5 Cylinder Radial Engine
-Assembly Instructions-
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INTRODUCTION

WELCOME TO THE MOST AMBITIOUS MECHANICAL 3D PRINTING PROJECT YOU HAVE EVER ATTEMPTED.

The 5 Cylinder Radial Engine is made up of more than 260 printed parts. Working continually with a single printer, you can expect to spend more than two weeks printing and several more days assembling.

Since the first Radial Engine was built in 1901, the technology has been synonymous with aviation. The first flight across the English Channel was powered by a 3 cylinder 12 hp radial engine built by Italian engine designer Alessandro Anzani. The heavy bombers of the Second World War were powered by massive 28 cylinder 4,300 hp radial monsters built by Pratt & Whitney. The basic operating principle illustrated by this model is accurate to both. Radial engines have largely been supplanted in aviation by gas turbines, but are still found today on specialized acrobatic aircraft.

This 5 Cylinder Radial Engine Model is based on the Forest Edwards Radial 5, a radial model aircraft engine.

NOTES

- Parts in these plans are represented in two colors, white and green. These colors correspond to the colors used in my models. In general, green parts are moving and attachment parts, while white parts are structural or case parts.

- PLA is a material that wears very quickly. During assembly, when you find parts that are too snug, forcing them through their motions several times will usually wear away enough excess material to ensure a good fit. After assembly, it’s critical to use some kind of grease on the cam surfaces and timing gears to keep them from wearing away.

- PTFE or Silicon grease should be used to lubricate the Engine

- Most parts of this model are designed to be attached with snap-pins.

- Some parts of the model need to be glued, and in some cases glue may need to be used to supplement the strength of the snap-pins. When gluing, remember to be patient and wait for the glue to fully dry. The last thing you want is to accidentally get super glue all over the inner working of the model.

- I recommend gel style super glue, it’s less likely to drip and run.

- A small tack hammer, hobby knife and sandpaper will be extremely useful during assembly.
SOURCE

This engine started from excellent paper plans drawn by Robert Sigler. The engine described in Roberts's plans is intended to be machined from metal, and had to be extensively modified to work with desktop 3d printing technology. Some pieces, like the cylinder barrels and cam ring, had to be subdivided into printable sub-units. Other parts were re-designed or had their tolerances altered in order to create a working mechanical model. Windows cut into the cam ring and cam housing make the moving parts of the cam system visible.

Robert Sigler's original plans for the Forest Edwards Radial 5 can be found by doing a Google search for the term 'forest edwards 5 cylinder radial engine'.

Mr. Sigler asked that I not include a link to his document

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QUESTIONS:

skimal@makerbot.com

The Engine described in this plan is only a model. It won't run on fuel. If you put fuel in it, you're a moron.
INVENTORY OF PARTS

**LOWER CYLINDER RINGS.STL**  Print 10 times
MakerWare - Medium
.270 mm layer height

**UPPER CYLINDER RINGS.STL**  Print 10 times
MakerWare - Medium
.270 mm layer height

**CYLINDER LINER.STL**  Print 5 times
MakerWare - High
.100 mm layer height

**CYLINDER BARREL BASE.STL**  Print 5 times
MakerWare - High
.100 mm layer height

**CYLINDER HEAD.STL**  Print 5 times
MakerWare - High
.100 mm layer height

**VALVE SLEEVE.STL**  Print 3 times
MakerWare - High
.100 mm layer height
INVENTORY OF PARTS

**VALVES.STL**  Print 3 times
MakerWare - High
.100 mm layer height

**CAM FOLLOWERS.STL**  Print once
MakerWare - High
.100 mm layer height

**ROCKER ARMS.STL**  Print 5 times
MakerWare - High
.100 mm layer height

**CAM CASE.STL**  Print once
MakerWare - High
.100 mm layer height

**CAM HOUSING.STL**  Print once
MakerWare - High
.100 mm layer height

**CAM RING PINS.STL**  Print 2 times
MakerWare - High
.100 mm layer height
INVENTORY OF PARTS

**CRANKCASE PINS.STL**  Print 2 times
MakerWare - High
.100 mm layer height

**CRANKSHAFT PIN.STL**  Print once
MakerWare - High
.100 mm layer height

**CRANKCASE.STL**  Print once
MakerWare - High
.100 mm layer height

**CRANKSHAFT.STL**  Print once
MakerWare - High
.100 mm layer height
20% Infill

**CRANKSHAFT BEARING SET.STL**  Print once
MakerWare - High
.100 mm layer height

**LOWER CAM RING.STL**  Print once
MakerWare - High
.100 mm layer height
INVENTORY OF PARTS

**UPPER CAM RING.STL**  Print once  
MakerWare - High  
.100 mm layer height

**LINK RODS.STL**  Print once  
MakerWare - High  
.100 mm layer height

**TIMING GEARS.STL**  Print once  
MakerWare - High  
.100 mm layer height

**MASTER ROD BEARING.STL**  Print once  
MakerWare - High  
.100 mm layer height

**5 PISTONS.STL**  Print once  
MakerWare - High  
.100 mm layer height

**MASTER ROD.STL**  Print once  
MakerWare - High  
.100 mm layer height
<table>
<thead>
<tr>
<th>PART</th>
<th>QUANTITY</th>
<th>LAYERS</th>
<th>SETTINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PISTON PINS.STL</td>
<td>Print once</td>
<td>.100 mm</td>
<td>MakerWare - High</td>
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<td>STAND.STL</td>
<td>Print once</td>
<td>.270 mm</td>
<td>MakerWare - Medium</td>
</tr>
<tr>
<td>CYLINDER PINS.STL</td>
<td>Print 5 times</td>
<td>.270 mm</td>
<td>MakerWare - Medium</td>
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<tr>
<td>STAND BASE PLATE.STL</td>
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<tr>
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</tr>
<tr>
<td>STAND STEM.STL</td>
<td>Print once</td>
<td>.270 mm</td>
<td>MakerWare - Medium</td>
</tr>
</tbody>
</table>
INVENTORY OF PARTS

**CLIPS.STL**  Print once  
MakerWare - Medium  
.270 mm layer height

**SPRINGS**  10 Total  
9/32” Outer Diameter x 1/2” Length  
compression springs, 24 gauge wire  
(Commonly found in spring bulk packs)

**CLIP COVERS.STL**  Print once  
MakerWare - Medium  
.270 mm layer height

**GREASE**  
PTFE or Silicon grease.  
Available at most hardware stores

**BRACKET.STL**  Print once  
MakerWare - Medium  
.270 mm layer height
Building the Cylinders
PREPARATION

Put the Cylinder Liner on a stable flat surface, with the lip end down.
ADD THE FIRST UPPER CYLINDER RING

With the lip of the Cylinder Ring pointing up, slide the ring down the exterior of the Cylinder Liner. Push straight down, applying even pressure on all sides.
FIRST CYLINDER RING

Keep sliding the ring down until it butts snugly against the lip of the Cylinder Liner.
THE NEXT RING
Add the next ring, using the same method. Make sure the holes on the two rings are aligned. Keep adding Upper Cylinder Rings to the Cylinder Liner until you have a stack of 6 of them.
LOWER CYLINDER RINGS

The Lower Cylinder Rings are similar to the Upper Rings, but with a smaller outer diameter. Slide the Lower Cylinder Ring down the Cylinder Liner. Make sure the holes on all the cylinder rings line up. Add 6 Lower Cylinder Rings to the stack.

PRINTED PARTS
Lower Cylinder Rings.stl x6
**CYLINDER BARREL - STEP 6**

**PRINTED PARTS**
Cylinder Barrel Base.stl

**ADDING THE BASE**
Align the Cylinder Barrel Base with the Cylinder Liner. Make sure the 5 notches in the Base line up with the 5 holes in the Rings. If any of the rings are misaligned, twist them into position so you can see clearly through the holes. When you’re satisfied that the holes are aligned, slide the Cylinder Barrel Base down to meet the rings. Give it a few taps with a small hammer to lock all the parts together.
Building the Cylinder Heads
ADD THE VALVE SLEEVES

Use a small drop of Super Glue to attach the Valve Sleeves to the top of the cylinder liner. Make sure the glue is fully dry before proceeding.
INSTALL THE VALVES
Slide the Valves into the Valve Sleeves. Make sure the Valves move freely in their sleeves. If they bind, remove them and sand the valve stem until it moves freely.
ADD THE SPRINGS
Slide the springs over the tops of the Valves and Valve stems.

PRINTED PARTS
(None)

Non-PRINTED PARTS
Spring x2
ADD SPRING RETAINERS
Push the tops of the springs down and slide the spring retainers onto the tops of the Valves. Twist them to lock them in place. The Spring should push up on the Retainer, keeping it in place. Push down on the top of each valve to make sure they open and close easily.

PRINTED PARTS
Valves.stl x2
ASSEMBLE ROCKER ARM
Slide the Rocker Arm into its supporting bracket. Make sure there is enough space for the Rocker Arm to move freely. If not, use sandpaper to adjust the fit. Once you have the fit right, align the holes and use a small hammer to push the pin though. Then build the second Rocker Arm.
INSTALL ROCK ARM ASSEMBLY

Press the Rocker Arm Assembly into the square hole on the Cylinder head. The long side of the rocker arm should make contact with the top of the valve stem. Lifting up on the back of the Rocker Arm should open its valve. The valve should close when the arm is released. Make sure the assembly is secure in its hole. If the fit is too loose, put a small drop of glue in the hole and then re-insert the assembly.
Building the Crankcase & Cam Housing
INSTALL CRANKCASE BEARING

Find Bearing (A). Press it onto the center of the crankcase.
ASSEMBLE THE CRANKSHAFT
Press the body of the Crankshaft down onto the Counterweight. A Small hammer may be needed to get the parts fully seated.

PRINTED PARTS
Crankshaft.stl
CRANKCASE AND CAM HOUSING - STEP 3

PRINTED PARTS
Crankshaft Pin.stl

INSTALL CRANKSHAFT PIN
Press the pin into the hole on the crankshaft until it is flush with the back side.
BUILDING THE CAM RING

Put the Lower Cam Ring on the table with the flat surface up. Use a small file or sandpaper to smooth down defects that would interfere with the movement of the gears.
PLACE UPPER CAM RING

Put the Upper Cam Ring on top of the Lower Cam Ring. Align the 6 holes.

PRINTED PARTS
Upper Cam Ring.stl
PIN THE CAM RING
Use a small hammer to Drive the 6 pins and lock to two halves of the Cam Ring together.

PRINTED PARTS
Cam Ring Pins.stl
INStaLL front cam BearIng

Press the Bearing labeled (B) into the front of the Cam Ring. It should lay flush with the rings upper lip.
**INSTALL REAR CAM BEARING**

Press the other Bearing labeled (B) into the back of the Cam Ring. It should lay flush with the bottom surface of the Upper Cam Ring.
InStaLL the cam foLLoWers

Fit the Cam Followers into their holes in the Cam Ring. The Followers need to move freely in their holes. If they don’t, use sandpaper or a small file to adjust the followers and holes until they can move freely.
OPEN HOLE IN CAM CASE
Use a small knife or drill bit to remove the thin skin of plastic blocking the 4 holes in the Cam Case.

PRINTED PARTS
Cam Case.stl
INSTALL CAM CASE BEARING

Press Bearing (C) into the front of the Cam Case. The surface of the Bearing should be flush with the surface of the Cam Case.
Crankcase Assembly

Put the Crankcase on the table with the flat side up.

Printed Parts
Crankcase.stl
The Cam Followers need to be on the upper side of the Cam Ring.
DOUBLE CHECK POSITION!
Make sure the Cam Housing is properly positioned. The large gap needs to be between the Crankcase and the Cam Followers. It’s easy to get backwards and will be very hard to correct later.

PRINTED PARTS
Cam Housing.stl
CRANKCASE AND CAM HOUSING - STEP 14

PRINTED PARTS
Crankcase Pins.stl x5

PIN CAM RING TO CRANKCASE
Flip the Assembly over and align the holes in the Crankcase with the holes in the back of the Cam Ring. Press the Crankcase Pins through the holes and use a small hammer to lock them into place.
INSTALL CRANKSHAFT
Flip the Crankcase over and slide the Crankshaft into place. Make sure it turns freely. If not, use sandpaper to adjust the crankshaft on until it turns with ease.
INSTALL SPACER D

Slide Spacer (D) down the crankshaft until it's resting on the surface of bearing A. Spacer (D) can be found in the Crankshaft Bearings set. Make sure the Crankshaft still turns freely.
INSTALL FIRST TIMING GEAR

Slide the Crankshaft Gear down the Crankshaft. This gear is keyed to the flat side of the crankshaft. Push it down the Crankshaft until it rest on top of Spacer (B). Make sure the Crankshaft still turns freely.
INSTALL SPACER (E)
Slide Spacer (E) down the crankshaft until it’s resting on the surface of bearing A. Spacer (E) can be found in the Crankshaft Bearings set. Make sure the Crankshaft still turns freely.

PRINTED PARTS
Crankshaft Bearings.stl (E)
INSTALL TIMING GEARS

Slide the Timing Gears onto their pin. Make sure they rotate freely on the pin, adjusting with sandpaper if needed. Test fit the pin into its hole on the face of the crankcase. The Timing gear’s teeth should engage with the teeth in the crankshaft gear. Make sure everything moves freely.
GLUE TIMING GEAR

Once you have a good fit, carefully glue the pin into the face of the Crankcase. Make sure the Crankshaft still turns freely.
INStaLL the cam rIng
Slide the Cam Ring Assembly down the crankshaft. Push all of the Cam Followers back so the ring can slide into place. It should rest on top of Spacer (E) and engage the teeth of the Timing Gear.
INSTALL THE CAM RING
Now turn the Crankshaft. The Cam Ring should rotate in the opposite direction. The Cam Followers should be positioned over the Cams on the outside of the Cam Ring.
CRANKCASE AND CAM HOUSING - STEP 23

PRINTED PARTS
Crankshaft Bearing Set.stl (F)

INSTALL SPACER (F)
Slide the Spacer Down the Crankshaft until it rest on top of the Cam Ring.
INSTALL THE CAM CASE

Slide the Cam Case down the Crankshaft. The missing leg of the Cam Case should be on the opposite side of the Timing Gear. Hold the Cam Case in place with your hand, and make sure the Crankshaft rotates freely and the Cam Ring rotates in the opposite direction.
PIN CAM CASE TO CAM RING
Aline the four hole in the Cam Case with the holes in the top of the Cam Ring. Use a small hammer to drive the four Crankcase Pins and lock the two parts together.
POSITION BRACKET
Position the Bracket on the side of the Crankcase. It should be located directly below the missing leg of the Cam Case.
PIN BRACKET TO CRANKCASE

Use two Cam Ring Pins to attach the Bracket to the side of the Crankcase.
PREVIOUS PAGE

TAKE A BREATH

Turn the crankshaft. The Cam Ring should rotate in the opposite direction, and the Cam followers should move up and down.

You’ve reached the half-way point and completed the most complex part of this engine.

PRINTED PARTS
(None)
Installing the Pistons
BUILD THE MASTER ROD

Press the center of the Master Rod onto the key in on one of the Master Rod Faces.
INSTALL PISTONS - STEP 2

PRINTED PARTS
Master Rod.stl

INSTALL ROCKER ARM ASSEMBLY
Press the other key of the other Master Rod Face onto the Master Rod.
INSTALL THE MASTER ROD BEARING
Align the Master Rod Bearing with the hole in the center of the Master Rod. Use a small hammer to drive the bearing into the hole, and lock all the elements of the Master Rod together.
INSTALLING PISTONS - STEP 4

PRINTED PARTS
5 Pistons.stl

INSTALL PISTON
Slide the Piston onto the end of the Master Rod and align the holes.
PIN THE PISTON

Use one of the long Piston Pins to attach the piston to the Master Rod. The pin should fit loosely, and the Piston should move freely.

PRINTED PARTS
Piston Pins.stl
INSTALLING PISTONS - STEP 6

INSTALL PISTON
Slide the Piston onto the end of the Link Rod and align the holes. The Link Rod's two holes are different sizes. The piston needs to go on the side with the smaller hole.

PRINTED PARTS
Link Rod.stl
5 Piston.stl
PIN THE PISTON
Use one of the long Piston Pins to attach the piston to the Link Rod. The pin should fit loosely, and the Piston should move freely.

Repeat these steps to build the other three Pistons.
INSTALLING PISTONS - STEP 8

INSTALL THE MASTER ROD
Slide the Master Rod’s piston through the top cylinder hole, opposite the Mounting Bracket. Slide the Master Rod Bearing over the Crankshaft Pin. When you turn the Crankshaft the piston should move up and down.

PRINTED PARTS
Master Rod Assembly
INSTALL THE OTHER PISTONS

Slide the 4 remaining pistons through their cylinder holes. The link rods go between the two faces of the master rod and align with the holes.
ATTACH THE PISTONS

Use the 4 short Piston Pins to attach the link rods to the Master Rod. If you’re having trouble getting the pin to go through, make sure you have assembled pistons with the smaller hole of the link rod inside the piston.

PRINTED PARTS
Piston Pins.stl
Installing the Cylinders
INSTALL THE FIRST CYLINDER
Slide the Cylinder over the Piston and down to the Crankcase. Align the hole in the Cylinder Barrel fins with the holes in the Crankcase. When the holes are aligned, press the Cylinder Barrel into the Crankcase until the Cylinder Barrel Base is flush with the surface of the Crankcase.
INSTALL CYLINDER HEAD
Position the Cylinder Head over the top of the Cylinder Barrel. The short ends of the rocker arms should extend over the Cam Ring. Align the holes in the Cylinder Head with the holes in the Cylinder Barrel and the Crankcase.
Insert the Cylinder Pins

Push the 5 cylinder pins through the Cylinder Head and Cylinder Barrel until they rest on top of the holes in the Crankcase.
PIN THE CYLINDER TOGETHER

Us a small hammer and a punch to drive the 5 cylinder pins into the crankcase.
INSTALLING PISTONS - STEP 5

PRINTED PARTS
Cylinder Head Assembly
Cylinder Barrel Assembly
Cylinder Pins.stl x20

INSTALL REMAINING CYLINDERS
Repeat the last several steps to install the remaining 4 cylinders. When driving the pins on the last two cylinders, rest the crankcase on top of something, like piece of 2x4, so you don’t hammering against the completed cylinders.
INSTALL PUSH RODS

Install the Push rods that run from the Cam Followers to the Rocker Arms. Install them by lifting the Rocker Arm, putting the tip of the rod into the back of the Cam Follower, align the other end of the Push Rod with the divot in the Rocker arm, and release the arm. The force of the spring should keep the arm in place.

PRINTED PARTS
Push Rods.stl x2
INSTALLING PISTONS - STEP 7

INSTALL REMAINING PUSH RODS

Add the Push Rods to the other 4 cylinders.

The push rods come in 3 different lengths. Variances in printers and construction may result in the cylinders being slightly different heights. Find the correct length of push rod that will work in your engine.
The Stand
**STAND - STEP 1**

**INSTALL STAND STEM**
Install the stem in the center of Stand. The Stem is not necessary for the basic model, but it is used to convey the power cable in the electrical sub-kit.

**PRINTED PARTS**
- Stand.stl
- Stand Stem.stl
STAND - STEP 2

PLACE THE STEM
Make sure the tip of the Stem comes out aligned with the slot in the top of the stand.

PRINTED PARTS
(None)
STAND - STEP 3

ALINE BASE PLATE
Position the Stand Base Plate over the bottom of the Stand.

PRINTED PARTS
Stand Base Plate.stl
STAND - STEP 4

PRINTED PARTS
(None)

INSTALL BASE PLATE
Press the Base Plate into the bottom of stand.
STAND - STEP 4

PRINTED PARTS
Clips.stl

PLACE THE CLIPS
Place the two clips in the cavities on the top of the stand. They should fit loosely.
INSTALL CLIP COVERS
Press the Clip Covers into the tops of the cavities above the clips. Make sure they end up flush with or below the surface of the Stand.
CLIP ENGINE ONTO THE STAND
Clip the Engine onto the stand. Align the Bracket on the Crankcase with the slot in the top of the stand. Push back firmly until the Engine snaps into place.
PRINTED PARTS
( None )

CLIPPED INTO PLACE
Done.
PRINTED PARTS
(None)

CONGRATULATIONS
You finished. Turn the crankshaft and watch all the parts of the engine move.
Grease
CRANKSHAFT PIN

Put a small amount of grease in the cavity created by the flat side of the Crankshaft pin.

PRINTED PARTS

(None)
CAM FOLLOWERS AND CAM SURFACE

Put a dab of grease at the point where the Cam Followers contact the Cam Ring. When you turn the engine, the grease will be spread around the Cam Ring.
TIMING GEARS
Put grease between the Crankshaft Gear and the Timing Gears. Turn the engine to spread the grease onto the gears.

PRINTED PARTS
(None)
CAM RING TEETH

Spread grease at various points along toothed inner surface of the Cam Ring. Turn the engine to spread the grease onto the gears.

PRINTED PARTS
(None)
When each piston is at the bottom of its stroke, smear a little grease around the exposed lower surface.
**STAND - STEP 9**

**PRINTED PARTS**

(None)

**TURN THE CRANKSHAFT**

The engine should now be much easy to turn, and move much more quietly. Re-grease whenever the engine starts to become hard to turn, and don’t be stingy.