Radial Engine Model Design Alternatives

Supplement

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thinkzone.wlonk.com/Radial/RadialModel.html

Contents

1 Introduction

1.1 Purpose of this document

Most readers may ignore this entire document.

This **Design Alternatives** supplement is for makers of the radial engine model. It describes some possible design alternatives (ideas) that we considered but did not implement for model 2. If you are a maker and you are thinking about changing the design of this model, then you might be interested to read about these possible alternatives. Otherwise, you may ignore this entire document.

Manuals. The model has a **User Manual**, an **Assembly Manual**, and a **Maker Manual**. You should read those before reading this supplement.

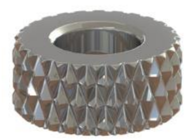
2 Minor part design alternatives

This section presents miscellaneous design alternatives for different parts of the radial engine model. These are ideas that we considered but did not implement for model 2. You may want to consider these ideas if you are a maker and are planning to make changes to the model. Each alternative in this section involves just a few parts of the model. Later sections (3 and 4) present bigger alternatives that involve the whole model.

2.1 Fasteners

2.1.1 Heat-set metal inserts

Heat-set insert with threaded hole.



Knurled bushing with smooth hole.

Hex washer with D-hole.

Heat-set inserts are metal tubes, knurled on the outside, with a hole in the middle, typically threaded. You install a heat-set metal insert into a plastic part by heating it to the plastic's melting point and pressing it into a hole in the plastic. You can also use metal press-fit inserts as heat-set inserts.

- **Threaded hole.** Most heat-set or press-fit inserts have threaded holes. They are used to make strong metal threaded screw holes in plastic.
- **Smooth hole.** Some heat-set or press-fit metal inserts have smooth round holes (like bushings). You can make a keyed hole from a smooth round hole by cutting (broaching) a slot (keyway).
- **Other hole shapes.** Heat-set or press-fit inserts with other hole shapes (such as D-holes, keyed holes, hex holes, or square holes) are not common. As an alternative, you can embed any small non-round (say, square or hex) metal part with the desired hole shape and size.

Our models 1 and 2 did not use any heat-set metal inserts. But you may want to consider using metal inserts to make strong metal holes, threaded or unthreaded, in the acrylic parts. Some of the design alternatives below involve the use of heat-set inserts.

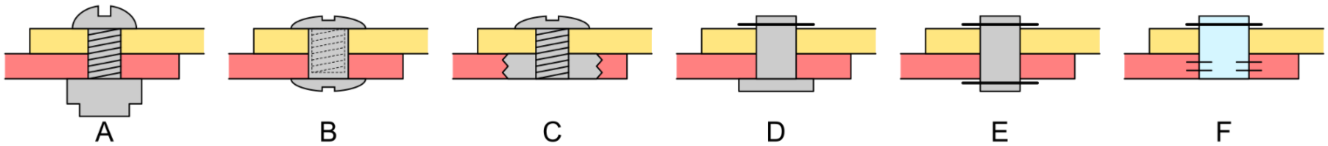
2.1.2 Pivot pins

The model has pivot pin joints on the con rods and pushrods.

The pivot pins must allow the joints to move, but they should not become loose over time as the parts rotate. The pivot pins should have a low-profile, so they do not require much clearance.

In our model 2, the pivot pins are made from common binder screws and posts, which require threadlocker. But your model could use different pivot pins, which may not require threadlocker.

Some alternative methods for making pin joints are sketched and described below. You may use these or other methods.



Sketches of alternative methods for making pivot pin joints. The methods (A-F) are described below.
Each side/section view show two acrylic parts (1/8”-thick) joined by a fastener (typically a #8 screw).

A. Screw and nut. You could use a common pan-head head screw and nylock nut. The nylock nut can be tightened enough to hold, but not so much that it binds the parts. The problem is that this fastener assembly is bulky and needs a lot of clearance.

B. Screw & post (barrel nut). Binder screws & posts have a very low profile, so they do not need much clearance. The problem is that the screw will loosen over time as the joint rotates, so you will need to apply threadlocker to keep the screw tight. (Note that threadlocker will make it difficult to unscrew the screw when you want to disassemble the joint. The low-profile round heads are difficult to grip with a screwdriver, and impossible to grip with a wrench, so you may need to use vise-grip pliers.)

C. Screw and heat-set threaded insert. A heat-set metal threaded insert is embedded in one acrylic part. The other part has a round hole. A screw with a low-profile head (such as a binder screw) connects the two parts. The problem is that the screw may loosen over time as the joint rotates, so you may need to apply threadlocker to keep the screw tight.

D. Pivot pin with flange and snap ring. The metal pivot pin is smooth and round, with a flange at one end and a snap ring groove at the other. This fastener assembly has no screw, so it will not loosen. For clearance, use a pivot pin that is not too long.

E. Pivot pin with two snap rings. The metal pivot pin is smooth and round, with snap ring grooves at both ends. This fastener assembly has no screw, so it will not loosen. For clearance, you would need to use a pivot pin that is not too long. You could make these pivot pins of any length by cutting a metal rod.

F. Acrylic rod, cemented, with snap ring. The pivot pin is an acrylic rod, bonded to a hole in one acrylic part with acrylic solvent cement. The other end of the rod has a snap ring groove. This fastener assembly has no screw, so it will not loosen. You cut the rod to the length required. The problem is that the acrylic-on-acrylic interfaces may have non-negligible friction. You may need to use dry lubricant or thin low-friction bushings.

For many of these methods, you could add thin low-friction washers or thin low-friction bushings, if necessary.

2.2 Plates

2.2.1 Back plate threaded inserts

You might consider using heat-set threaded metal inserts (see 2.1.1) in the back plate, wherever there are threaded holes.

Note: You should be expert at installing heat-set inserts, so you don't spoil the big back plate.

2.2.2 Front plate threaded inserts

You might consider using heat-set threaded metal inserts (see 2.1.1) in the front plate, wherever there are threaded holes.

If you design an alternative distributor cap attachment (see 2.8.2) using screws, then you may want to use threaded inserts in the front plate.

Note: You should be expert at installing heat-set inserts, so you don't spoil the big front plate.

2.3 Power system: Crankshaft, driveshaft, propeller

2.3.1 Shaft connectors

For model 2, the driveshaft and crankpin segments are made from acrylic tubes, and the shaft connectors are made by welding (with acrylic solvent cement) acrylic half round segments into the ends of the tubes.

You may want to devise a different way to connect the shafts.

2.3.2 Propeller locking

For model 2, the propeller can be removed simply by pulling it off. If that is a problem (perhaps children are removing the propeller), you could simply add a screw in the side of the driveshaft-propeller connector to prevent the propeller from being pulled off.

2.3.3 Propeller direction

Users are supposed to turn the propeller COUNTERCLOCKWISE as indicated by the arrows on the propeller. Counterclockwise is the normal propeller direction for single-engine airplanes. If you turn the propeller clockwise, the four-stroke engine cycle will run backwards. However, most right-handed people will naturally turn the propeller clockwise if they do not heed the arrows.

You might consider adding a ratchet on the driveshaft to prevent users from turning the propeller backwards.

2.4 Power system: Cylinders, pistons, con rods

2.4.1 Cylinder walls

For model 2, we widened the original (model 1) cylinder inner walls to make the piston slots deeper. This prevents the pistons from derailing. But we did not redesign or reposition the valves, so the cylinder inner walls have the original (model 1) dimensions near the valves, so the inner cylinder walls are not perfectly straight lines, unlike real cylinders. A prettier alternative design would have straight inner cylinder walls, like real cylinders. This may involve slightly changing the geometry of the cylinders and the valves.

2.4.2 Cylinder rocker-pusher support arms

For model 2, the rocker-pusher shafts have non-negligible friction where they rub against the support holes in the cylinders. You could modify the design of the rocker-pusher support arms to add low-friction bushings (such as nylon sleeves) in the holes.

2.4.3 Cylinder fronts with laser-etched slots

When the cylinder front and back are assembled with screws and nuts, they should not bind the enclosed moving parts (pistons, valves, and valve pushers). Binding is possible because the moving parts are the same thickness as the slots that hold them (1/8”-thick pistons in 1/8”-thick slots, 1/4"-thick valves and valve pushers in 1/4”-thick slots). There are two alternative methods to prevent binding: (A) The basic method is to simply not over-tighten the screws and nuts that squeeze the cylinder fronts and backs together (this is the method we used for our models 1 and 2). (B) The alternative method is to laser etch (or manually sand) the surfaces of cylinder fronts that that touch the moving parts (the slots for the pistons, valves, and valve pushers) so the slots are slightly roomier, and the cylinder front will not bind the moving parts even when you tighten the screws and nuts. The laser template for the cylinder front shows the areas to be laser etched. If you do laser etching, you should polish the rough etched surface to reduce friction. (You can use a hand-held rotary tool with sanding, buffing, and polishing heads.)

2.5 Small shafts for gears and rocker-pushers

The model has 20 small shafts (smaller than the driveshaft): the gears shaft, the distributor shaft, and 18 rocker-pusher shafts. The shafts transmit torque.

In model 2, all small shafts are 1/2"-diameter acrylic D-shafts connected to D-holes in the acrylic parts. But your model could use different kinds of shafts and different kinds of connections of parts to shafts.

2.5.1 Small shaft materials

Models 1 and 2 used acrylic shafts. But you could use metal (steel) shafts instead. Here are some things to consider about acrylic shafts versus steel shafts:

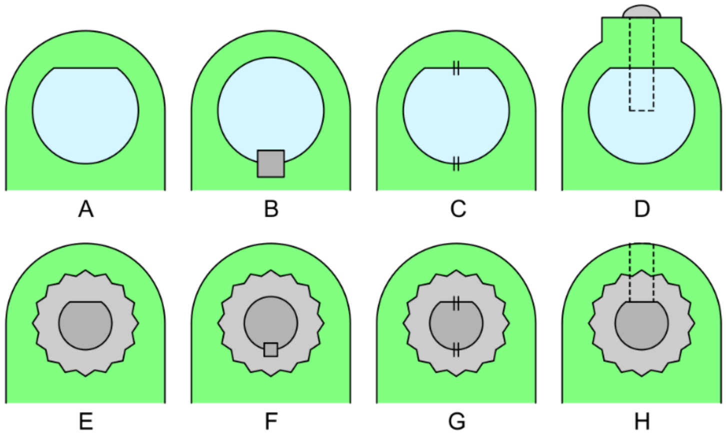
- **Diameter.** Steel shafts can have a smaller diameter (~1/4”) than acrylic shafts (~1/2").
- **Strength.** Steel is much stronger than acrylic. Acrylic shafts are normally strong enough, but they might break if they are over-torqued.
- **Wear-resistance.** Steel is more wear-resistant than acrylic. With usage over time, uncemented acrylic connections (like D-shaft connections or screw connections) may become loose.
- **Workability.** Acrylic is easier to cut and shape than steel. You may want to cut lengths of shaft, drill and tap holes, grind D-shafts, cut (broach) key slots, and/or cut snap-ring grooves.
- **Cementing/welding.** An acrylic part can be permanently bonded (welded) to an acrylic shaft using acrylic solvent cement. An acrylic part can be glued to a steel shaft. A metal heat-set insert can be glued, soldered, brazed, or micro-welded to a steel shaft.
- **Friction.** The rocker-pusher acrylic shafts have non-negligible friction where they rub against the round support holes. Smaller steel shafts would have less surface area contacting the support holes, so they may have less friction.
- **Standard materials.** Steel rods, steel D-shafts, and steel keyed shafts are all standard materials that you can buy. Acrylic rods are standard materials that you can buy, but acrylic D-shafts and keyed shafts are not (so you may need to make those).
- **Standard parts.** If you use metal shafts, you may want to use metal heat-set metal inserts for the holes in the acrylic parts. Heat-set inserts with threaded and smooth round holes are standard parts, but heat set inserts with D-holes or keyed holes are not common (so you may need to make those).

2.5.2 Small shaft connections

When selecting a method for connecting a part to a shaft, consider both rotational locking and axial locking.

- **Rotational locking.** To transmit torque, parts must be rotationally locked to the shafts. Rotational locking may be achieved by using a non-round shaft (D-shaft, keyed shaft, square shaft), by bonding (cementing or welding), or by using a fastener (screw or pin).
- **Axial locking.** You may want to lock some parts at the intended distance along the axis of the shaft. Axial locking may be achieved by bonding (cementing or welding), by using a fastener (screw or pin), or by using positioners (snap rings and/or spacer sleeves) on the shaft.

Some alternative methods for connecting the acrylic parts to the shafts are sketched and described below. You may use these or other methods.



Sketches of alternative methods for connecting parts to shafts. The methods (A-H) are described below. Each sketch shows a part joined to a shaft. The parts shown represent rocker arms or valve pushers, but most of these shaft connection methods also apply to the gears.

A. D-shaft (acrylic). An acrylic D-shaft is connected to a D-hole in the acrylic part. The part is rotationally locked to the shaft, but not axially locked. You can make a D-shaft by grinding a flat side into an acrylic round rod.

B. Keyed shaft (acrylic). An acrylic keyed shaft is connected (using a key) to a keyed hole in the acrylic part. The part is rotationally locked to the shaft, but not axially locked. You can make a keyed shaft by cutting a slot in an acrylic round rod.

C. Shaft (acrylic) bonded to part. An acrylic shaft (of any profile, including round) is permanently bonded (welded) to an acrylic part using acrylic solvent cement. The part is rotationally and axially locked to the shaft.

D. Shaft (acrylic) with screw. An acrylic shaft (of any profile, including round) is non-permanently fastened (with a screw) to an acrylic part. The part is rotationally and axially locked to the shaft. This method applies to rocker arms and valve pushers but not gears.

E. D-shaft (steel) with insert. A steel D-shaft is connected to a D-hole in a metal insert in an acrylic part. The part is rotationally locked to the shaft, but not axially locked. You can buy steel D-shafts.

F. Keyed shaft (steel) with insert. A steel keyed shaft is connected (using a key) to a keyed hole in a metal insert in an acrylic part. The part is rotationally locked to the shaft, but not axially locked. You can buy steel keyed shafts.

G. Shaft (steel) bonded to insert. A steel shaft (of any profile) is permanently bonded (glued, soldered, brazed, or welded) to a metal insert in an acrylic part. The part is rotationally and axially locked to the shaft.

H. Shaft (steel) with insert and set screw. A steel shaft (of any profile, perhaps a D-shaft) is non-permanently fastened (with a set screw) to a metal insert in an acrylic part. The part is rotationally and axially locked to the shaft. This method applies to rocker arms and valve pushers but not gears.

2.5.3 Small shaft bushings

Small shafts may have friction where they rub against the round support holes. You could add low-friction bushings (such as nylon sleeves) in the round support holes for the small shafts. (Models 1 and 2 had low-friction bushings for the large driveshaft and large crankpin, but not for the small shafts.)

2.6 Gears

This section has only minor gear design alternatives. For major gear train alternatives, see in section 3.

2.6.1 Gear shaft holes

If you redesign the gear shafts (see 2.5), you will need to redesign the shaft holes in the gears.

2.7 Valve system: Valves, rocker-pushers, pushrods, cam disk

2.7.1 Valve stem threaded holes

In both model 1 and model 2, the narrow valve stems had tapped threaded holes for the screw posts. It is quite difficult to drill and tap these threaded holes in the narrow valve stems without breaking the plastic.

Perhaps you can design the valve stems differently, so you do not need to drill and tap the threaded holes. You cannot use heat-set threaded inserts because the valve stems are too narrow. You may be tempted to replace the entire valve stem with a round metal post, but the valve stems should be square where they go through the square holes in the cylinders to prevent the valve from rotating.

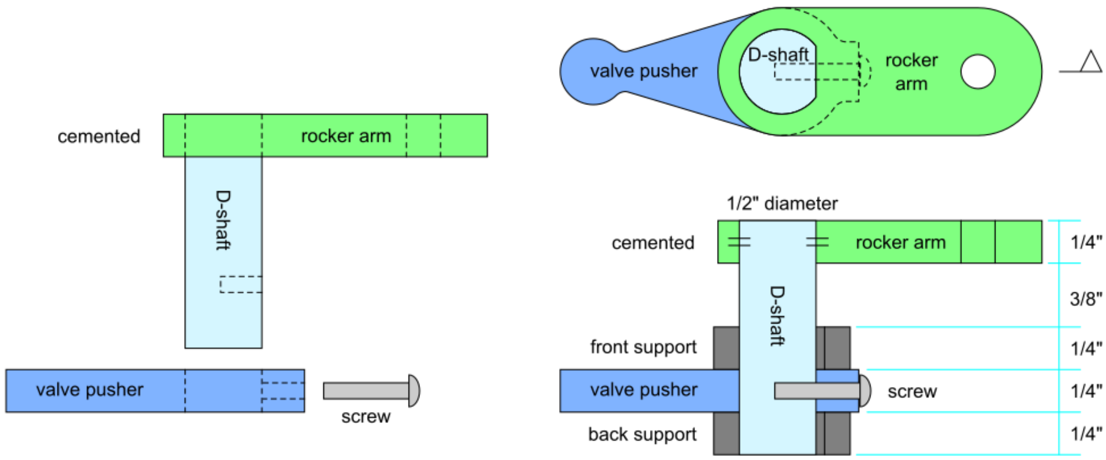
2.7.2 Adjusting valve stem lengths

In model 2, we individually adjusted the valve stem lengths by adding different numbers of washers under the heads of the valve stem screws.

Adjusting the valve stem lengths compensates for the inconsistency of the rocker-pusher assemblies. If the rocker-pusher assemblies could be built very consistently, it would not be necessary to individually adjust the valve stem lengths.

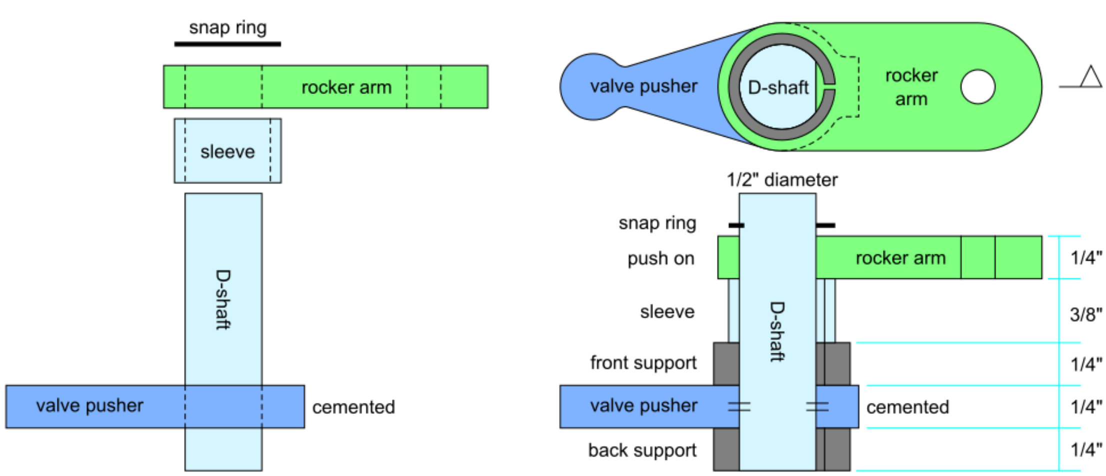
2.7.3 Rocker-pusher assemblies

There are many possible ways to attach the valve pushers and rocker arms to the rocker-pusher shafts. The valve pushers and rocker arms may be cemented to the shafts, fastened to the shafts with screws, or simply pushed onto D-shafts. But you cannot cement both the valve pusher and the rocker arm to the shaft because then the rocker-pusher cannot be disassembled from the rocker support on the cylinder front. Any alternative design should allow either the valve pusher or the rocker arm to be removable from the rocker-pusher shaft.



A. Rocker-pusher assembly with cemented rocker arm and fastened valve pusher.
(Model 1 used this design, but with a round shaft rather than a D-shaft.)

A. Rocker-pusher assembly with cemented rocker arm. Model 1 used this design. For this design, the rocker arm is cemented to the shaft and the valve pusher is removable from the shaft (see diagram A above). The valve pusher may be fastened to the shaft with a screw (such as a pan-head machine screw #4-40 × 1/2"). The shaft may be a round acrylic shaft (as in model 1) or a D-shaft (as shown in diagram A). An advantage of the removable valve-pusher is that it allows the rocker-pusher assembly to be installed and removed without separating the cylinder front from the cylinder back. A disadvantage of this design is that it requires the maker to precisely drill a hole edgewise in the valve pusher, and to precisely drill and tap a hole in the shaft. Another disadvantage of this design is that it locks in the distance along the shaft between the cemented rocker arm and the fastened valve pusher. Adjusting this distance would require drilling another hole in the shaft, possibly close to the previous hole.



B. Rocker-pusher assembly with cemented valve pusher and push-on rocker arm.
(Model 2 uses this design.)

B. Rocker-pusher assembly with cemented valve pusher. Model 2 uses this design. In this design, the valve pusher is cemented to the shaft and the rocker arm is removable from the shaft (see diagram B). If the shaft is a D-shaft, the rocker arm may be simply pushed onto the D-shaft, positioned by a sleeve and a snap ring. A disadvantage of the cemented valve-pusher is that it does not allow the rocker-pusher assembly to be installed and removed without separating the cylinder front from the cylinder back. An advantage of this design is that it has no screw, and it does not require the maker to precisely drill a hole edgewise in the rocker arm or valve pusher, nor to precisely drill and tap a hole in the shaft. Another advantage of this design is that it does not lock in the distance along the shaft between the cemented valve pusher and the push-on rocker arm. This distance can be adjusted by simply sliding the rocker arm, and possibly using a longer or shorter sleeve, and possibly cutting another snap ring groove in the shaft.

2.7.4 Consistent rocker-pusher angles

Ideally, any alternative rocker-pusher assembly design would set the angle between the rocker arm and the valve pusher consistently (say, always 180° for every rocker-pusher).

You could set the angle consistently if you could cement both the rocker arm and the valve pusher to the rocker-pusher shaft, but you cannot cement both.

For model 1, the angle between the rocker arm and the valve pusher was not consistent (not always 180°), because it was difficult for us to precisely drill the screw holes in the valve pusher and the shaft. For model 2, the angle between the rocker arm and the valve pusher was not consistent (not always 180°), because our D-shaft did not fit our rocker arm's D-hole tightly enough (it wiggled a bit).

You may be able to make the rocker-pusher angles more consistent by making better shaft connections (see 2.5.2).

If the rocker-pusher assemblies could be built very consistently, it would not be necessary to individually adjust the valve stem lengths.

2.7.5 Thicker cam shafts, non-grooved cam followers

Model 1 had thin cam tracks and thin cam follower wheels. It used non-grooved wheels, so they derailed.

Model 2 also had thin cam tracks and thin cam follower wheels, but it used grooved wheels to prevent derailing.

You might consider using thicker cam tracks and thicker cam follower wheels. Then you might be able to use non-grooved wheels without derailing.

2.7.6 Potential interference between cam followers and pushrods

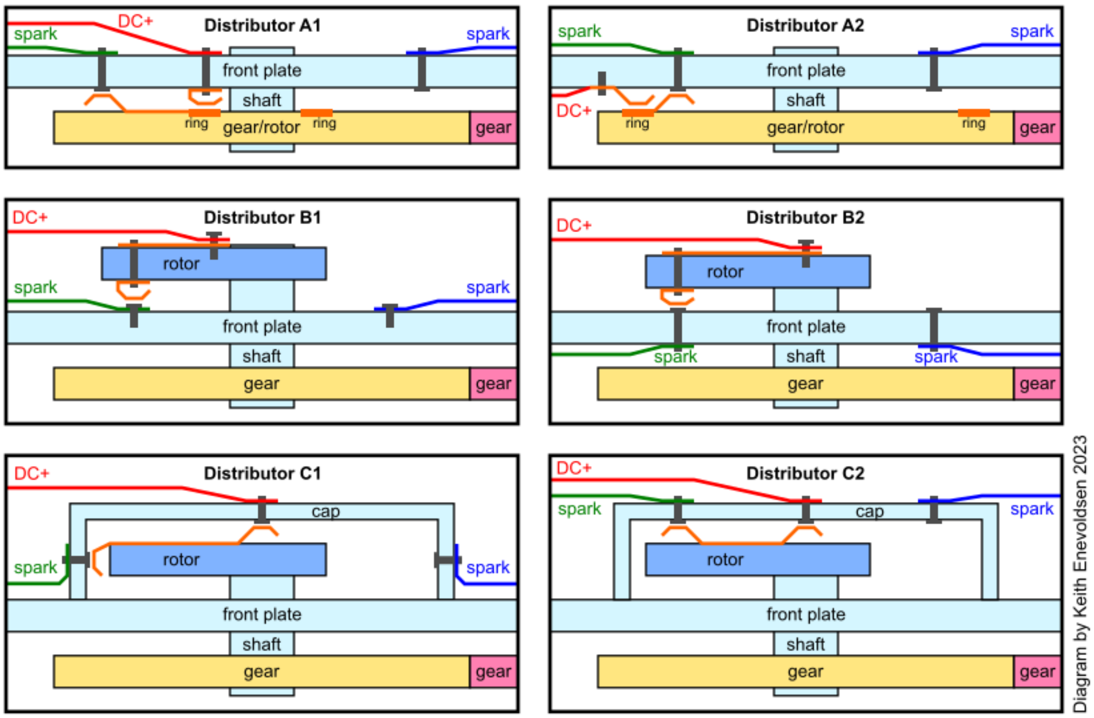
The flanges of the grooved wheels slightly overlap, and potentially interfere with, the neighboring pushrods. This potential interference is not a problem for our model 2, but it is worrisome. If you used non-grooved wheels, without flanges, the wheels would have smaller diameters and be less likely to interfere with the neighboring pushrods.

You could also reduce the potential interference by making the pushrods narrower. You could eliminate the potential interference by slightly repositioning the pushrods to put more space between neighboring cam followers, but this may require you to reposition the lobes on the cam disk.

2.8 Electrical system: Distributor

2.8.1 Distributor design alternatives

There are many and varied ways to design a distributor for this radial engine model. In all these alternatives, the distributor is on the front plate, connected to a distributor gear behind the front plate. There are three general design patterns for the distributor design: (A) with no rotor, (B) with a rotor but no cap, or (C) with a rotor and a cap. The following sketches show some of the possibilities.



Sketches of six possible distributor designs (side/section views).
A1 and A2 have no rotor (the gear is the rotor). B1 and B2 have a rotor but no cap. C1 and C2 have a rotor and a cap.

A. Distributor with no rotor. For these designs, the distributor gear itself functions as the rotor. Since there is no rotor, the distributor gear may be centered on the driveshaft, or it may be on a separate shaft. The spark plug wire contacts are arranged in a circle on the back side of the front plate. The distributor gear behind the plate has a contact that goes around, touching each of the spark plug contacts on the plate. The DC+ wire may contact a small-diameter contact ring near the center of the distributor gear (A1). The DC+ wire may contact a large-diameter contact ring near the edge of the distributor gear (A2).

B. Distributor with a rotor but no cap. Model 1 used this design pattern. For these designs, a rotor in front of the plate is attached to the distributor gear behind the plate. The spark plug wire contacts are arranged in a circle on the front side of the front plate. The rotor has a tip contact that rotates around, touching each of the spark plug contacts on the plate. The spark plug wires may be in front of the plate (B1). The spark plug wires may be behind the plate (B2). The DC+ wire contacts the center of the rotor (B2) or near the center of the rotor (B1).

C. Distributor with a rotor and a cap. Model 2 used this design pattern. For these designs, a rotor in front of the plate is attached to the distributor gear behind the plate, and a distributor cap encloses the rotor. The spark plug wire contacts are arranged in a circle on the cap. The rotor has a tip contact that rotates around, touching each of the spark plug contacts on the cap. The spark plug wire contacts may be on the wall of the cap (C1). The spark plug wire contacts may be on the lid of the cap (C2). The DC+ wire contacts the rotor at the center of the lid (C1 and C2).

2.8.2 Distributor cap connector

For model 2, the distributor cap is connected to the front plate with a twist connector. This allows you to remove and replace the cap quickly without any tools. But fabricating the twist connector is a bit complicated (the twist connector is made from four laser-cut rings with tabs and slots, two rings cemented to the front plate and two rings cemented to distributor cap).

You could design a different, perhaps simpler, way to attach the distributor cap to the plate.

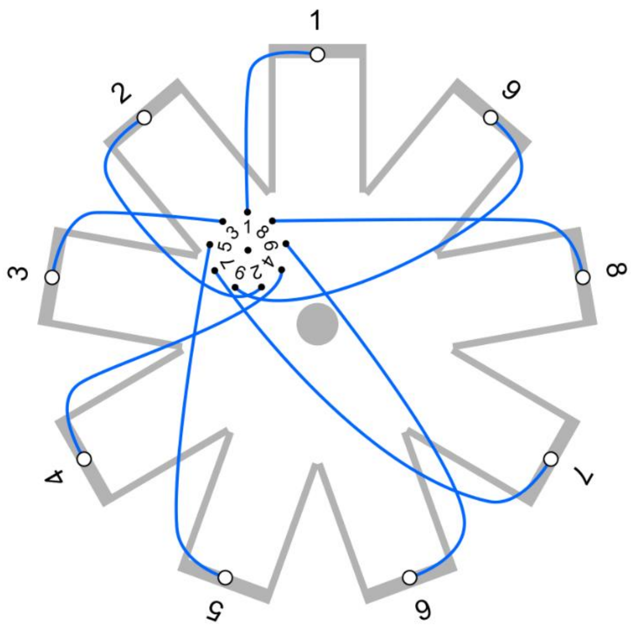
One alternative would be to install (three) heat-set threaded inserts in the front plate, and then attach the cap to the plate with (three) screws. If you used knurled-head thumbscrews, you would not need a screwdriver to remove and replace the cap.

2.9 Electrical system: Wiring, LEDs

Note that the distributor design alternatives (see 2.8.1) would also involve wiring changes.

2.9.1 Wire routing

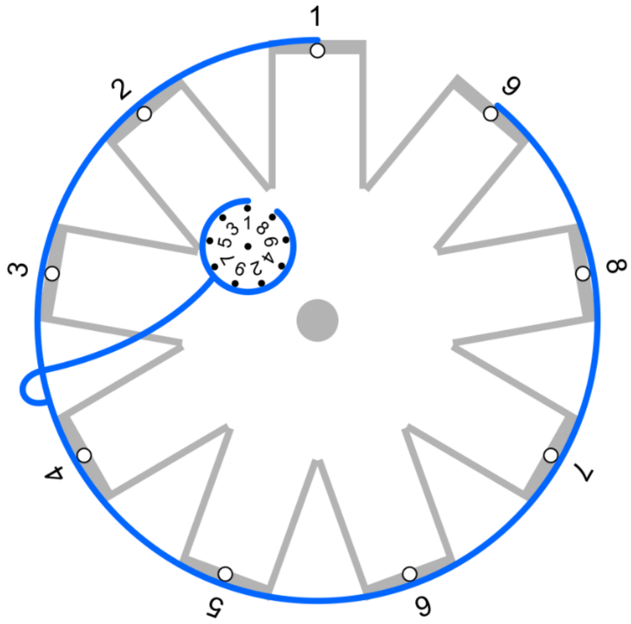
There are different ways to route the wires. Nine spark plug wires connect the distributor on the front plate to the spark plug LEDs in the cylinders on back plate. A tenth wire connects the distributor center to the battery positive terminal. Nine negative wires connect the LEDs to the battery negative terminal. The shortest-path routing (A) is direct but cluttered. The periphery routing (B) is indirect but uncluttered. We prefer the periphery routing.



A. Shortest-path wire routing.
Rough sketch of the nine spark plug wires (not a full wiring diagram).

A. Shortest-path wire routing. Model 1 used this wire routing. The nine spark plug wires are individually routed from the distributor to the spark plug LEDs, each wire taking roughly the shortest path. Each spark plug wire starts at a distributor contact point on the front side, goes to the edge of the front plate beside the destination cylinder, then back through small holes in the front and back plates, then behind the back plate to the LED hole in the back plate and cylinder, then forward to the positive lead of the LED. The tenth positive wire is routed from the distributor center to the battery positive terminal, also taking roughly the shortest path. The negative leads of the LEDs are connected to a common wire that goes to the battery negative terminal, taking roughly the shortest path, on the back side. An advantage of the shortest-path routing is that it is direct. It is easy for the user to trace the wires from the distributor to the spark plug LEDs. A disadvantage of the shortest-path routing is that it looks cluttered because there are many wires visibly crisscrossing through the middle of the transparent model. Another disadvantage is that the maintainer cannot easily separate the front wiring from the back wiring.

A2. Shortest-path wire routing, using the main screws as conductors. Here is an imaginative variation (which we never tried) of the shortest-path wire routing. In the shortest-path wiring, there are ten wires (nine spark plug wires and the distributor's center wire) that go through small holes drilled into the front and back plates. In this variation, each of the nine spark plug wires is connected to one of the two main screws for its cylinder, and the tenth center wire is connected to a tenth main screw. The metal main screws would conduct the electricity through the plates, so no wires would go through the plates. This design, like the shortest-path wiring, still looks cluttered because there are still many wires visibly crisscrossing through the middle of the transparent model.



B. Periphery wire harness on back side, and single cable on front side.
Rough sketch of the back wire harness and the front cable (not a full wiring diagram).

B. Periphery wire harness on back side, and single cable on front side. Model 2 used this wire routing. All the spark plug wires from the distributor are bundled into a front cable that goes to the left edge of the front plate and then back to the left edge of the back plate. On the back side, the front cable is connected to a back wire harness with a multi-pin cable connector. The back wire harness is routed around and behind the periphery of the circle of cylinders, where the wires connect to the positive leads of the spark plug LEDs. The tenth positive wire connecting the distributor center to the battery positive terminal is also bundled into the front cable. The negative leads of the LEDs are connected to a common wire that goes to the battery negative terminal, bundled into the back wire harness, around the periphery on the back side. A disadvantage of the periphery routing is that it is indirect. It is harder for the user to trace the wires from the distributor to the spark plug LEDs, but using colored wires will help to make it easier to trace. An advantage of the periphery routing is that it eliminates the clutter of wires visibly crisscrossing through the middle of the transparent model. Another advantage is that the maintainer can easily separate the front wiring from the back wiring by unplugging the cable connector. (The Assembly Manual has a wiring diagram and a description of this wire routing.)

2.10 Stand

2.10.1 Sturdier stand

The foldable stand for model 2 is sturdy enough, but it could be sturdier. The stand's metal legs and crossbars are only on the sides of the model, without cross bracing between the two sides, so the opaque structure does not interfere with the transparency of the model (without the backlight), when viewed or photographed from the front. You could make the stand sturdier by adding additional cross-bracing, but you should avoid adding any opaque structure directly behind the transparent model.

2.10.2 Carrying handle or strap

Our model 2 has no carrying handle or strap, so we must use two hands to carry our model. You could attach a carrying handle or strap to the top center of the back plate. You may need to drill two more holes in the back plate to attach the handle or strap. The handle or strap could be removed when the model is on display.

2.11 Backlight

2.11.1 Custom backlight

Model 2 has a backlight that is made from a dimmable 24”×24” ceiling LED panel (with a 23”×23” lit area). You may buy or make a different backlight. Any backlight should be bright and dimmable so it can be adjusted for any room lighting. Preferably, the lit area would be the full size of the model, 24”×24” (not 23”×23”).

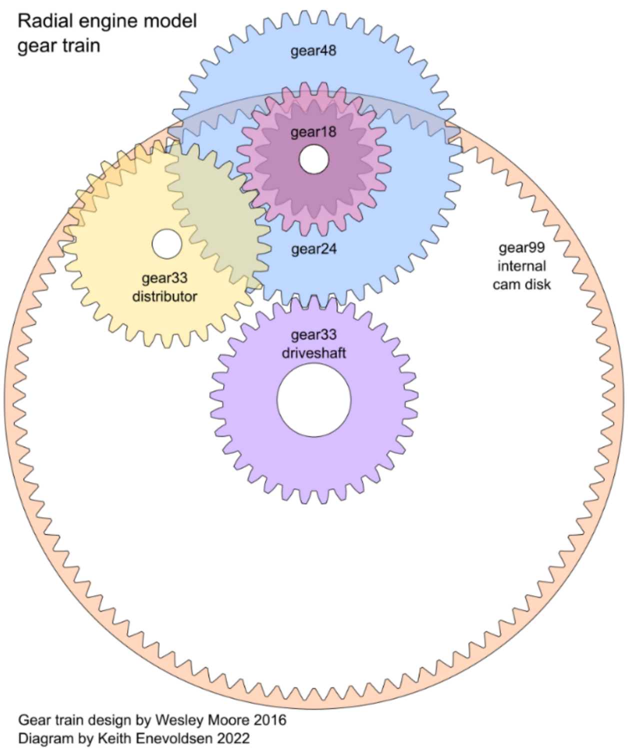
3 Major gear train alternatives

Wesley Moore designed two alternative gear trains for the radial engine model. They are very different with respect to the distributor gear. Changing the gear train would require a major redesign of the model.

3.1 Gear train A with off-center distributor

Gear train A has the distributor gear off the driveshaft axis. Using this gear train, the distributor can have a cap and rotor. Most airplane radial engines in the first half of the 20th century were like this, with a cap-and-rotor distributor that was not centered on the driveshaft.

Wes Moore designed gear train A for model 1. Models 1 and 2 used gear train A.



Gear train A by Wesley Moore (2016).

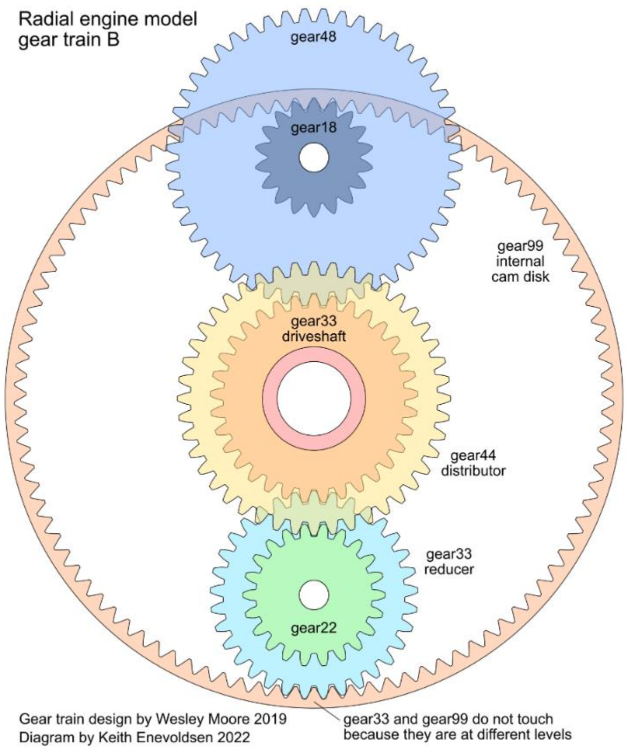
How it works:

- Two turns of the crankshaft-driveshaft = one four-stroke cycle.
- Cam disk gear train: 33 → 48 → 18 → 99.
    - The cam disk turns at (33/48)×(18/99) = 1/8 the rotation rate of the shaft.
- Distributor gear train: 33 → 48 → 24 → 33.
    - The distributor gear turns at (33/48)×(24/33) = 1/2 the rotation rate of the shaft.

3.2 Gear train B with centered distributor

Gear train B has the distributor gear on the driveshaft axis. Using this gear train, the distributor gear functions as the rotor. Some airplane radial engines of the very early 20th century were like this, with the spark plug contact points on a disk centered on the driveshaft.

Wes Moore designed gear train B after he had built model 1 using gear train A. Wes started to modify model 1 to use gear train B, but he never completed that version of the model.



Gear train B by Wesley Moore (2019).

How it works:

- Two turns of the crankshaft-driveshaft = one four-stroke cycle.
- Cam disk gear train: 33 → 48 → 18 → 99.
    - The cam disk turns at (33/48)×(18/99) = 1/8 the rotation rate of the shaft.
- Distributor gear train: 33 → 33 → 22 → 44.
    - The distributor gear turns at (33/33)×(22/44) = 1/2 the rotation rate of the shaft.

4 Major museum-quality redesign

The radial engine model could be redesigned to be more robust, suitable for unsupervised public hands-on display (say, at an aviation museum).

The existing model 2 design is not robust enough for unsupervised hands-on display. Model 2 is sturdy enough to allow children or teens to turn the crank, but only under the supervision of a responsible adult. We envision that model 2 could be kept in a staff room of an aviation museum and brought out occasionally by a museum docent, who would allow the public (children, teens, and adults) to turn the crank.

The following subsections describe some of the ways in which the model could be redesigned to be robust enough for unsupervised public hands-on display. (You should also consider the smaller part design alternatives in section 2.)

4.1 Thicker acrylic parts

We chose to use acrylic plastic for its wide range of transparent colors and its ease of laser cutting, not for its toughness. Acrylic parts are somewhat durable, but they are brittle and breakable when overstressed. For example, acrylic parts might break if over-enthusiastic children or teens turn the hand crank too forcefully, especially if the machine is jammed.

To make a more robust model, we think you can continue to use acrylic plastic, but just make some parts thicker.

Model 2 has acrylic parts that are 1/8"-thick and 1/4”-thick. The 1/8”-thick parts are most susceptible to breaking (for example, you can snap a 1/8"-thick con rod or pushrod by over-bending it in your hands). But even the 1/4”-thick parts can crack when overstressed.

You could redesign the entire model to have all acrylic parts be 1/4” thick. All parts that are 1/8"-thick would be replaced by parts that are 1/4” thick (namely, the pistons, cylinders, master rod, con rods, pushrods, cam tracks, and cam followers). This would increase the thickness of the levels, and the thickness of the whole model. So, you would also need to increase the lengths of the parts, like shafts, that span the levels (namely, the driveshaft segments, crankpin segments, gears shaft, distributor shaft, rocker-pusher shafts, pivot pins, main screws, and spacer sleeves).

Note that making the parts thicker will affect their transparency.

4.2 Larger model (optional)

You could scale up the size of the whole model so that all parts are bigger and stronger.

For example, you could scale up the whole model by a factor of 150%. The entire model would grow from 24”×24” to 36”×36” and every part would be 50% bigger.

At 150% scale, all acrylic parts should be at least 1/4" thick, and some parts should be scaled up to 3/8” thick. In particular, the gears should be thick enough to ensure that they stay meshed. Also, if you use non-grooved wheels as cam followers, then the cam tracks and cam followers should be thick enough to ensure that the cam followers stay on the cam tracks. Some other parts, like pistons, con rods, and pushrods, would not need to be thicker than 1/4".

4.3 Acrylic welds

The acrylic solvent welds can be very strong, but some welds might fail when overstressed. When making the model, you should make the best possible acrylic solvent welds (using a needle applicator). Make sure the parts fit together perfectly and make sure that the solvent wets 100% of the contact surfaces.

If you think some acrylic welds are not durable enough, you could add screws to reinforce those welds.

4.4 Reliable operation

Model 2 was reliable enough for moderate usage, but it was not 100% reliable for extended unsupervised usage. For permanent display, make sure all the parts are designed to work reliably for a year or more without maintenance. Specifically, make sure these parts are designed to work reliably: the cam followers should always stay on the cam tracks, the gears should never jam or skip, the distributor rotor should always make good contact with all nine contact points, and all the screws and nuts should always stay tight.

4.5 Durability testing

You should perform load tests to ensure that your acrylic parts and acrylic welds are durable. But do not load test your real parts, because load tests could start cracks that will weaken the parts and welds. Instead, you should make some sacrificial test parts and test welds and subject them to high loads until they fail. Then you will learn how strong your parts and welds are. Test the places that get the highest stresses, especially connections of parts to high-torque shafts: the driveshaft connectors, rocker arm and valve pusher connections to the rocker-pusher shafts, and gear connections to gear shafts.

4.6 Protective display case

Model 2 was designed to be a fully "hands-on" model. All parts of model 2 are exposed to touch. But this means that some parts might get broken. Children and teens might derail the cam followers from the cam tracks, open the distributor cap and change the rotor angle, pull the propeller off, loosen the screws and nuts, or tug on the wires. Furthermore, model 2 is mounted on a tabletop display stand, so the entire model can be knocked over and it can fall onto the floor and break.

To protect all the parts for unsupervised display, mount your model inside a protective display case that is anchored to a wall or table.

4.7 Accessible hand crank

If the model is in a protective display case, only the hand crank should be accessible by users. The hand crank may be the propeller, as in model 2, or you may design a separate hand crank for your display.

We recommend that the model be hand-cranked rather than motorized because it is more engaging to crank it yourself. Also, a motor would cause the model to undergo many more machine cycles, and the acrylic plastic parts would wear out and break sooner.

4.8 Spark plug LEDs

Model 2 uses small frosted white LEDs, which are quite bright, with a large viewing angle. But for a museum-quality display, you may want to use larger LEDs, or diffusor caps over the LEDs, to make them even more visible.

Model 2 has batteries for the spark plug LEDs. The batteries may get weak or die before they are replaced, especially if the on-off switch is left on all the time. For permanent display, you may want to use a permanent DC power source, such as an AC/DC adapter, rather than batteries that need to be replaced.

For model 2, the on-off switch for the LEDs is accessible by the user. If your model is in a protective display case, consider whether you want the on-off switch to be accessible.

4.9 Backlight

Model 2 has a backlight that is made from a dimmable 24”×24” ceiling LED panel, with a 23”×23” lit area. For a professional display, you may want to design a custom backlight panel, perhaps the entire back wall of the display case.

Model 2 has an AC power cord that is plugged into a wall socket. AC power cords are potential hazards for unsupervised children. For unsupervised display, any AC power cord should be concealed or out of reach.

For model 2, the on-off-dimmer control for the backlight is accessible by the user. If your model is in a protective display case, consider whether you want the on-off-dimmer control to be accessible.