spots later. Wipe the compressor clean.

Replace the rotor into the tube and check the balance again. Repeat the exercise above as required, gradually reducing the amount taken off as you get nearer fully balanced. It will get progressively harder to tell the imbalance but stick at it. Keep popping in a few drops of gasoline into the bearings to keep them absolutely free-running. Don't let it run over the compressor and this affects the balance!

When you have done as good as you can, do it once more - this is the difference between a running engine and a quiet running engine!

Balancing the turbine

When completed, the compressor nut, compressor, front spacer and bearing can all be removed, and the bearing re-fitted to the turbine end, complete with rear spacer, turbine wheel and turbine nut. Make sure you place the bearing with the thinner edge of the inner race facing toward the inner part of the shaft as we won't take it off for a long time now! Tighten with a tee-bar type socket – slightly firmer than the compressor so when we try to undo the compressor nut, it doesn't undo the turbine one instead. Use the "Dremel" + engraving tip, mark the turbine nut and turbine for future alignment.

Slip other bearing onto the compressor end and pop it in balance tube as before. This time any in-balance must be corrected by grinding a little from the balancing ring cast into the turbine wheel. Mark the wheel using a felt tip. Use a 20mm cutting disk in the "Dremel" and carefully protecting the bearings, grind a little from the balance ring at the felt mark. Make as many adjustments as required and persevere to remove even the smallest imbalance. As you get nearer to balance, try to ensure you are leaving a well smoothed finish to the ring to make sure weak points are not set up.

Balancing the complete rotor assembly

When completed, slip the other bearing onto the shaft. Slide on the balance tube, front spacer, compressor and nut, and tighten till your indexing marks align. Resting the balance tube on a narrow, raised base you can check the balance of the rotor complete. It should not show any need for adjustment. If there is, remove all the front-end parts and re-check the turbine on it's own. If this is ok you know it is the compressor end that needs a little shave. Put the front-end parts back on, recheck and make small adjustments to the compressor, till you're absolutely happy.

The whole process sounds quite a fiddle, the reality is it takes much longer to describe than it does to do, so there's no excuse for a noisy engine!! Put a couple of drops of turbine oil into the front bearing and replace into the shaft tunnel, don't forget the grease and the orientation - narrow part of inner ring facing towards combustion chamber. Replace shaft seal, checking the orientation and the securing screws, tightening evenly.

The rotor can now be replaced into the turbine end after popping a drop of oil on the turbine bearing. Put a smear of silicon grease on the back bearing outer race. The front-end parts can be assembled onto the shaft as it is slid in from the turbine end against the pre-load spring. Be careful not to catch the inner edge of the front bearing as you can push it out of the race and drop all the balls out! Feel for it just sliding in nicely. Tighten the compressor nut to the aligning marks and tightness as before.

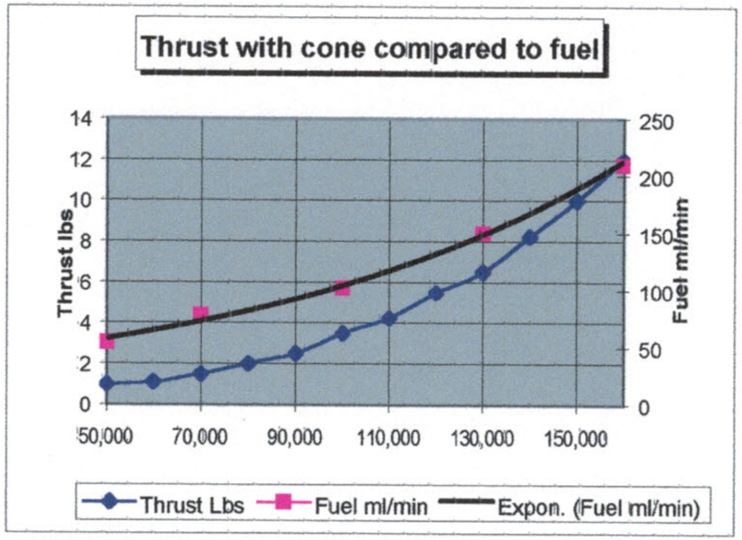
Check to ensure everything is completely free (apart from a slight drag caused by the pre-load). Your rotor should now be as smooth as smooth can be, when you spin it!!

The inlet cone (#4) can now be fitted and the clearance checked. If you are lucky it will fit perfectly. Most likely it will need a little skim to clear the compressor. If it does it can be gently gripped in the chuck by the outside end and the rounded file employed to ease the fit. You must have a little clearance here, about 0.1-0.2mm works well. Make small skims remembering the part is not very firmly held. If it is too far from the compressor, the mounting ring must be trimmed slightly back to suit.

Check regularly and when satisfied the cone securing screws (#41) can be inserted and gently tightened. Not too tight here, it's only plastic remember! The M3 "Festo" fittings for the services can now be screwed onto their adapters, use a short thread of PTFE tape to seal.

And that concludes the assembly of the engine. The cone is left off until the first test runs are completed. Use a blower or electric motor with nose driver to spin up the rotor to ensure it runs free, if ok we are ready for a test run. If rubbing somewhere, investigate and cure, do not try a run.

Fuel consumption chart



19.0 Starting the engine

Before thinking of running the engine read the safety section of this brochure.

You will need a test stand that ideally has a separate carriage that can slide on wheels so that thrust can be measured using a spring balance or kitchen scales reading 10-12Lbs (5kg). You will need a pressure gauge that can read on a scale 0-1.5bar minimum, ideally 0-2bar. This is connected to the air pressure connection with a length of 3mm "Festo" tube.

You should have a rev counter. The GTBA published a design that reads the revs through the hole in the spinner interrupting an infrared led beam and sensed with a phototransistor. This circuit will need modification to read up to 200,000 rpm. You will need a means of reading temperature. There are a number of commercial units that are relatively inexpensive. Alternatively, the rpm and temperature can be sensed using an ecu. There are several that are suitable at the moment. The "Orbit" ECU has been tested with this engine and works well.

The fuel and lubrication lines are connected to a "tee", connected to the main fuel feed from the pump. The flow restrictor is in the lubrication branch, the fuel feed to the engine from the other side of the "tee" Use clear piping for fuel pipes so you can see the fuel flowing, which will help your starts stay smooth. The flow restrictor is just a small piece of brass turned to fit firmly into your fuel tube with a hole down the middle to which is soldered a 0.6mm hypodermic needle. This restrictor is fitted in the line going to the lubrication connection on the engine.

You MUST fit a filter between the pump and the Y connection. Small car cartridge filters make good filters. Finally the fuel supply is connected to a pump. These can be home made from "MFA" parts and a machined aluminium body, or use a bought pump from "Behotec", "Orbit" or Peter Hausl or similar. The "Behotec" style pump needs only to be run with a 4-cell battery, unless run from an ECU where more may be required.

The pump is connected to a fuel tank of around 1 litre capacity which should be sufficient for a run of 6-8minutes. Oil should be added to the fuel, to a ratio of 6% oil to 100% fuel, that's 60cc of oil to 1Ltr of fuel. Use oil to grade TCW3 in preference to turbine oil, as it is better for your lungs and the environment. This oil is made for high performance outboard motors so is well up to the job!

The electric motor on the pump can be controlled via an electric flight speed controller, simple hand speed controller or ECU. Use of the "Orbit" ECU will save you the need to purchase a rev counter and temperature gauge. The hand controller is convenient for the first run's.

The air-starter fan

Both prototypes have been tested throughout with a simple fan starter and a small electric motor starter based on the Speed 300 motor. We recommend a fan for first runs and to build up experience, as the prototype engines needed to get to 35,000rpm before they would pick up speed easily. The current design should be able to pick up from 20,000rpm and idle at 25,000rpm now such has been the development!

The simplest fan that can be obtained is the cheap "Braun" hair dryer. After unscrewing the case the heating element is removed and thrown away and the motor is also removed and discarded after the fan has been pulled off the shaft. Replace the motor with a 7.2 volt "buggy" motor such as the "Speed 600". The plastic will need trimming to allow the motor to be pushed in. The fan is drilled out so it is a tight fit on the shaft and it is pressed on with a smear of cyno' glue. The switch is replaced and the case is screwed up. You should use an accumulator battery and though heavy a small 12volt-car battery makes a cheap and dependable power source.

The gas supply

A propane/butane or pure propane bottle is connected to the gas connection via a regulator or suitable tap connection – gas blowlamps have the valve and connection all in one and are ideal for conversion!

Check that the fan turns the engine with NO rubbing and that all your batteries are freshly charged. Fuel up your tank and we are ready to go!

Starting the engine

Make sure you are wearing your ear defenders and have your fire extinguisher close to hand. Re-read the safety Instructions at the front just to be sure.

Spin the engine up with the fan and move the fan away, whilst opening up the gas and as the revs die down turn on your glow-plug supply to light the gas or use a cooker sparker to ignite the gas.

You will hear a pop if the gas has lit back into the chamber and this is the signal to turn the gas on a little more, turn on the blower and place over the intake. The revs will rise as the gas heats the chamber and after a couple of seconds you can then start to feed the fuel in very slowly and the glow plug can be turned off if you were using one. You can observe the fuel supply reaching the engine by watching it travelling up the clear fuel pipe and listening to it picking up speed.

Watch to confirm fuel travelling up the lubrication line. If the engine starts to surge or flame excessively then ease the fuel flow down – do not allow excess fuel to reach the engine. After a few seconds the engine will be starting to show pressure on the pressure gauge.

Once you have about 0.2 bar you can take the fan away and shut off the propane supply. The engine should now run without the fan or propane. An initial bearing noise may possibly be present for the first acceleration cycle only as the bearings find their seat, after that they should be very quiet and no whining or rumbling. Any unusual noises should be investigated immediately by shutting the engine down and close checking for rubbing – particularly the turbine in the first couple of runs.

The engine is highly responsive and unlike early model turbines has an almost instant increase in speed and very little throttle lag. This will aid flying and make those overshoots easier! Do not exceed 1.0 bar unless you have a rev counter. (This approximates to 140K, cone off)

The first run should be made with no exhaust cone fitted where temperatures around 450'C or less should be seen. Check your results with the graphs on page 5 (cone off graph).

When satisfied that there are no problems you can fit the cone and complete the thrust tests, and enjoy your handywork!!.

Maintenance.

As the engine has no consumable parts as such, beyond the bearings, we would not recommend taking it apart beyond checking bearing wear, which only involves the rotor assembly. Bearing wear is expected to be minimal and is likely to be at its highest whenever the engine is reassembled and first run as the bearings have to settle back in onto their seating. For this reason it is advised to not do this too often unless any unusual noises are noted in which case immediate investigation is required. Do however check the various screws and fittings for tightness and note any apparent leaks. The O-ring seal at the front of the engine sometimes leaks a tiny bit, this is not usually a problem as it is very small.

How are we doing?

We always welcome feedback on any aspect of the engine or this plan/guidance notes. If you wish to contact us please quote your plan number in communications.

Thank-you for purchasing this plan pack from Wren Turbines. New designs are being worked on continuously and we would like to keep you informed of offers and new developments so please ensure we have a contact address where details can be sent.

Thank you.

Mike Murphy
John Wright
Roger Parish

Stop Press – tail-cone pictures!

Oops - we nearly missed the tail-cone!

The inner and outer are both formed as a taper – rolled up from thin stainless and spot welded along the seam.

An aluminium plug with a short section to the same internal angle and the rest parallel, is inserted into the large end and the whole lot is pushed through an aluminium ring, to form the straight portion.

The supporting vanes are best fitted and spot welded where they can be outside the exhaust stream as the repeated heating/cooling can cause the spot welds to crack otherwise. A thin slot can be cut to enable the vane to pass through the cones. Although less pretty they last!

Terry Lee's MW54 (our draftsman!)