Radial Engine Model
The Story of Models 1 and 2

Radial engine model 1.
[Photo by Wesley Moore.]

Radial engine model 2.
[Photo by Keith Enevoldsen.]

Model by Wesley Moore, modified by Keith Enevoldsen.

Photos and diagrams of model 1 by Wesley Moore. Document and photos of model 2 by Keith Enevoldsen.

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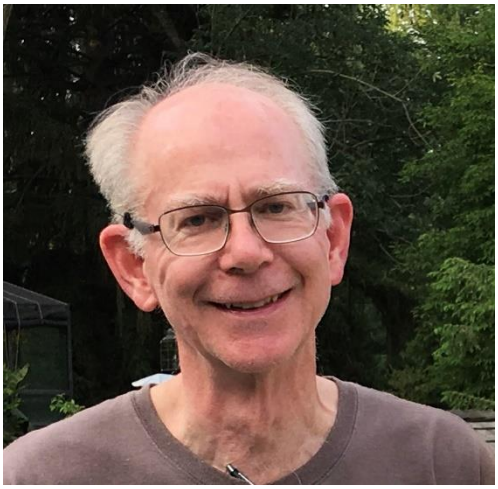
Wesley Moore’s original radial engine model 1

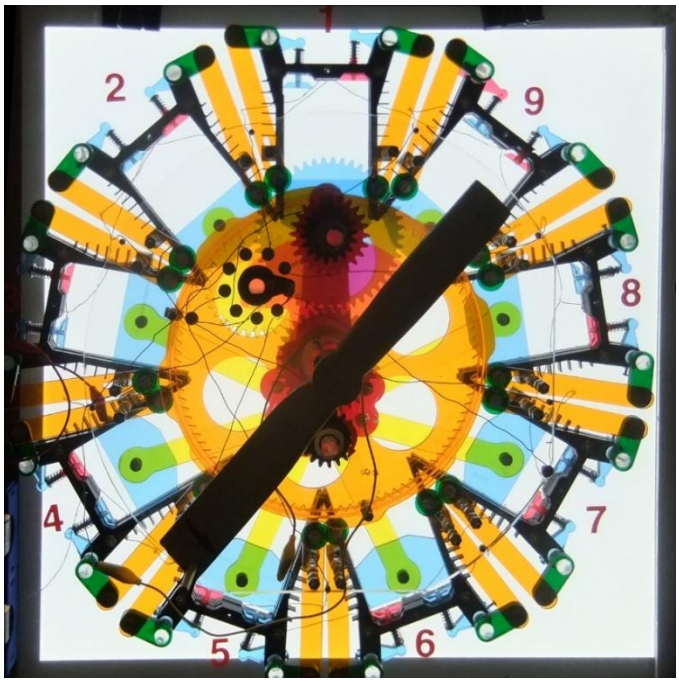


Wesley Moore (2016). [Photo by Sandra Walker.]

Wesley F. Moore (1948-2021), shortly after he retired in 2014, conceived of a transparent nine-cylinder airplane radial engine model, which he would design and build over the next few years. It was a perfect retirement project for Wes because of all his interests and skills.

Wes had an MS in Aeronautical Engineering (MIT). He had retired from a long career as an engineer at Boeing in the Seattle area. During his career, he used and developed 3D computer-aided design (CAD) software. Wes knew a lot about historical aircraft. He volunteered at the Museum of Flight. He was a member of the International Plastic Modelers’ Society. Years earlier, he had made injection-molded modification kits for model airplanes (under the name “Guano Aeroplane and Zeppelin Works”). Later, he made 3D-printed jewelry based on his own beautiful geometric equations (under the name “Ipso Factory”).

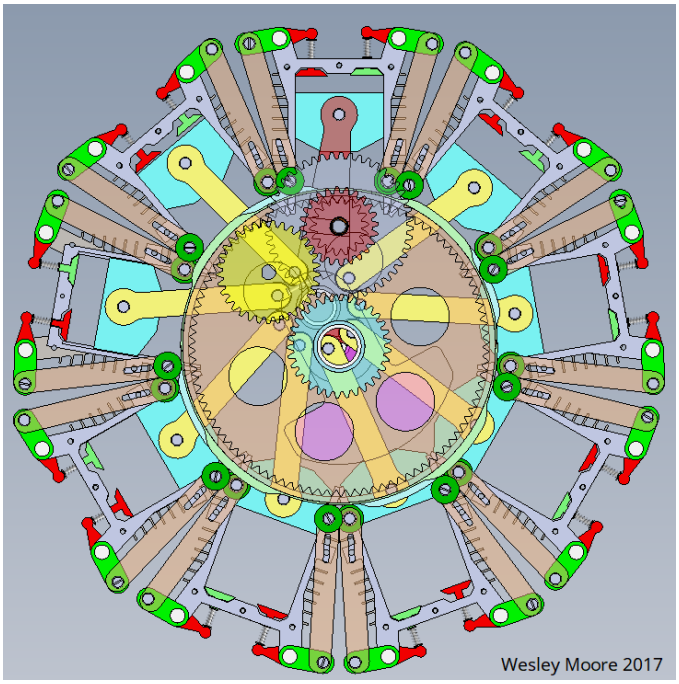
So, what could be a more suitable retirement project than designing and building a beautiful transparent plastic radial engine model? He would use 3D CAD software to design it and a laser cutter to make the parts. The machine would be low-tech, so both adults and children could see how every part works. Wes called it “the gadget”.



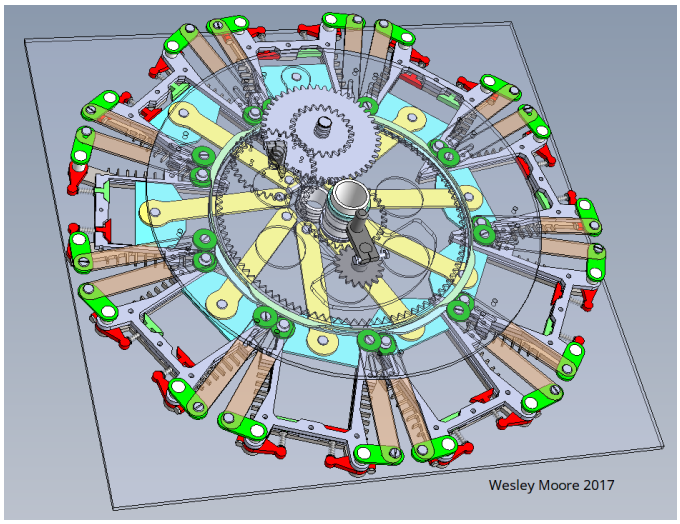
Wes's radial engine model 1. [Photo by Wesley Moore.]

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

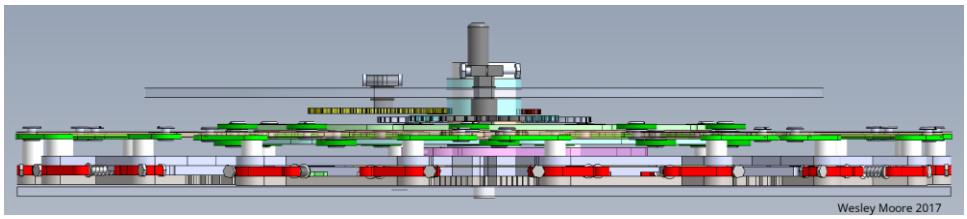
Radial engine model	
Key feature	**Description**
Airplane radial engine model	The 24"×24" model demonstrates the operation of an airplane four-stroke nine-cylinder radial engine. The power, valve, and spark systems are synchronized by gears.
Power system	The pistons move in and out within the cylinders. 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.



Radial engine model 1 design, front view.



Radial engine model 1 design, oblique view.



Radial engine model 1 design, side view.

Wes designed the model using SolidWorks, a 3D computer-aided design (CAD) tool. He refined the design through design-build iterations in 2016-2018.

Wes's radial engine model 1, with the mechanical parts, but not the electrical wiring.
[Photo by Wesley Moore.]

The 24"×24" physical model began to take shape during the design-build iterations in 2016-2018. Wes made 2D laser templates from his computer model, then laser cut the parts from colored transparent acrylic, using a laser cutter at Seattle Makers. For the earliest version of the model, Wes 3D-printed one part (the rocker arms / valve pushers), but his later versions of the model had no 3D-printed parts. Wes made other parts using hand tools. First, he made and assembled all the mechanical parts. Then, he added the electrical wiring and the spark plug LEDs.

Wes's first complete radial engine model 1, with the mechanical parts and the electrical wiring (2018). [Photo by Wesley Moore.]

In 2018, Wes completed the first fully working version of the model with all three systems: the power system (the crankshaft and pistons), the valve system (the cam disk and valves), and the spark system (the distributor and LEDs). The model was beautifully backlit with an LED panel light.

The model works like this: You manually turn the propeller with the crank handle (counterclockwise) to make the crankshaft turn. The crankshaft, via the con rods, makes the pistons go in and out. Gears turn the cam disk, which, via the pushrods and rocker arms, makes the intake and exhaust valves open and close. Gears turn the distributor rotor to make the spark plug LEDs flash in the correct firing order. The pistons, valves, and sparks are synchronized to demonstrate the four-stroke engine cycle.

Although the model worked in 2018, it did not yet run smoothly or reliably. For the next couple of years, Wes continued to tinker with the gadget, making small changes in the power system, the valve system, and the spark system. He did little things like adding shims here and there to make it run more reliably. Wes also continued to design bigger changes. In 2019-2020 he designed an alternative gear train with the distributor gear centered on the driveshaft (see the Design Alternatives document). He laser cut the new gears, but he never built this alternative version of the model.

Wes's Parkinson's disease prevented him from completing any major improvements after the 2018 version. Wes knew he wouldn't be able to complete the improvements all by himself. He had asked around to see if any younger modelers were willing to take on the project, but he did not find any takers at that time.

Wes passed away in 2021. The model was on his workbench, partly disassembled, but with all the parts necessary to reassemble it and make it go.

Model 1 on Wes's workbench (2022). [Photo by Keith Enevoldsen.]

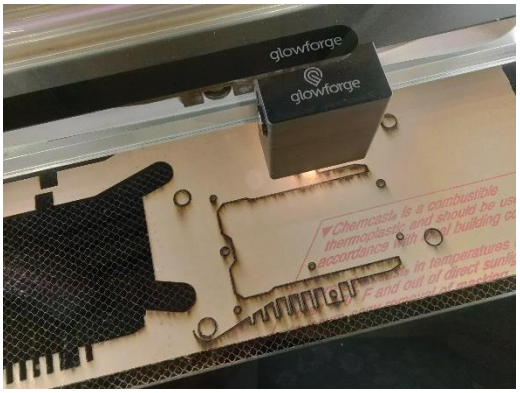
Keith Enevoldsen's renovated radial engine model 2

I'm Keith Enevoldsen (1956-), a friend of Wes. Wes and I first met when we worked together at Boeing in the 1980s. We worked on Boeing's TUBEND (tube-bend) project, a computer-aided design (CAD) application for hydraulic systems made with aluminum tubing. Wes and I shared interests and jokes, and we became good friends.

In 2018, Wes emailed a photo of his first working radial engine model to his friends, including me. Around that time, I bumped into Wes at the Museum of Flight, and he told me a little about the model he was working on. I thought it sounded like a fun retirement project for Wes. I didn't realize that a few years later it would also become my project.

In 2022, after Wes had passed away, Wes's wife, Sandra Walker, showed me the model, which was still on Wes's workbench. I was intrigued. I couldn't tell how well it worked until I re-assembled it. I decided it would be a fun retirement project for me to restore and possibly renovate the model.

I packed all the parts of the model and brought it to my house. I also copied Wes's computer design files, which included 3D SolidWorks designs of parts and assemblies and 2D laser templates for the parts. Then I started figuring out how everything was supposed to work. When I re-assembled Wes's model, I found that it worked, but not smoothly or reliably. It appeared to need both adjustments and modifications.



Laser cutting new parts.
[Photo by Keith Enevoldsen.]

Keith working with old model 1 and new model 2 (2023).
[Photo by Amelia Moore.]

In 2022, I started making fixes and improvements, one by one. I made many new parts that were slight modifications of Wes's parts. To make new laser-cut parts, I would first slightly modify the 2D laser template for a part, then I would laser cut the new parts from colored transparent acrylic using a home laser cutter (Glowforge). I made other new parts using hand tools. I engaged TAP Plastics in Seattle to cut and drill new front and back plates (Adam operated the drill press). No parts are 3D-printed.

By 2023, all three systems, the power system, the valve system, and the spark system, were working smoothly and reliably. I named Wes's original version "model 1" and my renovated version "model 2".

Radial engine model 2. [Photo by Keith Enevoldsen.]

I tried to keep my changes consistent with Wes's vision of a model that is functional, low-tech, transparent, and colorful. Model 2 looks almost the same as the original model 1, but you can see some differences. Model 2 has many functional improvements to make the model run smoothly and reliably, such as: deeper piston slots in the cylinder walls, grooved cam follower wheels, adjustable valve stem lengths, thicker gears, a middle plate between the front and back plates, spacer sleeves on the main screws, a distributor cap, and a foldable stand. Model 2 also has a few aesthetic improvements, such as: wiring routed around the periphery of the circle of cylinders, a colored transparent propeller, frosted LEDs with a wide viewing angle, and a dimmable backlight.

Keith Enevoldsen with the radial engine model 2 (2023). [Photo by Julie Enevoldsen.]

Wes's model 1 documentation was primarily his many 3D design files and 2D laser templates. He also had a few photos, a few pencil sketches, and a few spreadsheets, but no written documents. For model 2, I updated all the laser templates for the laser-cut parts, and I created printable paper templates for the hand-made parts. I also wrote several detailed documents, including the User Manual, Assembly Manual, and Maker Manual. I drew many diagrams and took many photos for the documents. The documents and templates are posted on my website at:

thinkzone.wlonk.com/Radial/RadialModel.html