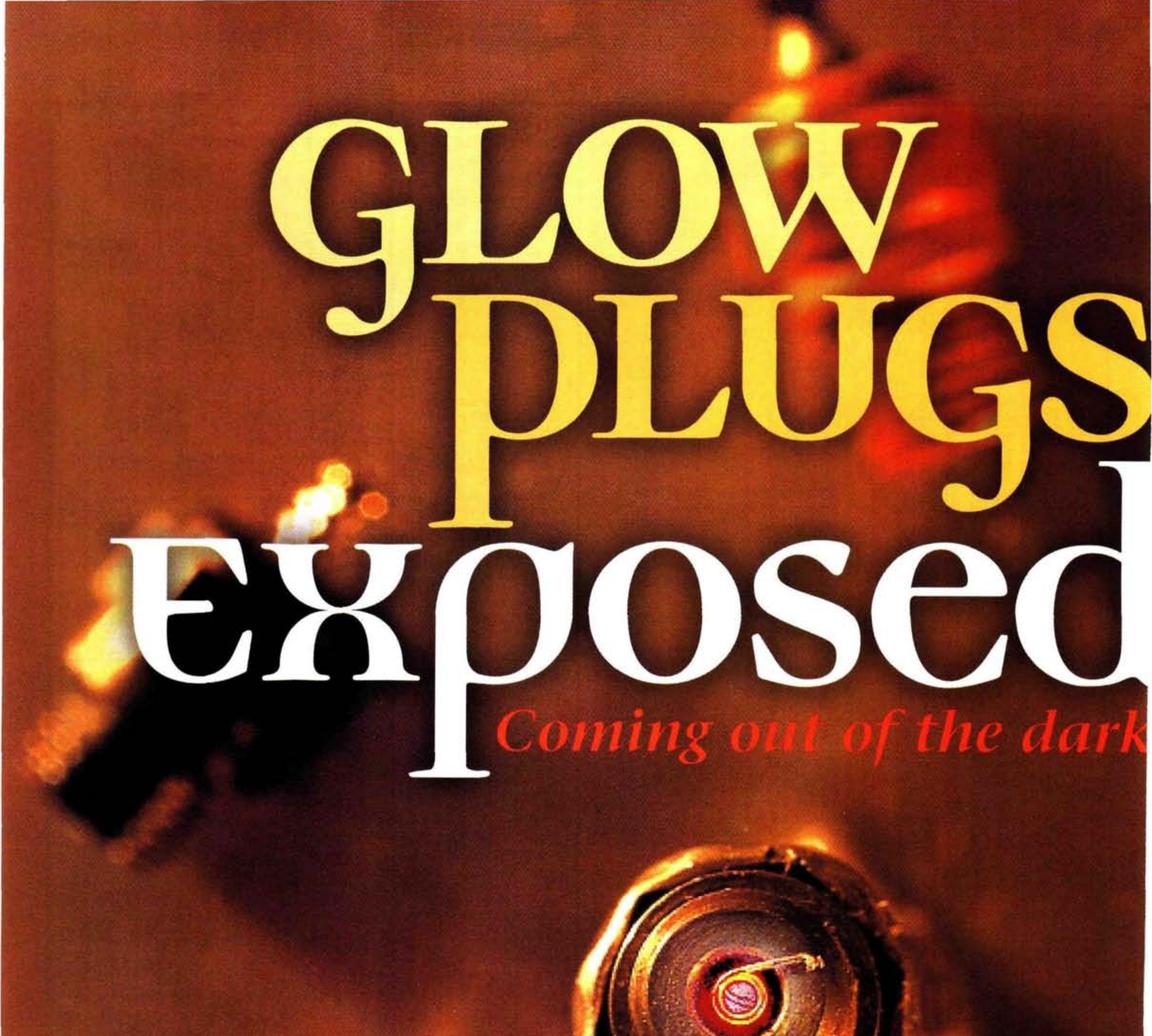


GLOW PLUGS exposed

Coming out of the dark

Shortly after the end of WW II, Ed Chamberlin was running a spark-ignition model-airplane engine on souped-up fuel he called "Liquid Dynamite." When he switched off the ignition, he got a surprise: the engine continued to run! After much head-scratching, a question emerged: was the combustion of Liquid Dynamite causing some part of the spark plug to glow red hot, igniting the next air/fuel charge? To test the theory, Chamberlin replaced the plug's center electrode with a coil of nichrome wire. When he passed low-voltage electricity through the coil, it glowed red. On the test stand, flipping the engine over by hand produced an immediate start, followed by normal high-speed operation—without the heavy, bulky and complicated spark-ignition accessories. Was it time for modelers to throw away their ignition coil, condenser, breaker points and onboard batteries? Not yet. Several years of intensive development remained before the glow plug emerged as the ignition system of choice.

BY C. DAVID GIERKE

With the advantage of 20-20 hindsight, I suggest that the glow plug is the most important invention associated with the 70-year production history of the model-airplane engine. In its present form, the glow plug has been produced for more than half a century. Although glow plugs are diminutive and simple in appearance, the science behind their design is surprisingly complex. Numerous magazine articles have been written about glow plugs over the years by authorities such as Nathan Gordon (1940s), Walton Hughes (1950s), Ted Martin (1950s), Bill Netzeband (1960s), Peter Chinn (1960s to '80s) and Clarence Lee (1960s to present); nevertheless, controversy and uncertainty continue concerning how to select and operate them.

As engine tuners, we are required to understand a bit of science and technology associated with the glow plug, along with an ability to observe, listen and analyze how it affects engine operation. Before addressing these issues, let's investigate two glow-plug dilemmas: does your engine need a short- or long-reach glow plug, and will an idle-bar glow plug improve performance?

SHORT- VS. LONG-REACH GLOW PLUGS

Short-reach plugs are intended for smaller engines with thin heads. If you use a long-reach plug in a short-reach head, it would encroach on the combustion chamber. In the days of baffle-top pistons and wedge heads, the plug might contact the piston at top dead center (TDC). With modern flat-top pistons and hemispherical combustion chambers, the extended plug would merely increase the engine's compression ratio and possibly cause pre-ignition due to hot-spot formations on the exposed threads. Conversely, if you use a short plug in a thick, long-reach head, you'll reduce the engine's compression ratio and, possibly, its power. The engine's instruction manual almost always stipulates which plug is required. If in doubt, remove the cylinder head and check how far the plug projects. The bottom of the plug should be flush with the top of the combustion chamber. If you're using an idle-bar plug, no more than the bar should extend into the chamber. If any threads show, change to a short-reach plug. Keep in mind that short-reach plugs can easily strip the threads in the aluminum alloy head, so tighten them carefully! Long-reach plugs are less likely to strip the threads, but they still have the potential to do so. Other than depth of the thread, there is no other significance to a glow plug's reach. Short-reach plugs are generally used in engines of .15ci displacement or less.

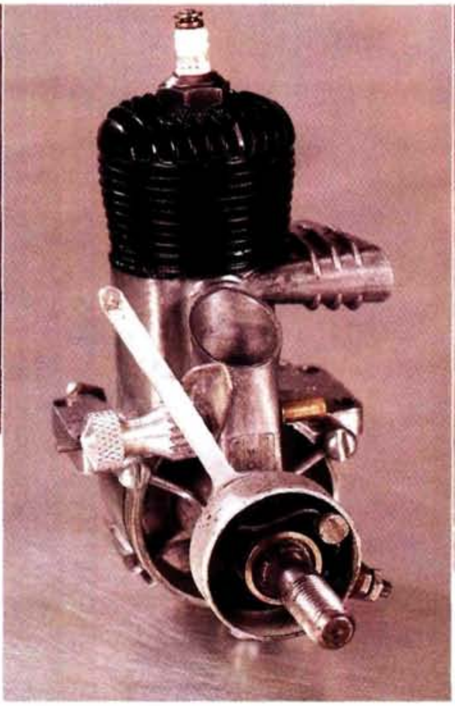
IDLE-BAR GLOW PLUGS

Idle-bar glow plugs are intended for use with engines that are equipped with throttles. While idling, 2-stroke engines have a tendency to form a pool of liquid fuel in the crankcase; this is called "loading." When the throttle is snapped open, the puddled fuel rushes through the cylinder transfer ports, impinging on the wire element of an unshielded plug and instantly quenching it. In theory, the idle bar is designed to deflect the stream of liquid fuel away from the plug's element. If your engine experiences a rich, erratic idle and/or a rich "flameout" during transition to wide-open throttle (WOT), try an idle-bar plug. If an engine doesn't need to be throttled (e.g., in certain racing events), it doesn't need an idle-bar plug. Idle bars protrude into the combustion chamber, disrupting normal flame propagation and potentially causing pre-ignition. Pre-ignition, a combustion defect, can originate from hot spots that form on the edges and corners of the idle bar and cause the air/fuel mixture to ignite earlier than intended. (See sidebar, "The idle-bar glow plug: treating the effect.")

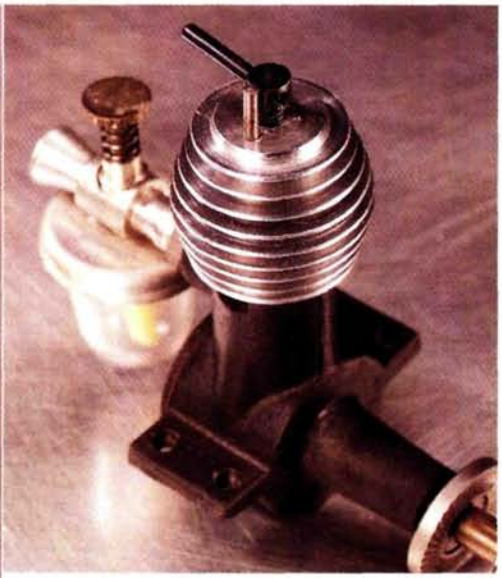
TEMPERATURE RATING AND SELECTION

That's it for the preliminaries. Glow-plug temperature rating and selection are more complicated and more difficult—but not impossible—to understand and to master. As I see it, there are six parts to the question:

With the cylinder head removed from the engine, the long-reach standard glow plug should be flush with the upper surface of the combustion chamber (as shown).



With the drive washer, prop washer and shaft nut removed from this antique Ohlsson & Rice .23 spark-ignition engine, you can see the interior of the ignition-timer mechanism. By the mechanical action of a cam that's machined onto the crankshaft inside the timer housing, a movable electrical contact opens and closes against a stationary contact. By moving the timer lever that's attached to the timer housing, the engine's ignition point (spark) may be advanced (lever moved up) or retarded (lever moved down) in relation to TDC.



Turning the compression adjustment lever clockwise (as viewed from the top) increases this model diesel engine's compression ratio; turning it counterclockwise lowers the compression.

1. How does the glow-plug engine ignite fuel?

Crankcase-scavenged 2-stroke glow engines have relatively low compression ratios, averaging between 7:1 and 9:1 with an alcohol (methanol)-dominated fuel blend. Methanol's ignition temperature (725 degrees F) cannot be reached by the engine's compression alone; something else is needed to attain this temperature. Note: the maximum possible temperatures at compression ratios of 7:1, 8:1 and 9:1 are: 692, 755 and 815 degrees F, respectively; because there are losses associated with compression leakage and heat transfer to the cylinder wall and head (plus other factors), these theoretical temperatures are never realized. Here's where the glow plug comes into play. For engine startup, electric current is passed through the plug's coiled-wire element, causing it to incandesce (glow) orange-white, producing a temperature in excess of 1,500 degrees F. When the engine is cranked over by hand or with an electric starter, the air/fuel mixture ignites in the combustion chamber. If the mixture ratio is within the range of combustibility, the engine will continue to fire, becoming self-sustaining. When the starting battery is removed, the plug element continues to glow and the engine continues to run.

2. How do glow plugs work?

Glow-plug ignition of the air/fuel mixture is controlled by three factors: combustion, catalytic action and compression. Combining the first two factors produces an element temperature that's high enough to ignite the engine's compressed air/fuel mixture, providing sustained (cycle-to-cycle) operation.

Heating the coil via combustion causes the glow-plug element's temperature to soar to over 1,500 degrees F. Although it cools rapidly, a significant portion of this temperature is carried over to the next cycle.

When alcohol vapor interacts with platinum (silver-white metal), an exothermic (heat-release) reaction takes place. Acting as a catalyst, platinum is not physically changed by the reaction, but its temperature increases. Therefore, the platinum-alloy wire element experiences a further increase in temperature as the vaporized air/fuel mixture is transferred into the cylinder and during compression. (Note: due to platinum's brittle state at high temperatures, a platinum-iridium or platinum-rhodium alloy is used to improve element longevity.)

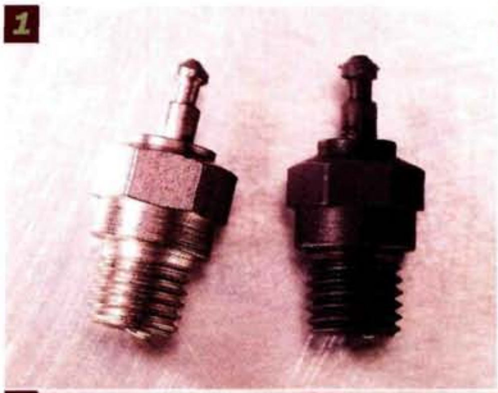
Although the glow engine's compression process cannot raise the temperature of the plug's wire element to the ignition point for methanol-based fuel, it still has an important role to play. By compressing the gaseous air/fuel mixture, its internal energy (heat) is increased; heating speeds up the motion of reactive molecules and produces something we call "compression condition-

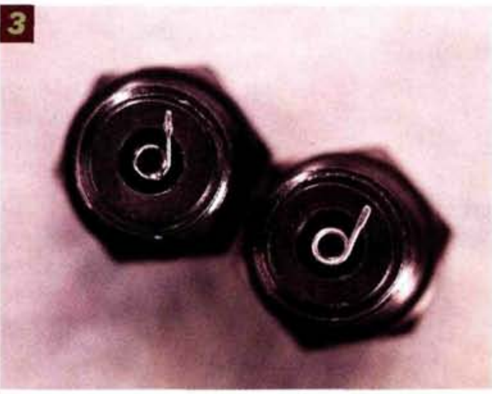
ing." The thermal theory for ignition suggests that burning starts only when the gaseous mixture becomes hot enough, and the molecules collide often enough. Some of these collisions result in an ignition reaction at the glow-plug element.

3. Why do we need glow plugs with different temperature ratings?

Some call the glow-plug engine a fixed-ignition-point design, but nothing could be further from the truth.Unfortunately, this myth confuses the glow-plug temperature-rating issue; sweep it from your mind.

Spark-ignition engines control ignition-point timing with a mechanical or electronic advance-and-retard system. Crankcase-scavenged model diesel engines control ignition timing by mechanically adjusting the compression ratio through a movable head known as a "contra-piston." Although adjusting the glow engine's ignition-point timing isn't as obvious, it happens regularly by changing variables such as the propeller load, nitromethane content, lubricating oil content, compression ratio and glow-plug temperature rating. The engine's mechanical condition, and even weather conditions, play a role. We adjust an engine's ignition point to attain the optimum peak-pressure point ("sweet spot") after TDC that ultimately produces the best engine performance and longevity. Changing glow plugs within the "hot to cold" range is often the first adjustment made to an engine's ignition point.





***1.** This is the Merlin glow plug type 2001; it features a nickel-plated plug body and a cold rating. The type 2005 has black-oxide plating and a hot rating. Merlin offers several other plugs with temperature ratings ranging from very cold to very hot. **2.** The nickel-plated Fox Standard long plug is rated medium. The nickel-plated Pro Series no. 8 is rated cold. The no. 8 plug has the smaller cavity diameter. Fox, a longtime manufacturer of glow plugs, has many other reaches and temperature ratings that include: Std. Long (hot); Std. Short (medium); and Std. Short (hot). **3.** The black-oxide-plated Novarossi C4-S plug is rated hot. The black-oxide-plated C8-S is rated very cold. The only discernible difference between the two is the diameters of their wire elements; the C8-S's element is thicker. Novarossi also offers a C5-S (cold), C6-S (cold) and a C7-S (very cold). **4.** The nickel-plated O.S. A3 plug is rated hot; the nickel-plated no. 8 is rated cold, and the black-oxide-plated R5 is rated very cold. O.S. also offers an A5 plug that is rated medium. **5.** The nickel-plated Enya no. 3 plug is rated hot; the nickel-plated no. 6 plug is rated cold. Notice the thicker wire element in the no. 6 plug. Enya also offers a no. 4 plug that is rated hot and a no. 5 that is rated medium.*

4. How does a glow plug's temperature rating change the engine's ignition point?

"Heat range" isn't the best term to describe what transpires within the glow plug. Outside the world of science and technology, words such as "heat" and "temperature" are often used interchangeably; unfortunately, however, they don't have the same meaning. Without belaboring the point, I'll just say that I prefer to use the term "temperature rating," which is more scientifically correct for describing how the glow plug advances or retards an engine's ignition-point timing. As long as you understand that the traditional words "hot" and "cold" actually refer to temperature, you can call the phenomenon anything you wish! There are times when "hot" and "cold" are less clumsy to use.

Example: assume that a "hot" (high-temperature-rated) glow plug has replaced a "cold" (low-temperature-rated) plug. How does this affect the engine's ignition-point timing? The ignition point advances; that is, it occurs earlier in the compression event. Why does this happen? During normal engine operation (with the starting battery removed), the "hot" plug's higher element temperature allows the compressing air/fuel mixture to arrive at its ignition temperature before that of the "cold" plug. Recall that plug-element temperature is the result of combustion temperature and catalytic action temperature, with compres-

SPECIAL GLOW PLUGS

Nelson plugs. In the late '70s, control-line speed flier Carl Dodge modified a GloBee plug into the first two-piece chamfer-nose (angled) design. Although the new design produced superior engine performance compared with conventional 1/4-32 plugs, the reason for this increase remains unclear. The problem with the 1/4-32 plug seems to be associated with its screw threads being exposed to high-pressure combustion gases, all the way to the sealing washer. Dodge's two-piece plug differs from the conventional glow plug in terms of fastening and combustion-gas-sealing methods; when the threaded retainer sleeve is screwed tightly into place, the chamfered nose of the element body matches a similar surface within the head, producing a sealed and seamless transition with the combustion chamber.

In the early '80s, Henry Nelson was the first to offer a one-piece plug that incorporated a chamfered nose to match an angled seat within the head, as with Dodge's design. As before, the gas seal occurs before the fastening threads. Today, these chamfer-nose units have 11/32-32 threads and are known to airplane-racing enthusiasts as "Nelson plugs" and to RC car modelers as "turbo plugs." In conjunction with Ohlsson, the assembler, Nelson also produces a version of the original GloBee two-piece plug for various speed and racing competition events.

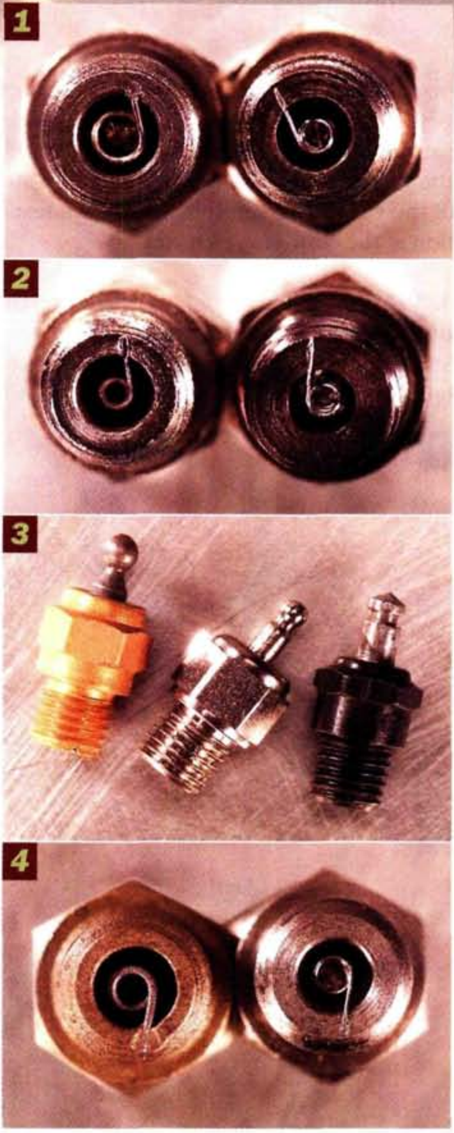
Above, left to right: Nelson's two-piece, GloBee-type, chamfered-nose plug closely resembles the original Carl Dodge innovation of the late 1970s; it's available in STD (standard), heavy STD and with a heavy (cold) coil. The one-piece, chamfered-nose Nelson plug is the granddaddy of all "turbo" plugs; the STD is rated medium. Henry Nelson also makes an HD (heavy duty) that's rated cold. The nickel-plated plug with the relatively small nose chamfer is the O.S. P6 "turbo" (hot). O.S. also makes a P7 (medium) and a P8 (cold). The black-oxide-plated plug is a Novarossi "Turbo Ultra" (C8TGF) that's rated very cold. Novarossi also makes a C7TGF (cold) and a C6TGF (medium).

4-stroke plugs. Four-stroke cycle engines are required to retain their plug-element temperatures throughout the exhaust and intake strokes before entering the compression event and the next ignition point. To accomplish this, 4-stroke plugs must have a very high temperature rating. In 1977, O.S. was the first to successfully incorporate a glow plug (type F) into a mass-produced 4-stroke cycle engine: the revolutionary FS-60 single-cylinder design.

Most 4-stroke glow plugs are characterized by an extended nose projecting into the combustion chamber.

Because of their location, the nose and wire element are exposed to higher temperatures than a standard plug, extending their useful temperature to the next ignition point.

Special glow plugs for 4-stroke engines (left to right): the O.S.-F plug is the granddaddy of all 4-stroke glow plugs and the originator of the extended-nose concept of temperature retention; the Merlin "Hosenose" plug incorporates interesting internal cavity dimensions and element design; Enya's latest entry features traditional technology.



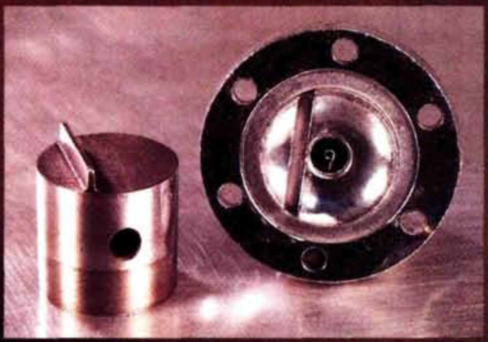
1. The number of coils within the plug cavity represents the total length of the element wire. Note the single coil (left) compared with the multiple-coil element. 2. The size of the element cavity affects the plug's rating. The small cavity (black-oxide plug) helps reduce the temperature rating; the large cavity (nickel-plated) helps increase the temperature rating. 3. The type of plating used for the plug body helps control the temperature of the element wire. Nickel plating reflects heat (infrared radiation), and that helps retain the element's temperature. Black-oxide plating absorbs heat, so it helps reduce the element's temperature. The qualities of Rossi's copper-plated R.A. (cold) plug fall somewhere between those of nickel-plated and black-oxide-plated plugs. 4. The diameter of the plug's wire element helps to determine its temperature rating. Smaller-diameter wires tend to increase the element's temperature, and larger-diameter wires tend to reduce its temperature. Larger-diameter wire is more durable than small-diameter wire—an important glow-plug design factor when you use fuel that has a high nitromethane content in high-performance engines.

sion conditioning of the air/fuel mixture acting to initiate combustion. The opposite happens when a "cold" plug replaces a "hot" plug; the lower temperature of its wire element requires more compression conditioning of the air/fuel molecules to reach its ignition temperature. This takes place closer to TDC and therefore acts to retard ignition-point timing.

With dozens of glow-plug brands available on the world market—each offering a range of temperatures—incremental changes to the engine's ignition-point timing can, theoretically, be made. Later, we will investigate the promise and the reality of "sweet spot" engine tuning by glow-plug temperature rating.

THE IDLE-BAR GLOW PLUG: TREATING THE EFFECT

Early cross-scavenged 2-stroke engines were equipped with piston baffles that deflected fresh air/fuel mixture toward the glow plugs, making them susceptible to element quenching during idle and throttle-up. The common boost-transfer-port variation of the modern Schnuerle-ported engine often exhibits this same problem.



Older (cross-scavenged) engines were susceptible to plug quenching during idle and throttle-up, due to transferred air/fuel mixture being directed toward the wire element by the piston baffle.

The idle-bar plug is a stopgap measure that treats the effect rather than the cause of element quenching. Plug-element quenching results from poor mixture control during throttle-down/throttle-up and idling, in addition to the engine's inability to keep fuel vaporized in the crankcase. Simple model airplane engine carburetors are not up to the task of maintaining the correct air/fuel ratio throughout its range of throttlability. Complex automotive-type carbs couldn't do it; that's why the auto industry moved to fuel injection when solid-state electronic technology became available.

An important—and often overlooked—factor concerns fuel vaporization in the crankcase. Vaporized fuel mixed with available air is in the best possible physical state (a gas) in preparation for combustion. If all the fuel is vaporized, crankcase "loading" and plug-element quenching would not occur. Unfortunately, methyl alcohol requires a lot of heat to change from a liquid state to a gaseous state, so the engine's crankcase quickly cools and thus limits the fuel-vaporization process while forming a pool of liquid fuel. One solution to this dilemma is to heat the crankcase, but this severely reduces the engine's ability to transfer a dense mixture charge into the cylinder. Although inconsequential at partial throttle, wide-open-throttle performance suffers greatly, with a 20- to 25-percent reduction in brake horsepower. Someone should invent a crankcase heater that works only when the engine is throttled, so we could throw away the inefficient idle-bar glow plug! While we're waiting, avoid directing cool air over the crankcase (below the cylinder fins) of your cowled 2-stroke engine; this promotes crankcase loading.

Above: this Super Tigre fuel-metering (twin-needle valve) carburetor illustrates a major technical advance in controlling the engine's air/fuel mixture during idle and throttle-up during the 1960s. Despite improvements in carburetion, crankcase-loading and plug-element-quenching continue to plague RC engines. Left: modern engines use Schnuerle transfer ports (usually two) and a third boost port. The boost port is usually angled toward the head causing plug-quenching problems during idle and throttle-up, similar to the baffle-piston configuration.

5. How do manufacturers make glow plugs "hot" or "cold"?

A plug's temperature rating depends on many factors, including:

- Element alloy specifications: platinum iridium or platinum rhodium; alloy percentages.
- Element dimensions: wire-gauge size, length, coil diameter, number of coils.
- Plug cavity and geometry (e.g., diameter and depth).
- Position of element in cavity.
- Plug body finish: reflective or absorbing.

The platinum-alloy element is usually the focus of attention when enthusiasts discuss a plug's temperature rating. The conversation often goes something like this: "This plug has a thick wire element, and it doesn't have many coils, either; it's a cold plug." This is likely, but many other factors contribute to a plug's temperature rating. My friend Clarence Lee once wrote:

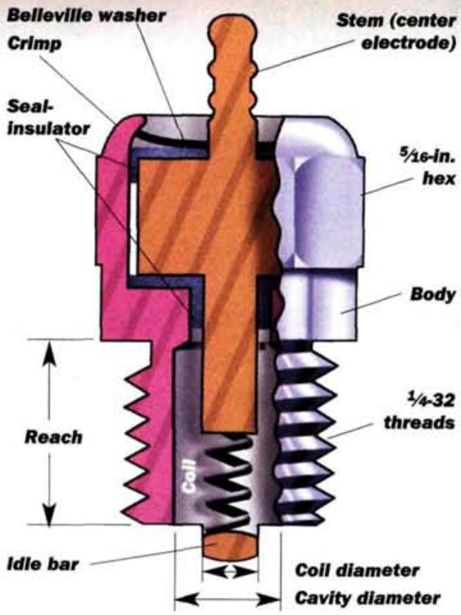
"As simple ... as the glow plug appears to be, it is actually more complicated than you might believe. You can't just stick a piece of platinum wire in the machined body and expect it to work. I had a hand in the development of the old Veco glow plug and can speak with some authority on this. You can completely change the characteristics [temperature rating] of a glow plug by using either a black-oxide or nickel-plate finish. With all of these variables, just think of all the possible combinations you can come up with for experimentation."

The difficult part of glow-plug design comes with assigning a value to each variable; things change when the variables interact! By modifying the plug's finish, how much will its temperature rating change? What about the length of the element wire in relation to the diameter of the element cavity? How about the thickness of the element wire compared with the number of coils, etc., etc.? Although no single factor determines a glow plug's temperature rating, some generalizations can be made:

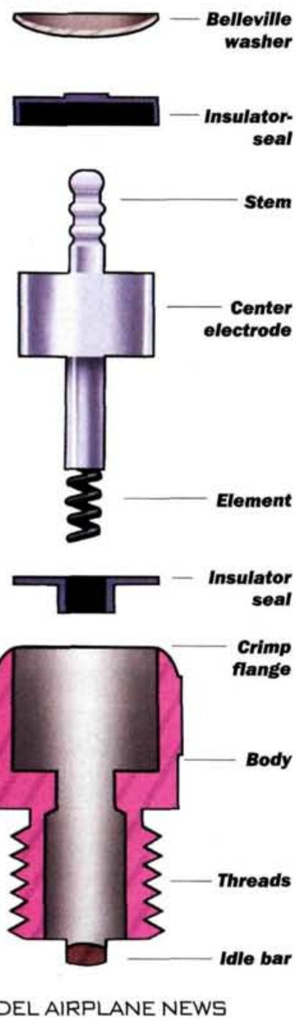
- A small-gauge element wire tends to raise the plug's temperature rating.
- A small-diameter plug cavity tends to lower the plug's temperature rating.
- A reflective finish (nickel plating) within the plug cavity raises the temperature rating.
- An absorbing finish (black oxide) within the plug cavity lowers the temperature rating.
- Extending the element coil beyond the plug body elevates the temperature rating.
- Pushing the element into the plug cavity lowers the temperature rating.

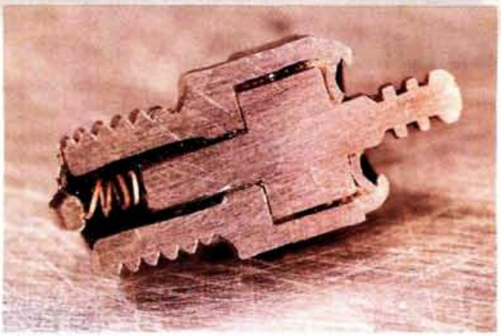
GLOW PLUGS EXPOSED

GLOW-PLUG CUTAWAY

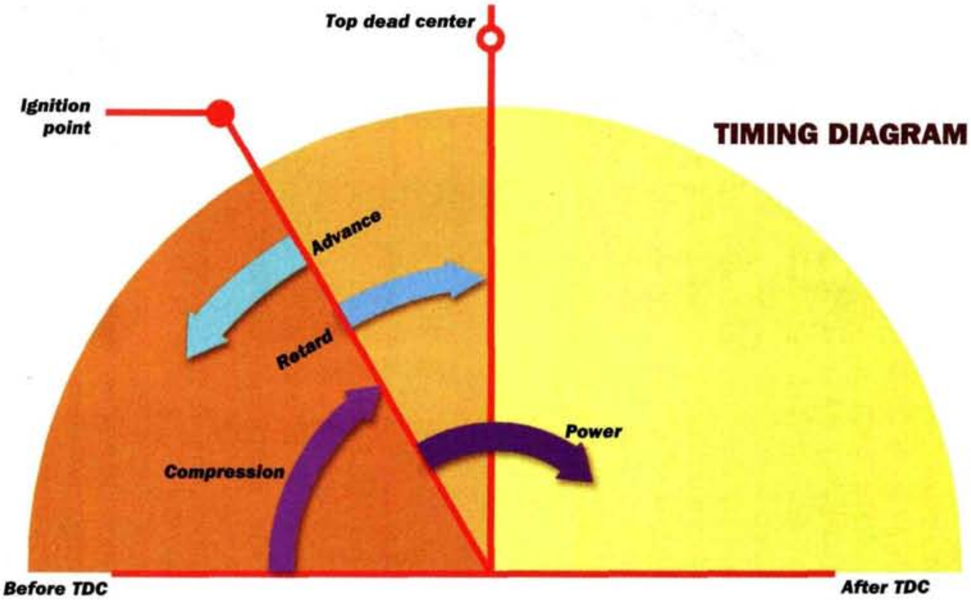


GLOW PLUG EXPLODED-PARTS VIEWS





Left: typical glow-plug cross-section. Plugs' designs, materials and fabrication techniques vary with their producers.



Thermodynamics research engineer Frank Vassallo says, "There are some very complex interactions taking place inside a glow plug." I think you get the picture. At the risk of offending glow-plug designers and manufacturers, there are no glow-plug experts. Glow plugs represent a form of black art, where empirical knowledge (trial and error) reigns supreme. In the end, determining the engine's ignition point in relation to TDC is probably the best method of evaluating a glow plug's relative temperature rating; more about this in part two.

There are other design considerations besides the glow plug's temperature rating. The physical dimensions of the wire element determine the voltage that must be applied to the plug to achieve white-orange incandescence for engine startup. There are also issues of element attachment, electrical insulation, center electrode retention and high-pressure gas sealing.

Next time, I'll discuss question 6: how to select a glow-plug temperature rating for your engine. I'll also describe how to "read" a glow plug, give solutions to common problems, and more. We're just getting started! Now, how many of you would have thought that a tiny glow plug could be so complex? See you next month. ✈

Enya; *distributed by MRC (732) 225-2100; modelrectifier.com.*

Merlin *(708) 246-3730; merlinglowplugs.com.*

Nelson Competition Engines *(412) 538-5282.*

Novarossi; *distributed exclusively by Trinity Products Inc. (732) 635-1600; novarossi.com.*

O.S.; *distributed by Great Planes Model Distributors (217) 398-6300; (800) 682-8948; osengines.com.*

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