Radial Engine Model
Revision History of Models 1 and 2

Supplement

Radial engine model 1.

Radial engine model 2.

Model by Wesley Moore, modified by Keith Enevoldsen.

Document and diagrams by Keith Enevoldsen.

thinkzone.wlonk.com/Radial/RadialModel.html

Contents

1 Introduction

1.1 Purpose of this document

Most readers may ignore this entire document.

This **Revision History** supplement is for makers of the radial engine model. This document lists the past design revisions of models 1 and 2, including reasons for the changes and lessons learned. If you are a maker and you are thinking about changing the design of this model, then you might be interested to read about the lessons learned from the past revisions. 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.

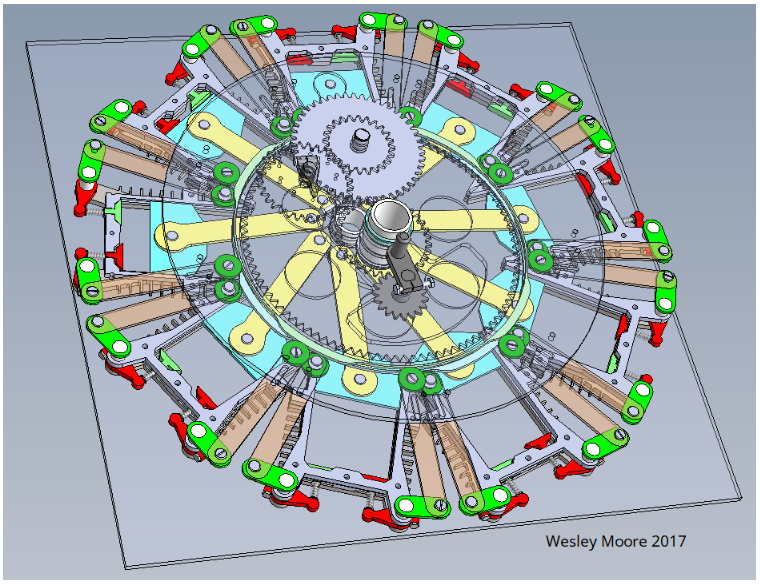
1.2 Model numbers

Model 1 is Wesley Moore’s original model, including all revisions (2016-2020).

Model 2 is Keith Enevoldsen’s renovated model, including all revisions (2022-2023).

2 Design methods for models 1 and 2

2.1 Design methods for model 1 (3D)



3D model of the radial engine model (model 1).

3D design methods. Wes designed model 1 (2016-2018) using SolidWorks, a commercial 3D computer-aided design (CAD) tool. The primary design files were 3D SolidWorks parts (SLDPRT) (extruded from 2D sketches) and 3D SolidWorks assemblies (SLDASM). Wes then used SolidWorks to generate 2D laser templates (PDF, XPS, DXF) and drawings (SLDDRW). After Wes completed the first working physical model (2018), he stopped updating the SolidWorks 3D model, but he continued to make small changes to the physical model (2018-2020).

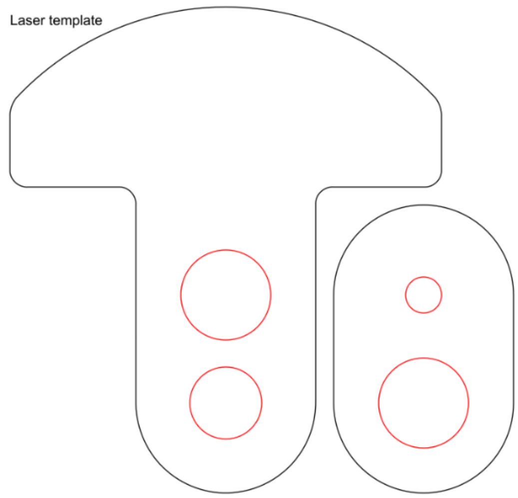
Rationale for using 3D design methods. Wes had decided to use 3D design for these reasons:

- Wes was experienced with 3D modeling using SolidWorks.
- With a 3D model of the entire machine, he could check that all the parts would fit before generating the 2D laser templates and making the physical parts.
- Wes did not intend to publish the design files, so the 3D model would not need to be maintained after making the laser templates.

Revision numbers. Wes used revision numbers for model 1 while he was using SolidWorks.

- Wes created the original design, revision 1, in 2016-2017.
- Wes made revisions 1.2, 2, 2.2, and 2.3 in 2017-2018. These revisions included some changes that were adopted and some changes that were abandoned.
- Wes built the first working model in 2018, and it looked very much like the rev 2.2 design.
- Wes's later changes in 2018-2020 do not have revision numbers.

2.2 Design methods for model 2 (2D)



2D laser template for one part (the crank).

2D design methods. I (Keith) revised model 1 to make model 2 (2022-2023) using 2D design methods only. The primary design files are 2D laser templates, paper templates, and diagrams. The 2D design files are SVG format. SVG is a common 2D vector graphics format. Laser cutters read 2D vector graphics formats. I used Inkscape to create the SVG files, so the files are in Inkscape SVG format. Inkscape SVG files can be converted to other vector formats, such as Plain SVG, PDF, DXF, and EPS.

Rationale for using 2D design methods. When I took up this project in 2022, I received Wes's physical model 1 and a copy of Wes's design files for model 1, both 3D SolidWorks design files and 2D laser templates. I planned to make small changes to the design of the parts. I decided to abandon the 3D design and go forward with 2D design only, for these reasons:

- I was more experienced with 2D drawing tools than 3D modeling tools.
- 2D design is appropriate for this model because the model consists of a stack of flat layers made from flat parts. Most of the parts are made on a 2D laser cutter, and no part is made on a 3D printer.
- The 2D laser templates had already been created from Wes's 3D model, so the 3D model was no longer needed. After making the 2D laser templates, Wes had stopped maintaining the 3D model.
- I planned to make only small tweaks to the existing parts, which I could do by directly editing the existing 2D laser templates.
- I preferred simpler design tools because I planned to make the design public. Creating and editing 2D laser templates (2D drawings) of the individual parts is simpler than creating and editing 3D models of the parts, the subassemblies, and the entire machine.
- I preferred free design tools because I planned to make the design public. 2D Inkscape is free. 3D SolidWorks is not free.

Revision numbers. Keith did not use revision numbers for model 2.

3 Revision history of models 1 and 2

3.1 Main screws

Model 1

- The 18 main screws were 3” 10-32 (fine thread) machine screws.
- The spacing between the two plates and the pushrods was set with several nuts on each of the main screws. It was laborious to carefully adjust all these nuts.

Model 2

- We changed the main screws to 4” 10-24 (standard/coarse thread) machine screws. Longer screws were needed because the model was thicker due to thicker gears and the added middle plate. We changed from fine thread to standard/coarse thread to speed up the assembly/disassembly of nuts on these very long screws.
- We added spacer sleeves of preset lengths on the main screws, to set the precise spacing between the three plates and the pushrods. Using more spacer sleeves and fewer nuts makes assembly faster and more accurate.

3.2 Pivot pin joints

Model 1

- Pivot pins on the con rods and pushrods were made from common binding screws & posts. Binding screws & posts have wide, thin heads, so they are well-suited to be used as pivots in this model, which is made of thin, flat layers. But binding screws & posts come loose very easily.

Model 2

- We added threadlocker to all binding screws & posts that are used as pivot pins on the con rods and pushrods. This was a major improvement!
- You may want to consider using different pivot pins that do not require threadlocker. (The Design Alternatives document has descriptions of alternative pivot pins.)

3.3 Back plate

Model 1

- The back plate is a 24”×24” square.
- The model 1 back plate was a test plate. Eventually it was riddled with experimental holes.
- We attached adhesive vinyl numbers next to each cylinder.

Model 2

- We made a new back plate to replace the old test plate. (Cut and drilled by TAP Plastics in Seattle.)
- The main screw holes were not repositioned.
- We repositioned the holes for the electrical parts, such as the switch and the cable.
- We attached brackets to make the stand.
- We cemented laser-cut, colored transparent acrylic numbers next to each cylinder. We repositioned the numbers inward from the edge of the plate, for better backlighting.

3.4 Front plate

Model 1

- The front plate is a 16” circle.
- The model 1 front plate was a test plate. Eventually it was riddled with experimental holes.
- The rev 2 design added three large struts connecting the back plate to the front plate. These struts seem structurally unnecessary because the plates were already connected by 18 structural screws. Perhaps the purpose of the struts was to set the distance between the plates. The three struts were never built and were removed from later design revisions.

Model 2

- We made a new front plate to replace the old test plate. (Cut and drilled by TAP Plastics in Seattle.)
- We moved the gear33_distributor shaft hole slightly farther from gear33_driveshaft. These two gears are on different levels and should never engage, but the added clearance gives extra assurance that these two gears will never accidentally engage and jam.
- We cemented the distributor twist connector to the front plate.

3.5 Middle plate

Model 1

- The model originally had no middle plate.
- The rev 2.3 design added a large triangular middle plate, behind the cam disk, perhaps to stabilize the cam disk. This middle plate was never built.

Model 2

- We added a middle plate, roughly 14”×2”, in front of the cam disk, to stabilize the gear shafts. The two gear shafts’ back ends, which cannot reach the back plate, are held by the new middle plate, and the shafts’ front ends are held by the front plate.

3.6 Crankshaft-driveshaft

Model 1

- The crankshaft-driveshaft assembly has four segments (crank back, crank front, middle driveshaft, and propeller). The shaft is made from 1.25”-OD acrylic tubes. The shaft connectors are never shown in Wes’s design files. The 2018 model had connectors made from wooden dowels and screws.

Model 2

- We rebuilt the four segments of the crankshaft-driveshaft assembly (crank back, crank front, middle driveshaft, and propeller) with push-in shaft connectors. The segments simply slide together without any screws. These shaft connectors are made with 1”-diameter half-round acrylic rod cemented inside the 1”-ID 1.25”-OD shaft tubes.

3.7 Propeller (with crank handle)

Model 1

- The propeller is never shown in any of Wes’s design files.
- The 2018 model had store-bought 14”-15” model airplane propeller, with a crank handle added.
- In 2019, the model had a custom-built heavy-duty 16” flat propeller manually cut from 1/2"-thick transparent acrylic, with a big crank handle and a sturdy metal tab to connect to the driveshaft. This big propeller-crank was needed because model 1 required a lot of torque to overcome friction. This big crank may have been too big because a user could apply too much force and break the model.

Model 2

- Store-bought propellers have aerodynamic shapes and are typically opaque. Custom-made propellers are made from colored transparent acrylic, to enhance the transparency of the model.
- All model 2 propellers used the new push-in driveshaft connector, made from 1.25”-OD acrylic tube and 1”-diameter half round (described above).
- The first model 2 propeller was a store-bought 10” model airplane propeller. It had no crank handle. The sharp aerodynamic blades made it uncomfortable to turn by hand. The propeller had a small 0.75" hub, which was not easy to connect sturdily to the big 1.25”-OD custom-built driveshaft connector.
- The next propeller was a custom-built 12” pitched-blade propeller, laser cut from 1/4"-thick colored transparent acrylic. This propeller had flat (non-aerodynamic) blades, which were pitched slightly and cemented to the hub. It had no crank handle. The pitched blade-to-hub connection was not easy to make and was not durable (the blades broke off). It was easy to cement and screw the big flat propeller hub to the big flat end of the driveshaft connector.
- The latest propeller-crank is a custom-built 12” flat propeller, laser cut from 1/4"-thick colored transparent acrylic. The entire propeller is flat, laser cut as a single piece, and the blades are neither aerodynamic nor pitched. The propeller has a crank handle. This propeller-crank is easy to make and durable. It is easy to cement and screw the big flat propeller hub to the big flat end of the driveshaft connector.

3.8 Small hand crank

Model 1

- All the model 1 designs (rev 1 to 2.3) show a small hand crank on the front plate adjacent to the driveshaft. The 2018 model had this small hand crank. This small hand crank was too small, with not enough torque to drive the mechanism.
- In 2019, the small hand crank was removed, because the big propeller-crank worked better.

Model 2

- Model 2 does not have a small hand crank, because the propeller is the hand crank.

3.9 Cylinders

Model 1

- In the original design, and first built model, the piston slots in the cylinders were shallow, so some pistons would derail or jam. Wes tried to temporarily fix this by cementing thin shims to some cylinder inner walls and cementing extremely thin shims to some piston edges.

Model 2

- We slightly redesigned the cylinders and rebuilt all the cylinders.
- We widened the 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.
- We modified the cylinders so that all layers fully engage all four screws. This allows you to use all four screws to precisely align all the cylinder layers while you are cementing them together.
- We modified the cylinder cooling fins to be thicker, less fragile.
- We added spacer rings, cemented to the back side of the cylinders, to separate the cylinders a little farther from the back plate. This helps align the pistons with the master rod flange, putting the master rod and con rods all at the same level. It also increases the access space behind the pistons, which is helpful when you want to tighten the screws & posts.

3.10 Pistons

Model 1

- The original (rev 1) pistons were rectangles, 2.5" tall and 3.063" wide. This was clearly unworkable because neighboring pistons would collide at the bottom of the stroke.
- The rev 2 pistons were shorter (2"), and had the two bottom corners cut off, so neighboring pistons would not collide at the bottom of the stroke. They were wider (3.125"), to stay in the tracks, but they were still unreliable.
- The rev 2.2 pistons were wider (3.15"), to stay in the tracks, but they were still unreliable.
- We added shims to some pistons, to keep the pistons in the tracks.

Model 2

- We made no changes to the pistons (still 3.15" wide). (But the cylinder walls had deeper piston slots.)

3.11 Master rod

Model 1

- The master rod is cemented to the flange (collar), unlike the eight con rods, which are fastened to the flange with pivots.

Model 2

- We slightly revised the master rod to be the same length as the con rods.

3.12 Con rods

Model 1

- Rev 2 added a circular bulge around the pivot hole at the piston end, for aesthetics, not strength.
- Rev 2 and rev 2.2 changed the length of the con rod.

Model 2

- No change.

3.13 Small shafts for gears and rocker-pushers

Model 1

- The gears shaft (for gear18, gear24, and gear48) was an acrylic D-shaft.
- The distributor shaft (for gear33_distributor) was an acrylic D-shaft.
- The eighteen rocker-pusher shafts were acrylic round shafts.

Model 2

- We changed the rocker-pusher design to use D-shafts (see rocker-pushers).
- In model 2, all the small shafts are acrylic D-shafts.
- You may want to consider using different small shafts. (The Design Alternatives document has descriptions of alternative small shafts.)

3.14 Gears

Model 1

- In 2016, Wes designed the original gear train with the distributor off the driveshaft axis. There were six gears: gear33_driveshaft, gear18, gear24, gear48, gear33_distributor, and gear99_internal_cam_disk. (The

Assembly Manual and the Design Alternatives document each have a diagram and description of this gear train.)

- The gears shaft (for gear18, gear24, and gear48) and the distributor shaft (for gear33_distributor) were acrylic D-shafts.
- The original gears were all thin, 1/8" thick. Wes originally envisioned the entire model to be very thin (sort of like a mechanical pocket watch). But thin gears do not mesh reliably.
- Rev 2.2 and the 2018 model had just one thicker gear, gear18.
- In 2019, Wes designed an alternative gear train with the distributor gear centered on the driveshaft. (The Design Alternatives document has a diagram and description of this gear train.)
- Wes started to modify the model to use this alternative gear train, but he never completed that version of the model.

Model 2

- For model 2, Keith opted to keep the original gear train with the distributor off the driveshaft axis. One reason was to allow the distributor to have a cap and rotor. Another reason was to keep the driveshaft simpler.
- Model 2 has all new thicker gears, 1/4" rather than 1/8". Thick gears mesh more reliably because they have more tolerance for misalignment. Thicker gears are more durable.
- We found that some of Wes's gear outlines were slightly too small or too large, so we generated all new gear outlines before cutting the new gears. (The Maker Manual specifies the gear parameters.)

3.15 Valves

Model 1

- Originally, each laser-cut valve had only the valve head without an acrylic stem. The entire stem was a screw with a long post extension screwed into the valve head. However, the round stem in the square hole allowed the valve to rotate, so the valves became misaligned.
- In rev 2, each laser-cut valve had a short stem with a square cross section, and a screw with a shorter post extension. The square stem in the square hole kept the valve aligned, but the stem was not long enough.
- In the 2018 model, each laser-cut valve had a long stem with a square cross section, and a screw with a shorter post extension. The square stem in the square hole kept the valve aligned. Drilling and tapping the screw hole partway down the middle of the thin stem is a tricky job because it is easy to break the brittle acrylic.

Model 2

- We implemented a simple and effective method to individually adjust the valves to make them fully open and close. The maintainer adjusts the valve stem lengths by adding or removing small washers to the valve stem screws. Adjusting the individual valve stem lengths compensates for irregularities in the individual rocker-pusher assemblies. (The Assembly Manual describes the valve stem adjustment washers.)

3.16 Rocker-pushers

Model 1

- Originally, each rocker-pusher was 3D-printed as a single part. This was the only part of the model that was ever 3D-printed. Redesigning this part to be laser-cut eliminates the need for a 3D-printer.
- Rev 2 introduced the laser-cut rocker arm and laser-cut valve pusher, both attached to a round acrylic shaft. The valve pusher was screwed to the shaft and the rocker arm was cemented to the shaft. (The Design Alternatives document has a diagram and description of this rocker-pusher design.)

- The angles between the rocker arms and the valve pushers were somewhat inconsistent because the drilled screw holes were inconsistent. To make the valves work consistently, individual adjustments were required for each valve. For model 1, individual adjustments were made by adding improvised shims (dome-head pins) to the valve pusher tips, but this was a stopgap solution.

Model 2

- We changed the rocker-pusher design to use flat-sided D-shafts, eliminating the need for screws. The valve pusher is cemented to the shaft, and the rocker arm may be pushed onto the D-shaft to any desired distance from the valve pusher. (The Assembly Manual and the Design Alternatives document each have a diagram and description of this rocker-pusher design.)
- The angles between the rocker arms and the valve pushers are somewhat inconsistent because the D-holes in the rocker arms are not perfectly fit to the D-shafts. To make the valves work consistently, individual adjustments are required for each valve. For model 2, individual adjustments are made by adjusting the valve stem lengths by adding or removing washers (see valves).

3.17 Pushrods

Model 1

- Rev 1.2 and rev 2.2 changed the length of the pushrod.

Model 2

- No change.

3.18 Cam followers

Model 1

- The original cam followers were simple disks laser-cut from 1/8”-thick acrylic. These wheels would often derail from the 1/8”-thick cam tracks.

Model 2

- We replaced the cam followers with store-bought nylon grooved wheels. The flanges on the wheels keep the cam followers on the cam tracks.
- The flanges of the grooved wheels slightly overlap, and potentially interfere with, the neighboring pushrods. This potential interference is not a problem in our model 2, but it is worrisome.

3.19 Cam disk

Model 1

- Originally, each cam lobe was laser cut separately from the cam disk, then cemented onto the edge of the disk. The lobes were a different color from the disk, to make them more visible. The cemented lobes may have been too weak for the high stresses on the cam tracks.
- In the 2018 model, each cam track was laser cut as a single piece with all cam lobes included.
- The gear99 internal teeth were only on the front cam track ring (1/8” thick).

Model 2

- The cam disk has gear99 internal teeth on both the front cam track ring (1/8” thick) and the middle spacer ring (1/4” thick), making the internal gear teeth very thick (3/8” thick). This makes the cam disk gear99 and gear18 mesh more reliably.

3.20 Distributor

The distributor underwent many significant design revisions. There are three general design schemes for the distributor: (A) with no rotor, (B) with a rotor but no cap, and (C) with a rotor and a cap. All three schemes were tried. (The Design Alternatives document has sketches and descriptions of these alternatives.)

Model 1

- The original (rev 1) distributor design was unusual. It had a circle of nine miniature snap-action switches attached to the front plate, with the switch roller levers poking through holes to the back side of the front plate. The distributor gear's flat face had a bump that would go around triggering the switch rollers, so the gear itself functioned as the rotor. The store-bought switches would have made very reliable contact, but the nine-switch design looked unconventional.
- The rev 2.2 distributor design was more conventional, with a circle of nine contact screws on the front plate, and a rotor with an unspecified tip contact and an unspecified center contact. The distributor gear shaft was a D-shaft, but the rotor had a round shaft hole and a squeeze clamp, so the rotor angle could be adjusted, but an over-tight squeeze clamp could break the brittle acrylic.
- The rev 2.3 distributor design had a circle of nine contact screws on the front plate, and a rotor with a bent-metal tip contact and an unspecified center contact. The rotor had a flat-sided D-hole, so the rotor angle could be adjusted only by disengaging and re-engaging the gears. The rotor was held down by a screw.
- The 2018 model had a circle of nine contact screws on the front plate, and a rotor with a bent-metal tip contact and some kind of center contact. The center contact is not clear in the photo, but it appears to be very simple, perhaps merely a wire wrapped around a screw, tightly enough to maintain contact but loosely enough to rotate. The rotor had a flat-sided D-hole, so the rotor angle could be adjusted only by disengaging and re-engaging the gears.
- In 2019, Wes designed an alternative gear train with the distributor gear centered on the driveshaft. The distributor gear itself was intended to function as the rotor. The front plate would have a circle of nine contact screws around the driveshaft. Wes started to modify the model to use this alternative gear train, but he never completed that version of the model. (The Design Alternatives document has a diagram and description of this gear train.)

Model 2

- For model 2, Keith opted to keep the original gear train with the distributor off the driveshaft axis. One reason was to allow the distributor to have a cap and rotor. Another reason was to keep the driveshaft simpler. (The Assembly Manual has a diagram and description of this gear train.)
- For model 2, Keith opted to make the distributor have a cap and rotor. The cap wall and lid are transparent acrylic so you can see the rotor. The cap attaches to the front plate with a twist connector, so it is easy to remove the cap to adjust the contacts or the rotor angle. The cap-and-rotor design allows the rotor's spring contacts to push against the top or sides of the cap. The cap-and-rotor design is modular because all contacts are on the cap and rotor, and no contacts are on the plate or the gear, so you can change the design of distributor by changing the cap and rotor, without changing the plate or the gear.
- The first revision of model 2 had a transparent, partially enclosed, distributor cap with a rotor inside. A circular acrylic ring in the wall of the cap had nine contact screws and the top center of the cap had one contact screw. The rotor had one metal spring contact on the rotor tip, pushing out against the inside wall of the cap, and one contact on the rotor top center, pushing up against the inside lid of the cap. But this design was difficult to make because nine contact screw holes in the cap wall and one spring hole in the rotor tip had to be manually drilled into the edge of 1/4-inch-thick acrylic sheet, rather than laser cut.
- The next revision has a transparent, completely enclosed, distributor cap with a rotor inside. The cap's lid has a circle of nine spark plug contact screws and one center contact screw. The rotor top has a metal

contacts strip, with two contact points at the tip and center, with two conical springs underneath, pushing up against the contact screws inside the lid of the cap. This design is easier to make because all ten contact screw holes in the cap and both spring holes in the rotor can be laser cut into the face of the acrylic sheet.
- The latest revision is the same as the previous revision, but the rotor connects to the shaft with a many-pointed spline connector, so it is easy to change the rotor angle to set the spark timing.
- We replaced the thin aluminum contacts strip with a thin stainless steel contacts strip, because the aluminum strip started to wear out at the contact points.

3.21 Battery pack

Model 1

- The original battery pack provided 3 volts (for the 3V LEDs), with two 1.5 V D-cell alkaline batteries. The D-cell batteries were bulky.

Model 2

- The battery pack provides 3 volts (for the 3V LEDs) with two 1.5 V AA alkaline batteries. The AA batteries are smaller, but still big enough to light the LEDs for a long time.
- We used a transparent battery holder to enhance the transparency of the model.
- We added a clip to hold the battery pack to the back plate.

3.22 On-off switch

Model 1

- A toggle switch was mounted to the front of the back plate (on the left side). The old-fashioned toggle switch looks appropriate for an old-fashioned airplane.

Model 2

- We moved the switch (to the bottom left corner).
- We added an ON-OFF label plate.

3.23 Wiring

Model 1

- Model 1 used solid wire (24 gauge).
- All spark plug wires were the same color.
- For model 1, the wire routing has individual wires routed along the roughly shortest-paths from the distributor to the spark plug LEDs. This shortest-path wire routing looks cluttered because there are many wires visibly crisscrossing through the middle of the transparent model. (The Design Alternatives document has a description of this wire routing.)

Model 2

- We used stranded wire (24 gauge). Stranded wire is more flexible than solid wire, so it is less likely to break when the wires are flexed during assembly and disassembly.
- The nine spark plug wires are nine different colors, to make it easier to trace the wires.
- For model 2, the wire routing has a periphery wire harness on the back side and a single cable on front side. This periphery wire routing eliminates the clutter of wires visibly crisscrossing through the middle of the transparent model. (The Assembly Manual has a wiring diagram and a description of this wire routing.)

3.24 LEDs

Model 1

- Originally, the model had clear white LEDs with a narrow viewing angle. Viewers could see the LEDs flash only when standing directly in front of the model. Photographs and videos often failed to show the flashes.

Model 2

- We changed to frosted white LEDs with a wide viewing angle. Viewers can see the LEDs flash even when standing to the side of the model. Photographs and videos show the flashes.

3.25 Resistor

Model 1

- Resistors are used to prevent LED burnout.
- Originally, there were nine resistors, each soldered to an LED.
- The original resistors had relatively high resistance, 300 ohms. The clear white 3V LEDs were not fully bright with the 3V battery pack. The 300-ohm resistor protected the 3V@20mA LEDs if the supply voltage is 9V or less, so it allowed the use of battery packs ranging from 3V to 9V.

Model 2

- We used a single resistor near the on-off toggle switch, rather than nine resistors soldered to the nine LEDs. This simplifies the soldering and makes it easier to try different resistors.
- The new resistor has relatively low resistance, 47 ohms. The frosted white 3V LEDs are very bright with the 3V battery pack. The LED flashes should be eye-catching even when the model is in a sunlight room or has the backlight turned on. The 47-ohm resistor protects the 3V@20mA LEDs only if the supply voltage is less than 4V, so you must use a 3V battery pack.

3.26 Stand

Model 1

- Model 1 had no stand.

Model 2

- We added a stand with folding legs so the model can stand upright on a tabletop. The stand can be used with or without the backlight. The stand is helpful during assembly because it holds the model upright (with legs deployed) and it elevates the model when lying flat (with legs stowed).

3.27 Backlight

Model 1

- The model originally had a 24”×24” backlight, which was just a ceiling LED panel.
- Wes may have originally chosen the size of the entire model to be 24”×24” because that is the size of a US standard 24”×24” ceiling LED panel light, used as a backlight.
- No power cord was installed on the backlight.
- The LED panel was dimmable, but no dimmer control was installed.
- There was nothing to hold the backlight.

Model 2

- The added stand has brackets to hold the backlight.

- We bought a dimmable ceiling panel light that also had a built-in power-saver switch with three brightness settings.
- We installed a power cord on the backlight so it can be plugged into a wall socket.
- The ceiling panel light was too bright. First, we tried simply switching the built-in power-saver switch to the lowest setting, but it was still too bright.
- We tried adding a 24”×24” light gray filter gel (Lee Zircon) in front of the panel light. This was good for some room lighting conditions but not others.
- We installed a dimmer control knob on the ceiling panel light. We bought a dimmer control of the right type (0-10V) that came in a fully enclosed box. We mounted the dimmer control box on the back of the panel and wired it up. This works well in all room lighting conditions because the user can control the brightness.

3.28 Plaque

Model 1

- A printed plaque was attached to the back plate. It had the name of the model (POSSUM-9), the serial number (00-001), the firing order (1-3-5-7-9-2-4-6-8), and other info and jokes. Wes did not put his name on it!

Model 2

- We attached a new laser-scored plaque to the back plate. We incremented the serial number (00-002). We added the names of the makers (Wesley Moore and Keith Enevoldsen).