# Radial Engine Model
# User Manual


Model by Wesley Moore, modified by Keith Enevoldsen.

Document, diagrams, and photos by Keith Enevoldsen.

thinkzone.wlonk.com/Radial/RadialModel.html

# Contents

# 1 Introduction

## 1.1 Purpose of the radial engine model

The radial engine model is a hand-cranked transparent display model that demonstrates the operation of an airplane four-stroke radial engine.

## 1.2 Purpose of this manual

This **User Manual** is for users of the radial engine model. It introduces the radial engine model (model 2) and tells how to operate the model. It spotlights many things to observe while operating the model. It explains the four-stroke engine cycle. For background, it presents some photos of a real radial engine.

**Manuals.** The model has a User Manual, an Assembly Manual, and a Maker Manual. Read this User Manual first.

## 1.3 Overview of the model


*Radial engine model 2.*

Wesley Moore conceived of this transparent cross-section radial engine model with these key features:

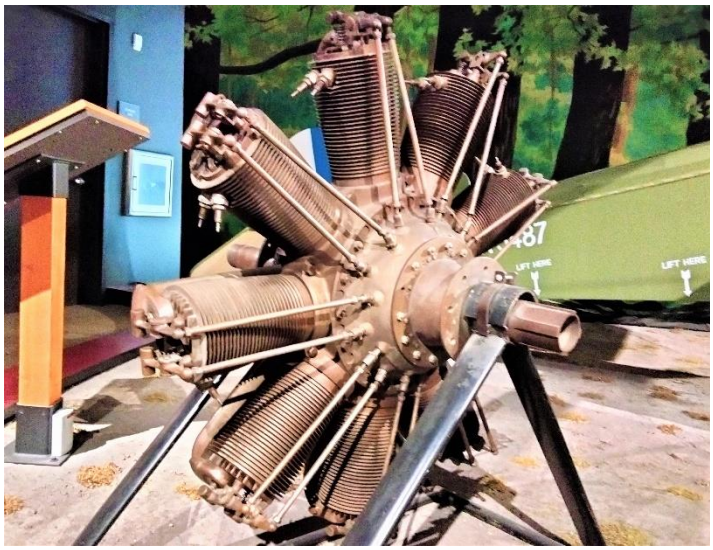
| **Radial engine model** | |
|---|---|
| **Key feature** | **Description** |
| **Airplane radial engine model** | The 24”×24” model demonstrates the operation of an airplane four-stroke nine-cylinder radial engine. The power, valve, and spark systems are synchronized by gears. |
| **Power system** | The pistons move in and out within the cylinders. The pistons are connected by one master rod and eight con rods to the crankshaft, which is directly connected to the driveshaft and propeller. |
| **Valve system** | The intake and exhaust valves open and close. The valves are opened by valve pushers on rocker arms, which are connected by pushrods to cam follower wheels, which ride the cam tracks on the big cam disk. |
| **Spark system** | The spark plugs are flashing LEDs. A distributor with a rotor controls the sparks. The firing order is every alternate cylinder. |
| **Hands-on** | You turn the propeller with the crank handle, which turns the driveshaft and crankshaft, which makes all the other parts move. The model is hand cranked, not motorized, because it is more engaging to crank it yourself. |
| **Transparent, colorful, luminous** | The model is made of colored transparent acrylic plastic. You can clearly see all the moving parts. The colors are delightfully luminous when backlit. |
| **Cross-section** | The model is a stack of flat layers, made from flat laser-cut parts. The engine cylinders, pistons, and valves are 2D cross sections. The model is a hybrid between a 3D model and a 2D cross-section illustration. |

**WARNING: BREAKABLE.** Do not turn the propeller hand crank too fast or too forcefully, especially if the machine is stuck, because you could break the plastic parts! The acrylic (plexiglass) plastic parts are brittle and breakable when overstressed. This model may be operated by children and teens under the supervision of a responsible adult.

## 1.4 Introduction to real radial engines

*1916 Sopwith Triplane.*

*Sopwith Triplane with Clerget 9B radial engine.*



*Clerget 9B radial engine.*

*Clerget 9B radial engine, showing cylinders, pushrods, rocker arms, valve springs, and spark plugs.*

*Photos by Keith Enevoldsen at the Museum of Flight near Seattle (2023).*

A radial engine has cylinders positioned radially, like the spokes of a wheel, around the crankshaft. Many airplanes in the first half of the 20th century had radial engines.

The Clerget 9B (shown here) was a popular radial engine of the WW1 era. Compare these photos of the Clerget 9B with our radial engine model. You can see many similarities. The Clerget 9B radial engine, like the model, has nine cylinders, 18 pushrods, 18 rocker arms, and 18 valves. You can also see differences. The real propeller is wider than the real engine, but the model propeller is narrower than the model engine. The Clerget 9B has two spark plugs on the side of each cylinder, but the model has one spark plug at the top of each cylinder. The model has a distributor with a cap and rotor, but the Clerget 9B's contact points are on a disk (not shown) that is centered on the driveshaft.

# 2 Operating the model

## 2.1 Ready ...

Set up the stand, with or without a backlight (as described farther below). If you are using a backlight, plug in and turn on the backlight. If the backlight has a dimmer, adjust the brightness.

## 2.2 Set ...

The spark plug LEDs are powered by batteries. Turn on the on-off switch on the front side of the back plate. You may shout, “Contact!”

## 2.3 Go!

*Turning the propeller (without the backlight).*

*Turning the propeller (with the backlight).*

**Manually turn the propeller, using the crank handle, COUNTERCLOCKWISE** (from your point of view in front of the model) as indicated by the arrows on the propeller. Counterclockwise is the normal propeller direction for single-engine airplanes. You may be accustomed to turning other cranks clockwise, but this crank turns counterclockwise. If you turn the propeller clockwise, the four-stroke engine cycle will run backwards!

**WARNING: BREAKABLE.** Do not turn the propeller hand crank too fast or too forcefully, especially if the machine is stuck, because you could break the plastic parts! The acrylic (plexiglass) plastic parts are brittle and breakable when overstressed. This model may be operated by children and teens under the supervision of a responsible adult.

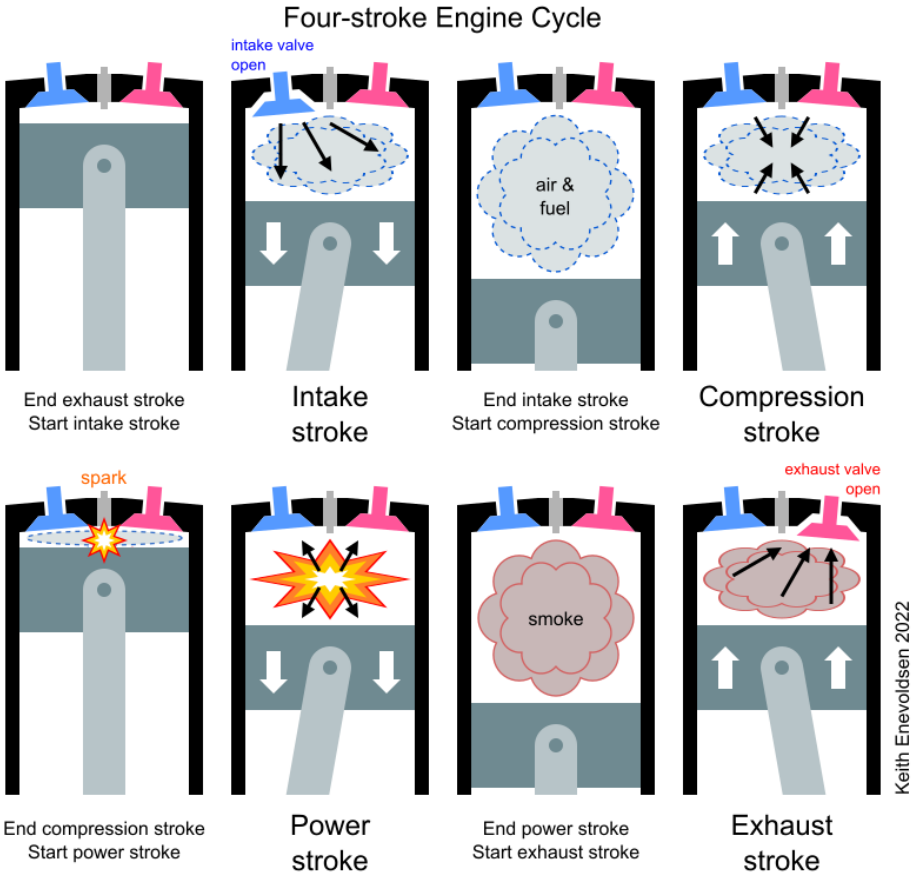
While you are slowly turning the propeller, carefully observe all the moving parts.

When you are done using the model, remember to turn off the on-off switch to conserve battery life.

# 3 Observing and learning

## 3.1 Four-stroke engine cycle

**Observe the four-stroke cycle.** As you turn the propeller COUNTERCLOCKWISE, the pistons, valves, and sparks are synchronized to demonstrate the four-stroke engine cycle. (If the timing is wrong, the maintainer should set the timing.)




*Four-stroke engine cycle.*

| Four-stroke engine cycle | | | | |
|---|---|---|---|---|
| **Stroke or event** | **Piston** | **Intake valve** | **Exhaust valve** | **Action** |
| **Intake stroke** | expanding | open | closed | Only the intake valve is open. The piston pulls air and fuel into the cylinder. |
| **Compression stroke** | compressing | closed | closed | The valves are closed. The piston compresses the air/fuel mixture. |
| ***Ignition*** | compressed | closed | closed | The spark ignites the air/fuel mixture. The spark is at the end of the compression stroke. |
| **Power stroke** | expanding | closed | closed | The valves are closed. Combustion of the air/fuel mixture pushes the piston, driving the crankshaft, driveshaft, and propeller. |
| **Exhaust stroke** | compressing | closed | open | Only the exhaust valve is open. The piston pushes the exhaust gases out of the cylinder. |

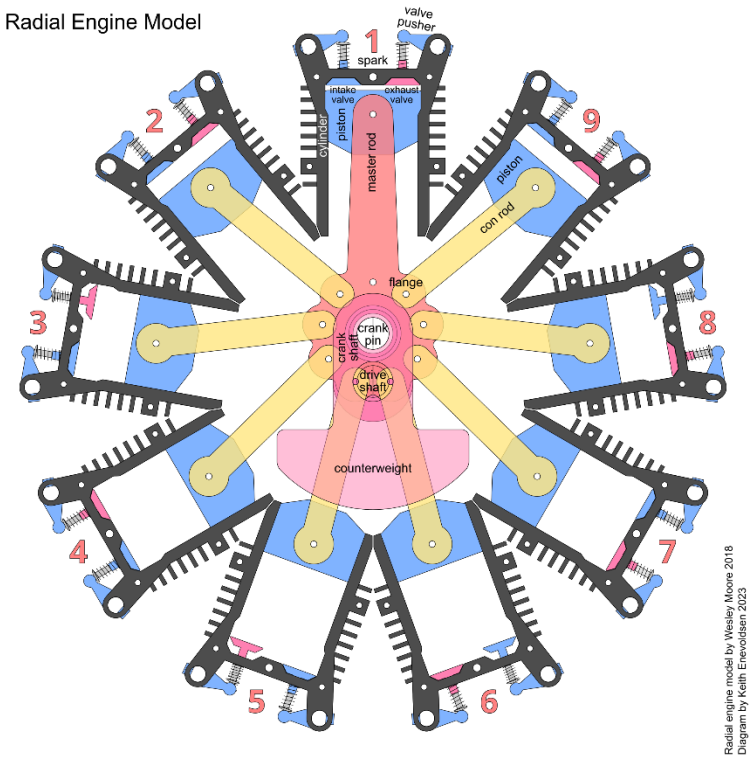
## 3.2 Parts and systems

**Observe all the moving parts.** As you turn the propeller, you should observe that about a hundred parts move, and nine lights flash. Look closely. Can you figure out what each part does?

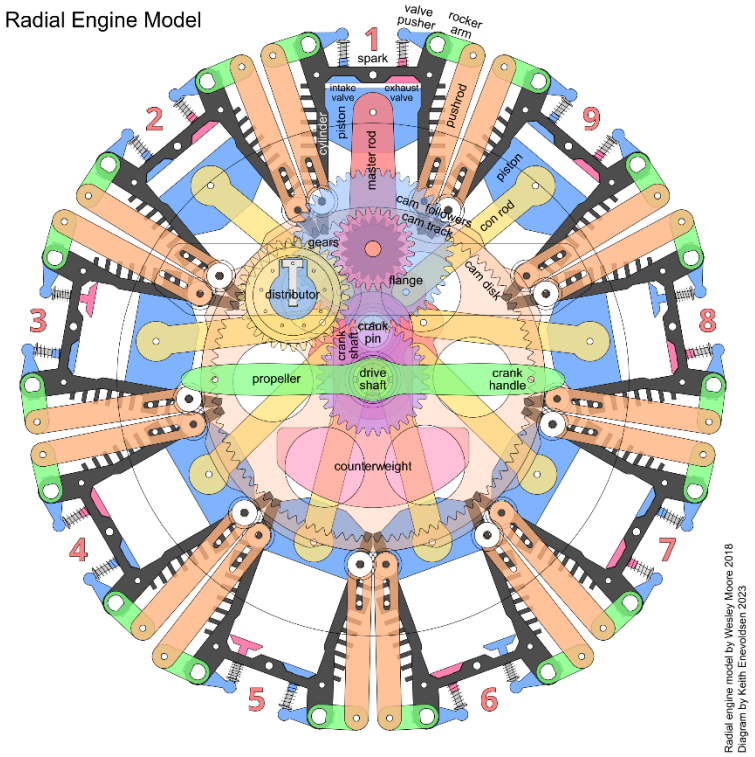

*Radial engine model, with parts labeled.*

The model has three systems, synchronized by gears:

| System | Description |
|---|---|
| **Power system** | The pistons move in and out within the cylinders. The pistons are connected by one master rod and eight con rods to the crankshaft, which is directly connected to the driveshaft and propeller. |
| **Valve system** | The intake and exhaust valves open and close. The valves are opened by valve pushers on rocker arms, which are connected by pushrods to cam follower wheels, which ride the cam tracks on the big cam disk. |
| **Spark system** | The spark plugs are flashing LEDs. A distributor with a rotor controls the sparks. The firing order is every alternate cylinder. |




*Radial engine model, back levels only (cylinder level).*




*Radial engine model, all mechanical parts. (Electrical wiring not shown.)*

## 3.3 Power system

**Observe the connections between the pistons and the propeller.** In a real radial engine, the driving force goes in this direction:

Combustion pushes piston → con rod → master rod flange → crankshaft → driveshaft → propeller.

In this model, the driving force goes in the opposite direction:

User turns propeller → driveshaft → crankshaft → master rod flange → con rod → piston.

**Observe how the pistons are connected to the crankshaft**. There are nine rods that connect the pistons to the central flange (collar) that fits around the crankpin on the crankshaft. Notice that one rod, the master rod, is rigidly connected to the flange, while the eight other con rods (connecting rods) can pivot where they connect to the flange. If all nine rods could pivot, the machine would not work well because it would be too wobbly.

## 3.4 Valve system

**Observe the intake and exhaust valves.** Observe that each cylinder has an intake valve (blue/cool) (on the left side of cylinder 1), and an exhaust valve (red/hot) (on the right side of cylinder 1).

**Observe how the cam disk makes the valves open and close.** The big cam disk has two cam tracks, each with four lobes (bumps). The cam followers (wheels) follow the cam tracks and each time they go over a cam lobe, they push on a pushrod, which pushes on a rocker arm, which pushes open a valve. The nine cam followers for the intake valves (blue) are on the intake cam track (front track) and the nine cam followers for the exhaust valves (red) are on the exhaust cam track (back track).

**Observe that it takes two full turns of the shaft to complete one engine cycle.** One full turn of the propeller and crankshaft corresponds to each piston moving in and out once. But, if you watch the pistons and the valves, you can see that *two* full turns of the crankshaft are needed to make *one* complete four-stroke engine cycle (intake, compression, power, exhaust).

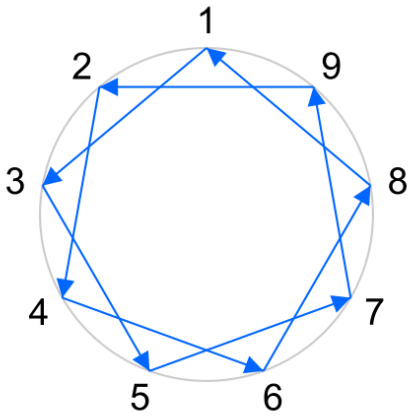
**Observe the valve timing.** Observe that the pistons and valves are synchronized as described in the four-stroke engine cycle diagram (above). (If valve timing is wrong, the maintainer should set the valve timing.)

## 3.5 Spark system

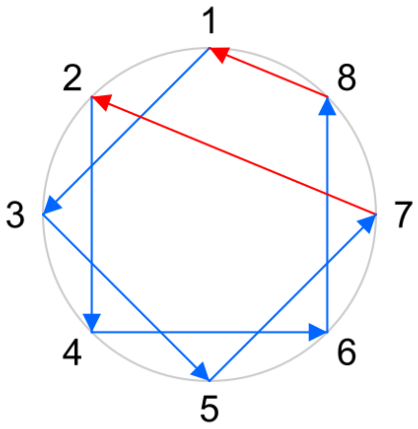
**Observe the distributor**. The distributor has a rotor and a circle of contacts that makes each spark plug (LED) flash at the correct time. One turn of the distributor rotor makes electrical contact with each of nine contacts in the distributor cap, firing each of the nine spark plugs once.

**Observe the spark timing.** Observe that the sparks are synchronized with the pistons and valves as described in the four-stroke engine cycle diagram (above). (If the spark timing is wrong, the maintainer should set the spark timing.)

**Observe the firing order.** Observe that the number of cylinders (nine) is an odd number and the spark plug firing order is every alternate cylinder: 1-3-5-7-9-2-4-6-8. Every four-stroke single-row radial engine has an odd number of cylinders, and the firing order is every alternate cylinder. There is a reason for this. In one four-stroke cycle, the piston goes in and out twice, but the spark fires only once. So, for each cylinder, the spark must fire on every alternate turn of the crankshaft. With an odd number of radial cylinders, firing every alternate cylinder, the firing of the cylinders has equal timing (see diagram). With an even number of radial cylinders, no firing order has equal timing (see diagram). Equal timing makes the engine run smoothly and it simplifies the design of the valve system and the spark system.

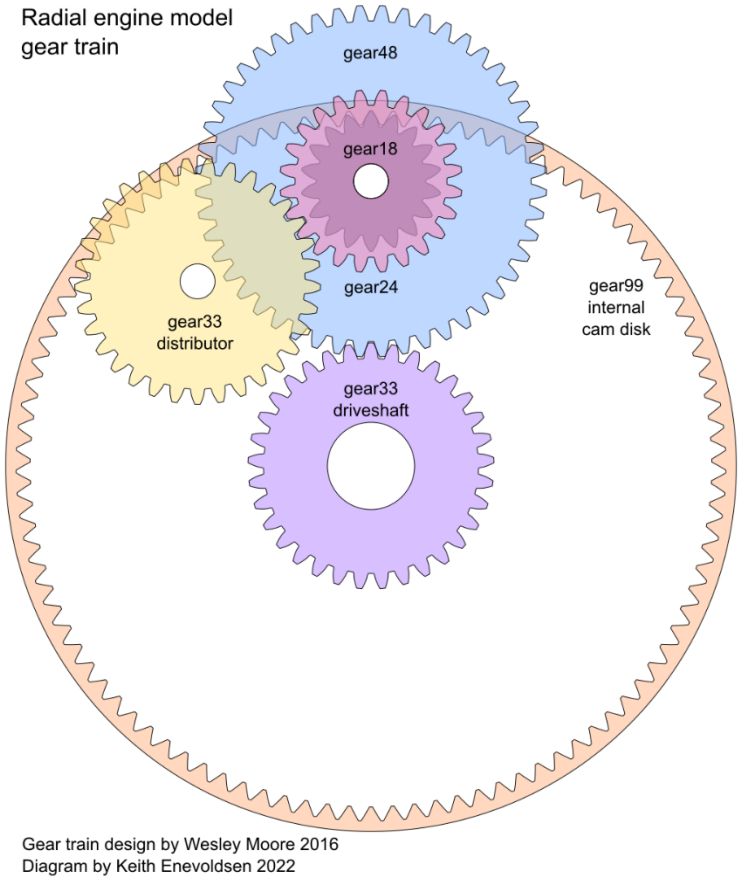



*Number of cylinders = 9 (odd).*
*Firing order: 1-3-5-7-9-2-4-6-8.*
*This has equal timing.*




*Number of cylinders = 8 (even).*
*Try this firing order: 1-3-5-7-2-4-6-8.*
*Interval 7-2 is long and 8-1 is short.*
*This has unequal timing.*

## 3.6 Gear train



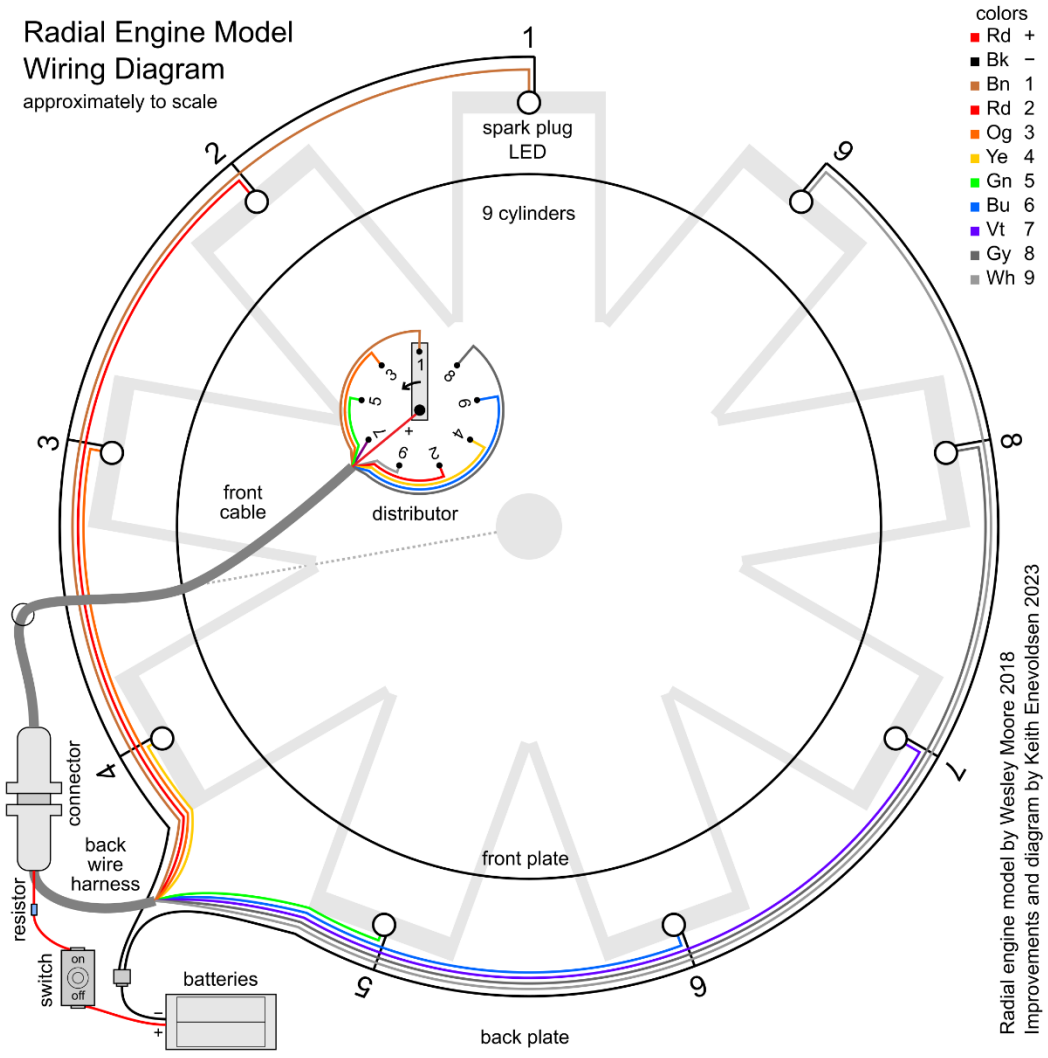

*Grear train.*

**Observe the entire gear train.** The gear train has six gears: gear18, gear24, gear33_driveshaft, gear33_distributor, gear48, and gear99_internal_cam_disk (the numbers indicate the number of teeth). There are two parts to the gear train: the cam disk gear train and the distributor gear train. You can count the gear teeth to calculate the rotation rates.

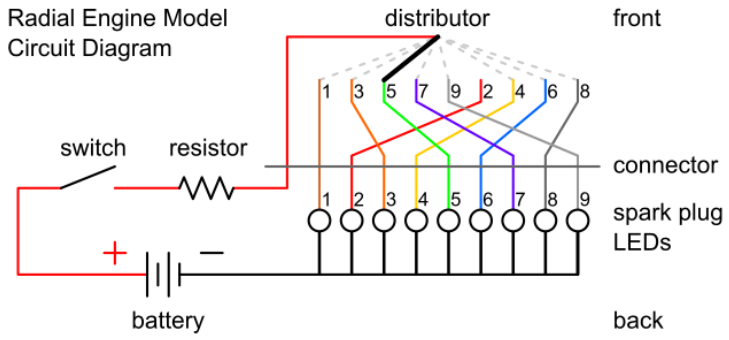
**Observe the cam disk gear train.** The cam disk causes the valves to open and close. When the propeller turns counterclockwise, the big cam disk turns clockwise. The cam disk gear train works like this: gear33_driveshaft meshes with gear48, which is on the same shaft as gear18, which meshes with gear99_internal_cam_disk. You can calculate that one full turn of the driveshaft corresponds to (33/48)×(18/99) = 1/8 turn of the cam disk. A complete four-stroke cycle corresponds to two turns of the crankshaft-driveshaft, which is 1/4 turn of the cam disk. So, the cam disk requires four intake cam lobes and four exhaust cam lobes, to open each intake valve once and each exhaust valve once, per four-stroke cycle.

**Observe the distributor gear train.** The distributor fires the spark plugs. When the propeller turns counterclockwise, the distributor rotor turns counterclockwise. The distributor gear train works like this: gear33_driveshaft meshes with gear48, which is on the same shaft as gear24, which meshes with gear33_distributor. You can calculate that one full turn of the driveshaft corresponds to (33/48)×(24/33) = 1/2 turn of the rotor. A complete four-stroke cycle corresponds to two turns of the crankshaft-driveshaft, which is one full turn of the rotor. So, the distributor fires each spark plug once per four-stroke cycle.

## 3.7 Wiring




*Wiring diagram.*




*Schematic circuit diagram.*

**Observe the wiring.** Trace the wires on the front and back of the model to see how the turning of the distributor rotor controls causes the spark plug LEDs to flash in the correct firing order: 1-3-5-7-9-2-4-6-8. Compare the wiring in the model to the wiring diagram and the schematic circuit diagram.

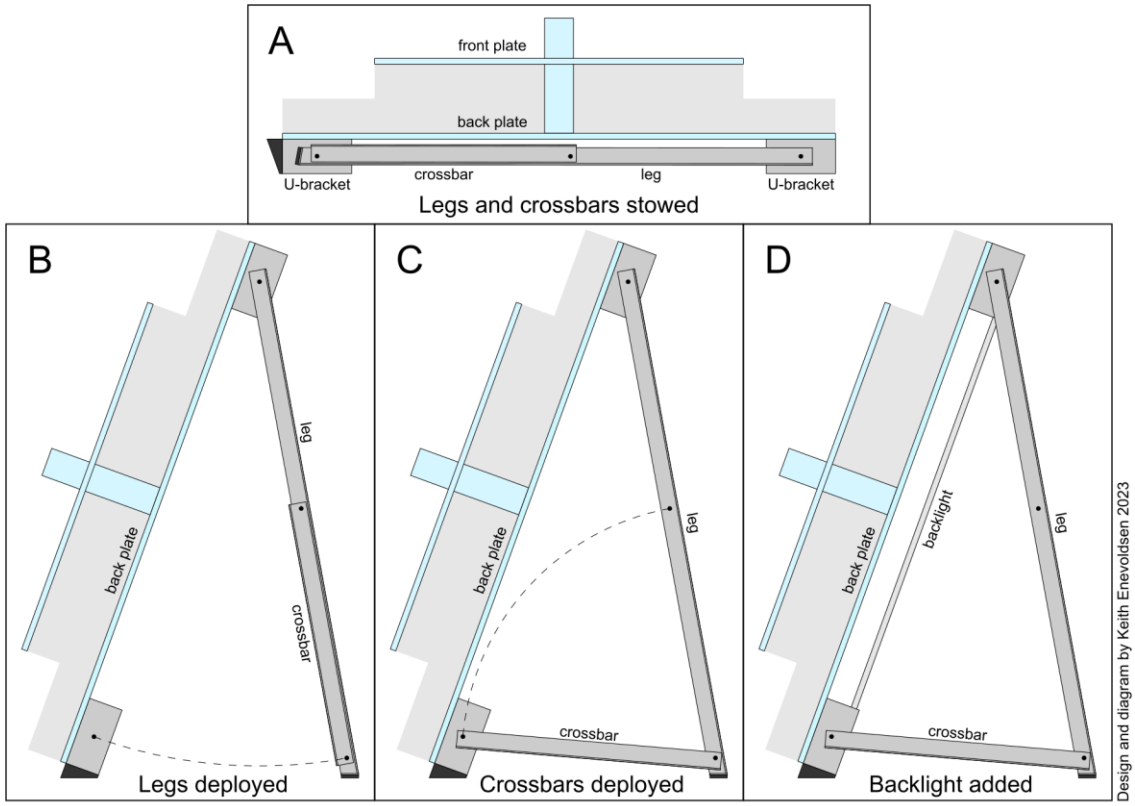
# 4 Stand and backlight

*Model on stand, without backlight.*

*Model on stand, with backlight.*

The model has a foldable stand. The model may be displayed with or without a backlight.

**WARNING: ELECTRICAL.** Take precautions with the backlight panel and power cord, as you would with any other appliance that is plugged into a (grounded) wall socket. Ensure that the custom-made electrical wiring connections are safely enclosed in an electrical box (on the back of the panel) and that the power cord is safely secured to the electrical box. (See the Maker Manual.)




*Setting up the stand.*

| Instructions: Setting up the stand | | |
|---|---|---|
| # | Step | Instructions |
| 1 | Unstow the legs. | Starting from the stowed configuration (figure A), detach each leg from the bottom bracket, keeping it attached to the top bracket. |
| 2 | Deploy the legs. | Hold the model upright while you unfold each leg toward the back, then let the model stand up by itself (figure B). |
| 3 | Unstow the crossbars. | Detach each crossbar from the middle of the leg, keeping it attached at the foot. |
| 4 | Deploy the crossbars. | Fold each crossbar down and attach it to the bottom bracket, making a sturdy A-frame (figure C). |
| 5 | Insert the backlight (optional). | Slide the LED backlight panel into the U-brackets that are attached behind the back plate of the model (figure D). The backlight panel should sit directly behind the transparent back plate, separated by a gap of about 1 inch. |

To stow the stand, reverse the steps.

# 5 Troubleshooting

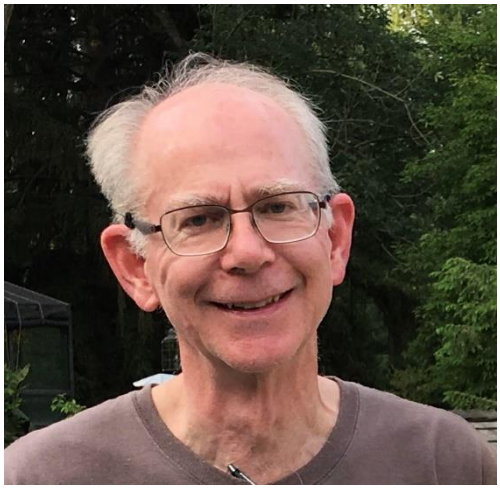
If you can see what is causing the problem, you (the user) may be able to fix it yourself. Here are some problems that you can fix yourself.

- Remember to turn the propeller COUNTERCLOCKWISE. If you turn the propeller clockwise, the four-stroke engine cycle will run backwards!
- If a part is stuck, you may be able to free that part simply by wiggling it.
- If a valve is not working because a cam follower wheel has derailed from the cam track, you can grasp the pushrod and put the cam follower wheel back on the track.
- If the LEDs are not flashing or dim, perhaps it just needs new batteries. Our model uses two 1.5V AA alkaline batteries.

If you cannot see how to easily fix the problem yourself, the person who maintains the model will need to fix it.

The Assembly Manual has a complete troubleshooting guide with instructions for fixing many problems, such as: incorrect spark timing, incorrect valve timing, gears skipping or jamming, pistons jamming, valves not opening or closing fully, cam followers derailing, loose screws, LEDs not flashing, and broken parts.

# 6 The model makers



*Wesley Moore (2016).*
*[Photo by Sandra Walker.]*

*Keith Enevoldsen (2023).*
*[Photo by Julie Enevoldsen.]*

Wesley F. Moore (1948-2021), retired Boeing engineer, designed and built the original radial engine model (model 1).

Keith Enevoldsen (1956-), retired Boeing software engineer, Wes's friend, renovated the model (model 2).