How Mags Work… and Fail

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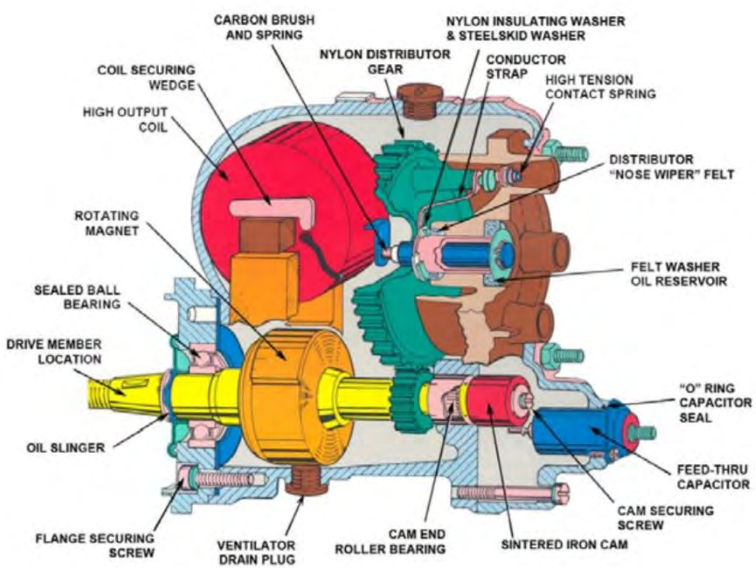

Mo 1000 #7	The EGT Myth
Mo 1300 #7	How Healthy Is Your Engine?
Tu 0830 #7	To TBO and Beyond…
Tu 1000 #7	Leaning The Right Way
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Fr 1000 #7	Where Fuel Meets Air
Fr 1300 #7	Benefits of Running Oversquare
Sa 1000 #7	**How Mags Work…and Fail**
Sa 1300 #7	**Predictive Maintenance**

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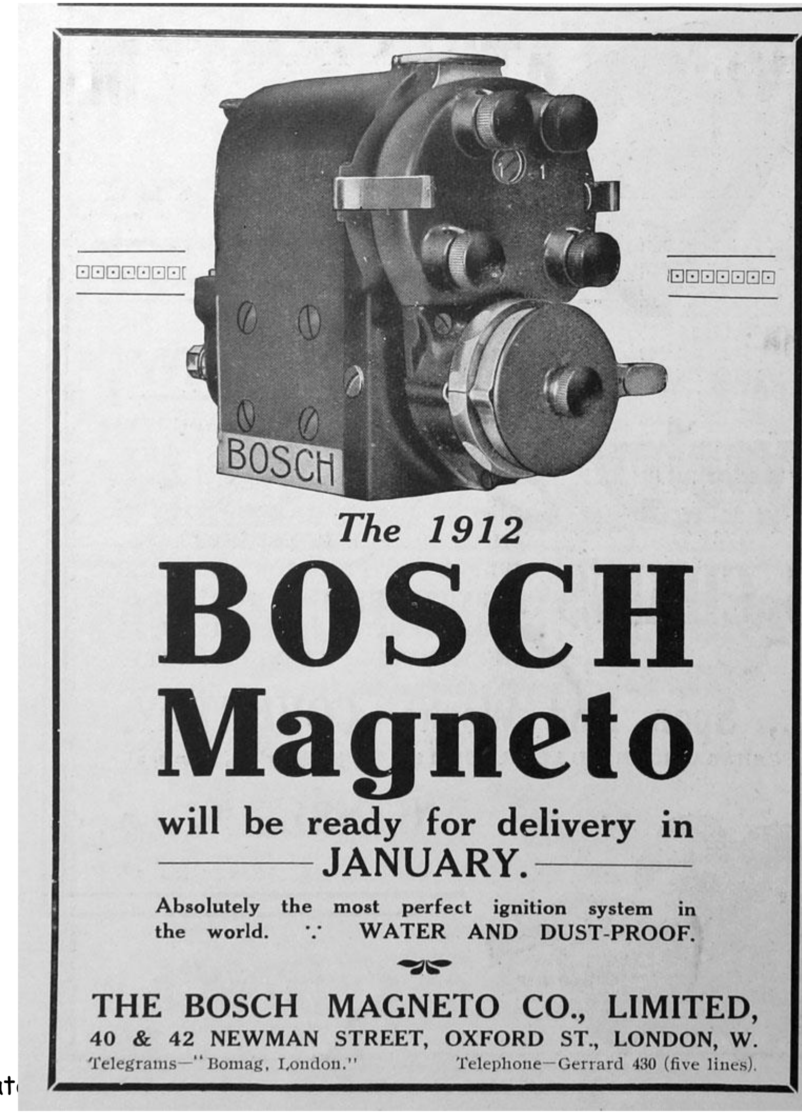
My airplane's piston engines utilize a magneto ignition system

If you're flying a certificated airplane, chances are good that yours does, too

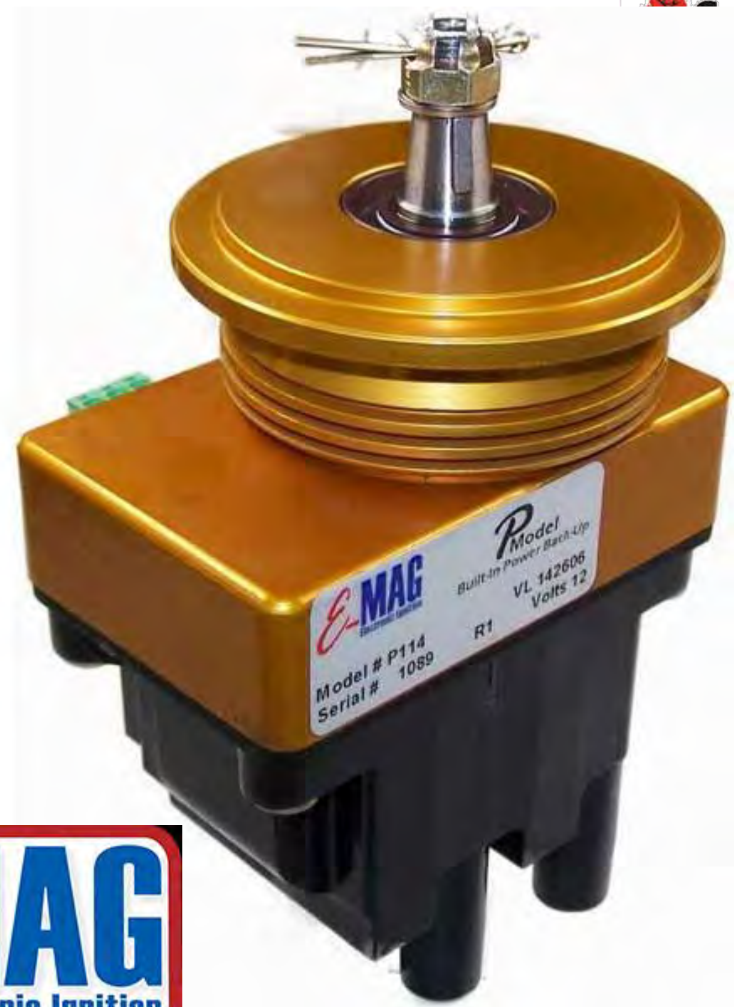
The fact that we're still stuck with these superannuated mechanical black boxes is a testament to just how hard it is to get modern technology FAA-certified

Magneto ignition first appeared on the 1899 Daimler automobiles, and high-voltage magnetos were introduced by Bosch in 1903



Mags were largely abandoned in autos in the 1920s in favor of battery-powered ignition

Electronic ignition systems (EIS) are almos universally used on experimental amateur-built aircraft…

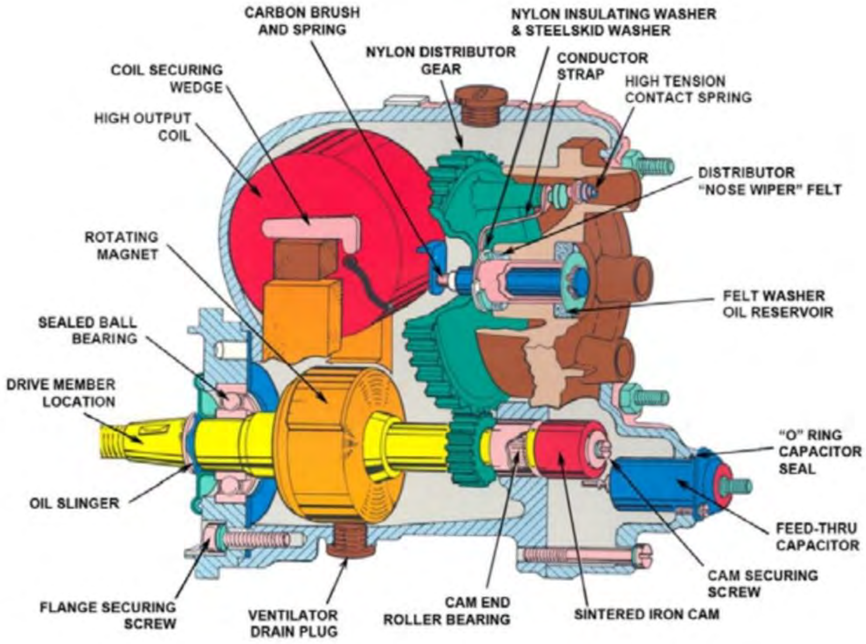


E-MAG Electronic Ignition

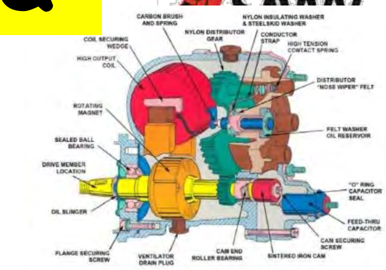
…but are still quite rare on certificated airplanes thanks to FAR Part 33 (“Airworthiness Standards: Aircraft Engines”) which remains firmly rooted in the Dark Ages

The S-1200 magnetos on my airplane are essentially indistinguishable from the ones that Bendix built in the 1940s

How Mags Work

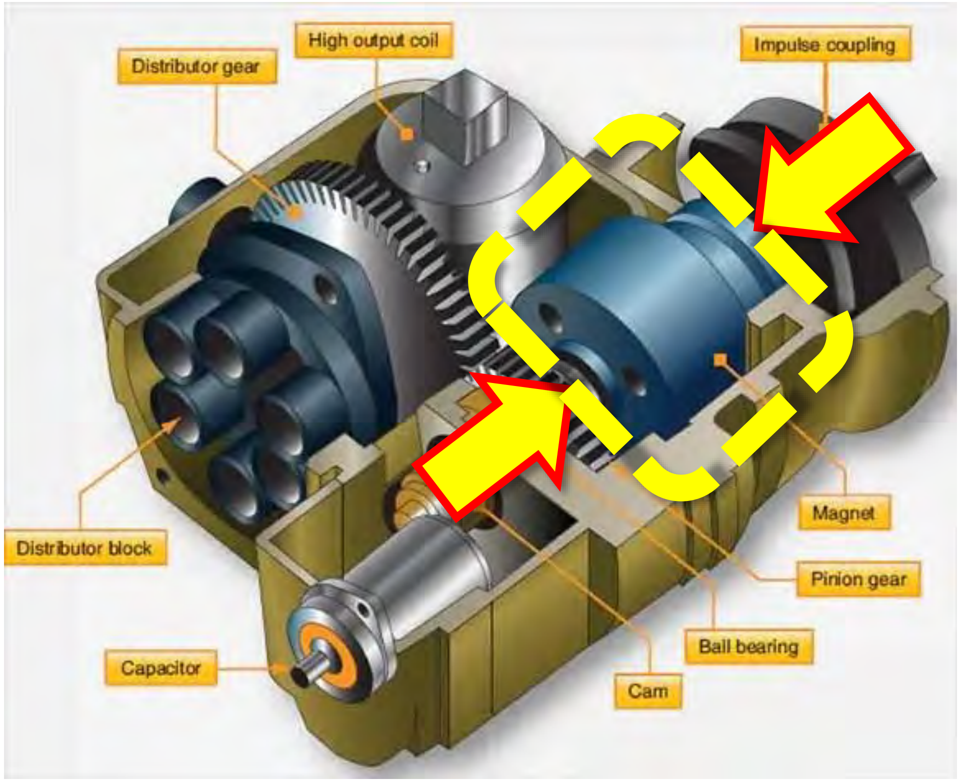


A high-voltage magneto is a self-contained ignition system that converts mechanical rotation into high-voltage pulses used to fire the spark plugs and does so **without the need for external power from a battery or electrical system**



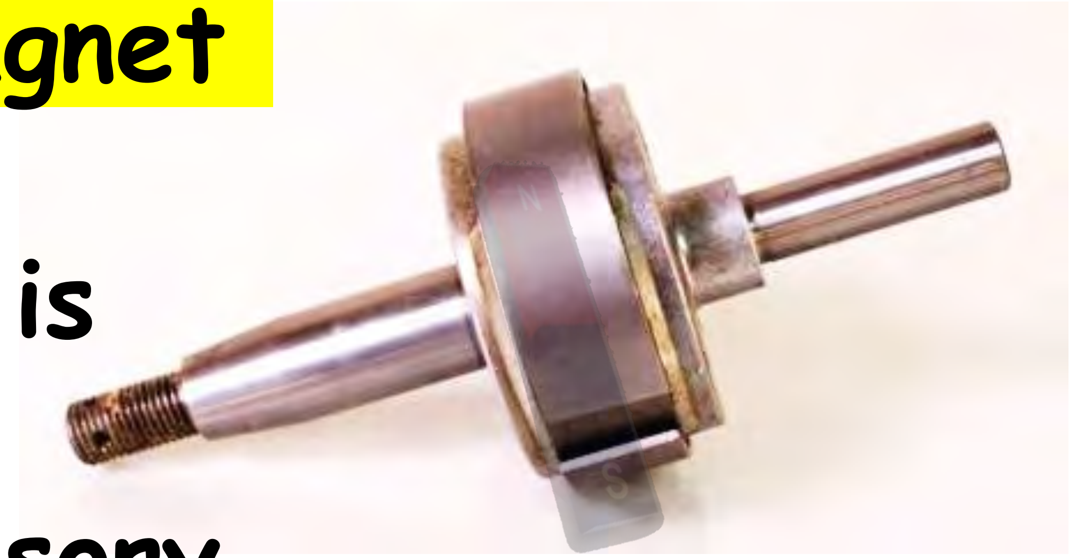
They became the ignition system of choice for aircraft engines because they continue to function perfectly even in the face of a total electrical failure (that for some reason the FAA considers more likely than mechanical failure)

The Rotor

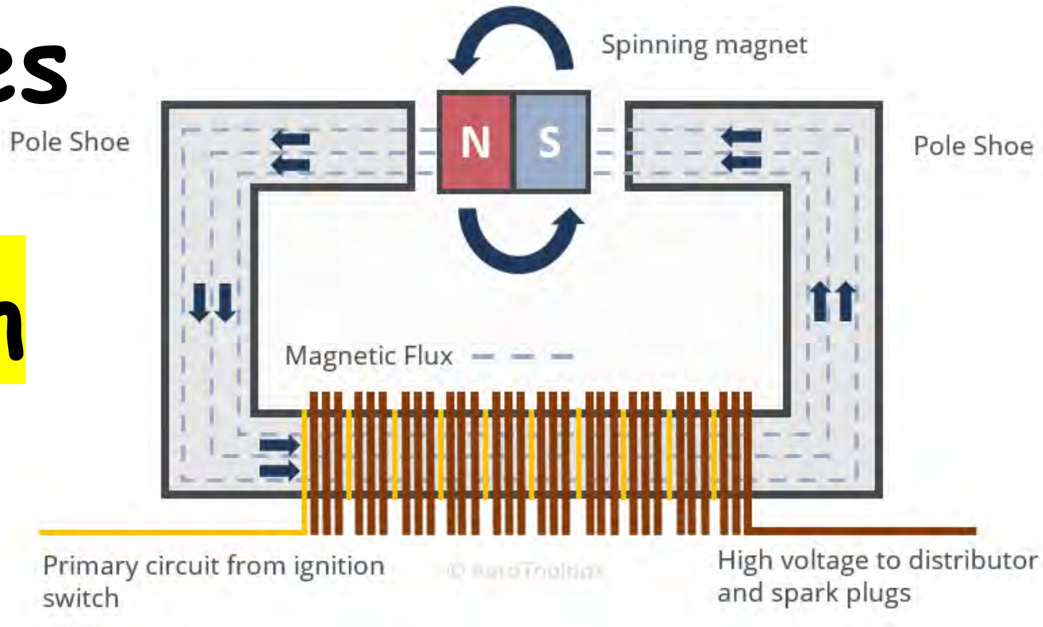


High output coil
Distributor gear
Impulse coupling
Magnet
Distributor block
Pinion gear
Ball bearing
Capacitor
Cam

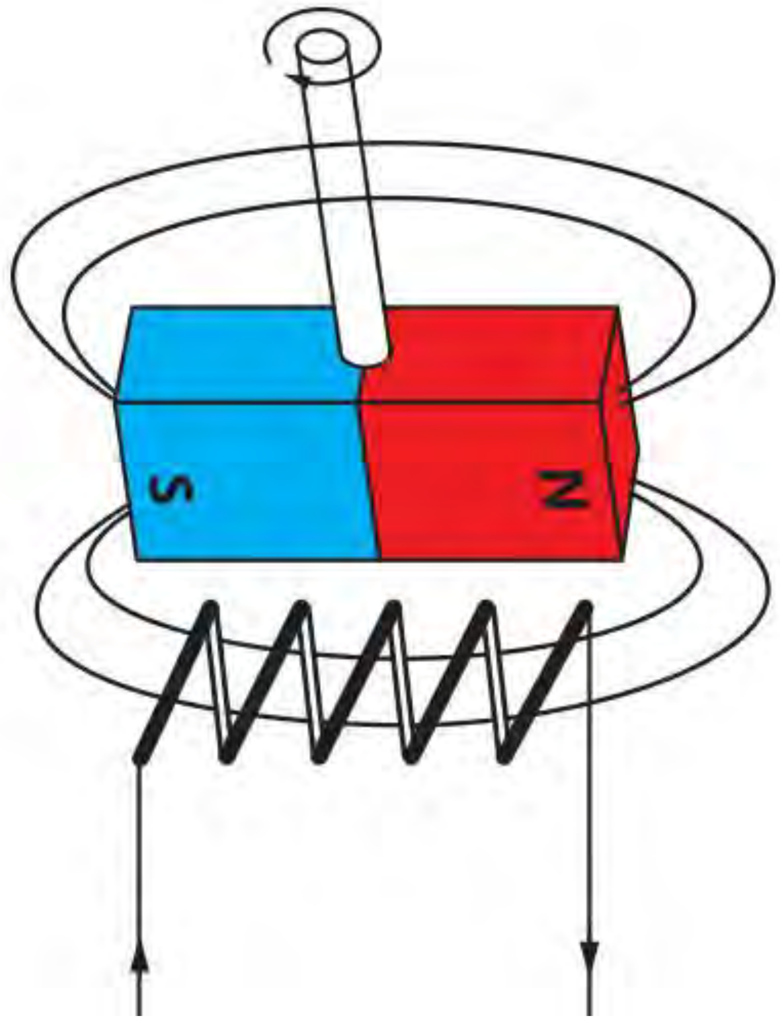
The term "magneto" comes from the rotating permanent magnet assembly or "rotor" which is spun by the engine's accessory gearing



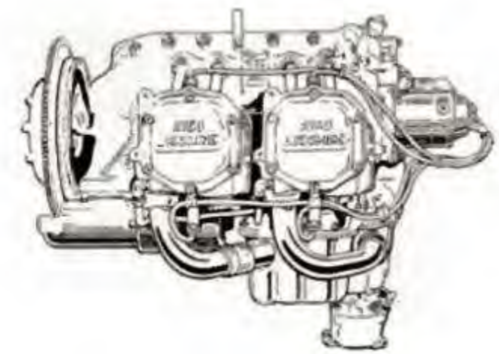
This magnetized rotor generates alternating current flow in the primary winding of the coil as the rotor turns



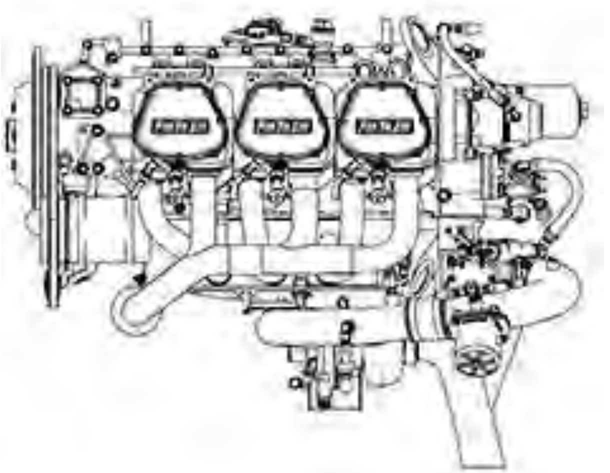
Each full rotation of the rotor induces two waves of alternating polarity electric current in the primary coil



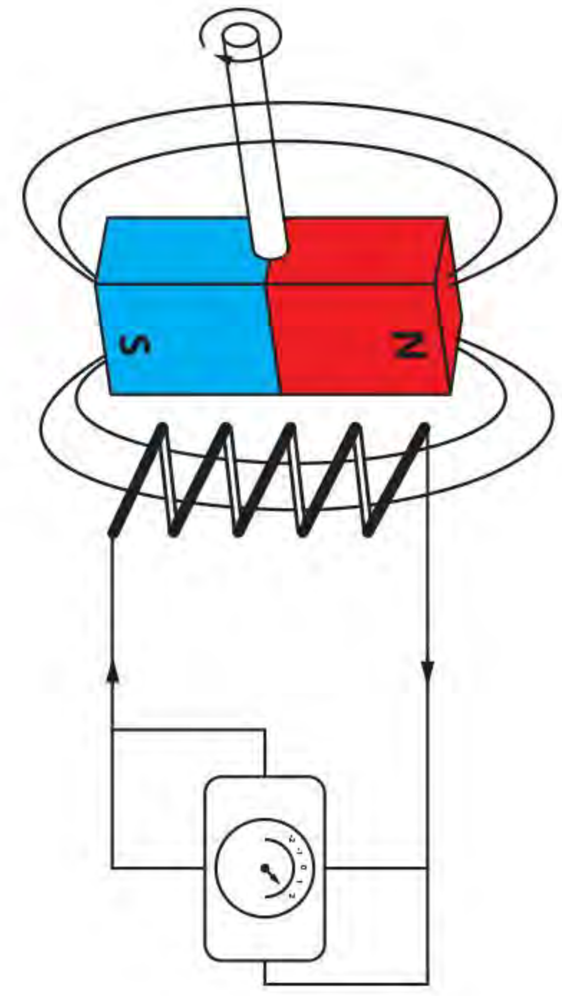
In a 4-cylinder engine, the rotor turns at crankshaft speed



In a 6-cylinder engine, it turns 1.5 times crankshaft speed



The amount of energy generated in the primary coil winding is a function of how strong the rotor's magnet is and how fast it turns



The Four Families

Bendix S-20/S-200

Bendix D-3000

Bendix S-1200

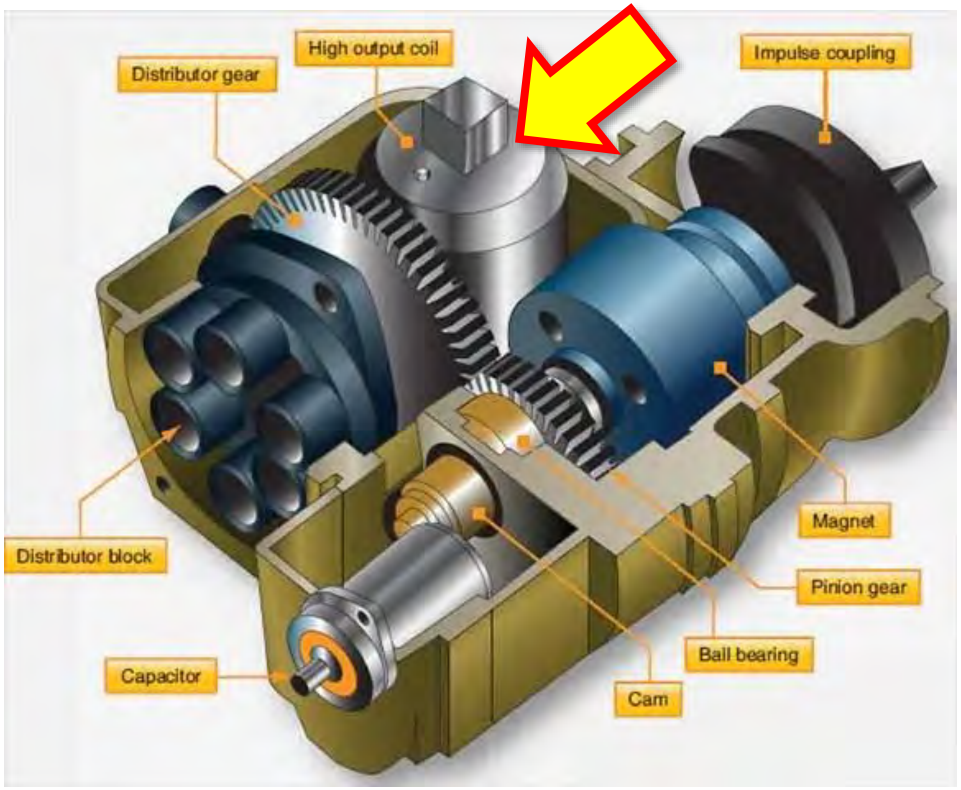
Slick 4300/6300

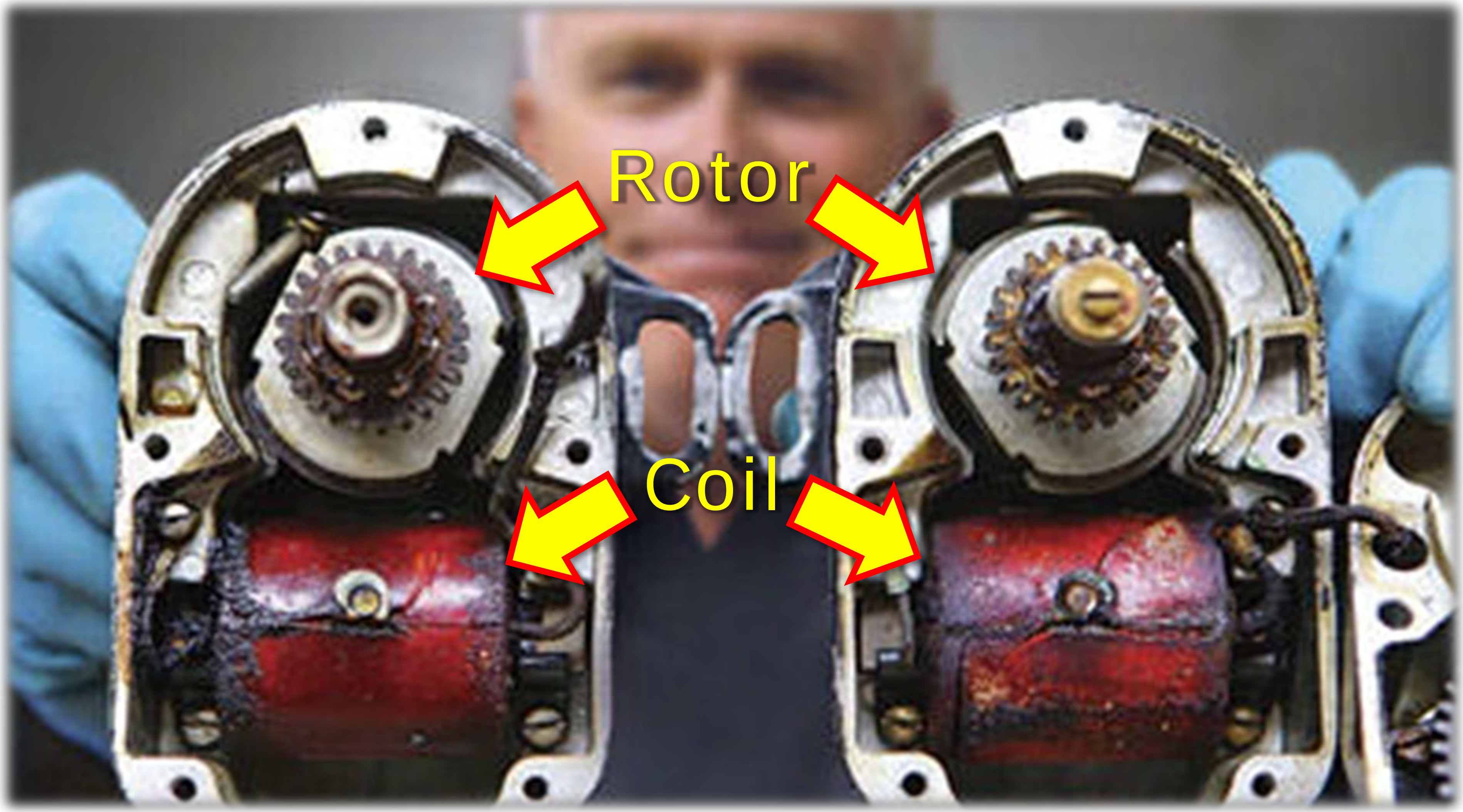
Big mags (like the Bendix S-1200s in my airplane) generate more energy than do smaller ones (like the Slick 4300/6300) because their rotors have bigger, more powerful magnets

Even more important is the rotor's rotation speed

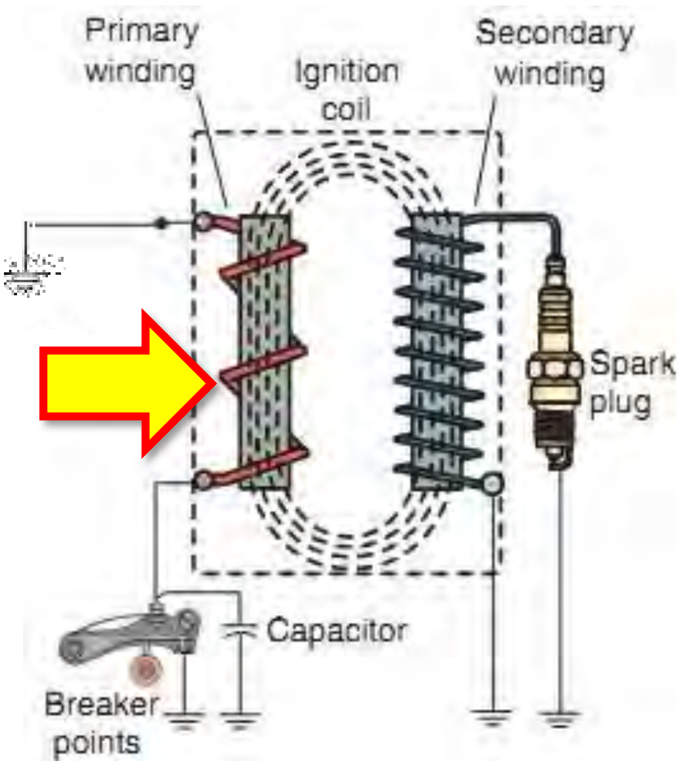
Mags generate their maximum energy when turning at full operating speed and put out a lot less energy at slow RPMs (like when the engine is at idle)

The Coil and Breaker Points



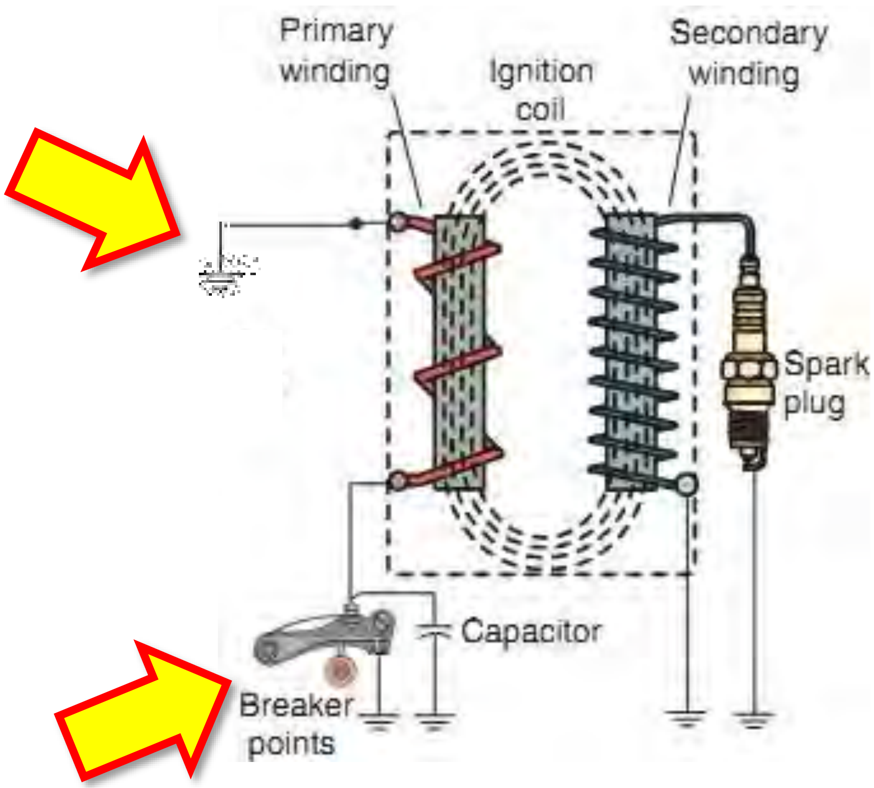

Rotor
Coil

The primary winding of the coil consists of typically 180 turns of heavy-gauge copper wire wound around a laminated iron armature

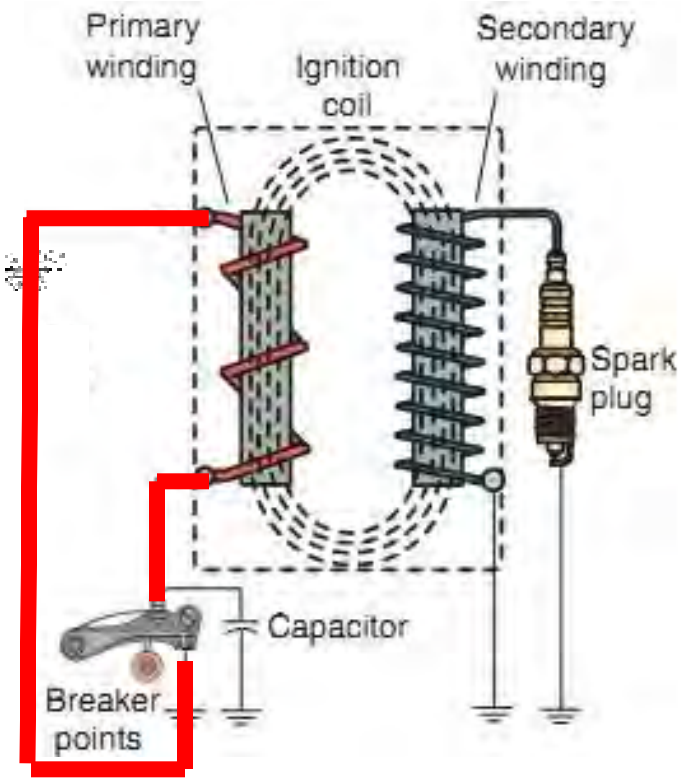


One end of the primary winding is grounded

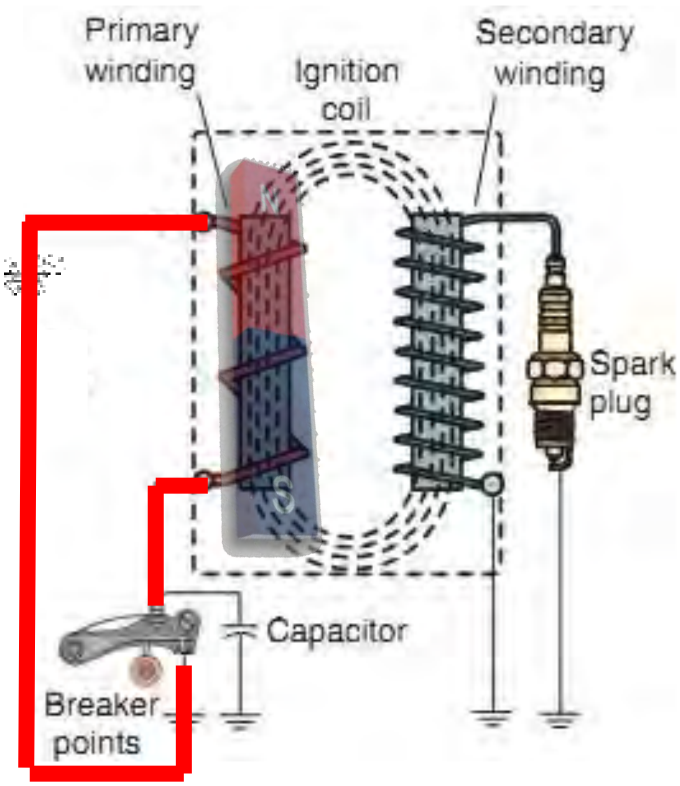
The other end is connected to a set of cam-operated tungsten breaker points



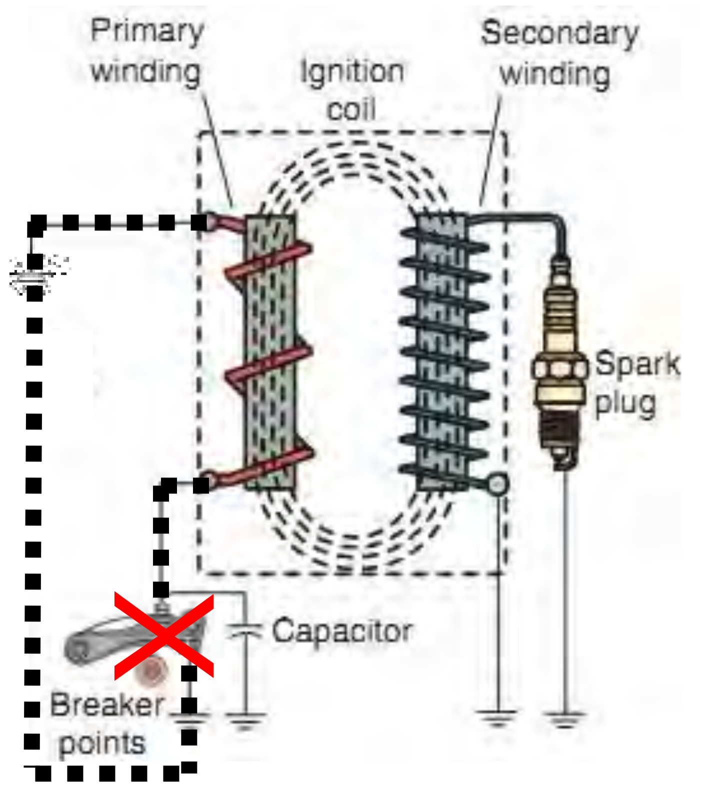
Normally, the points are closed, grounding both ends of the primary coil and allowing current induced by the rotor magnet to flow continuously around and around the coil



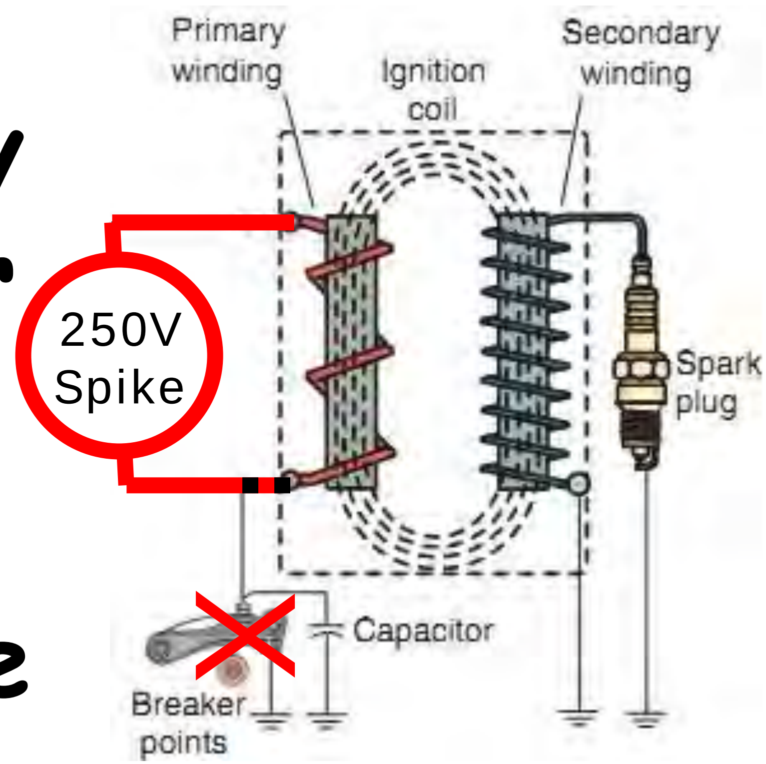
This current flow creates a powerful magnetic field in the coil's iron core



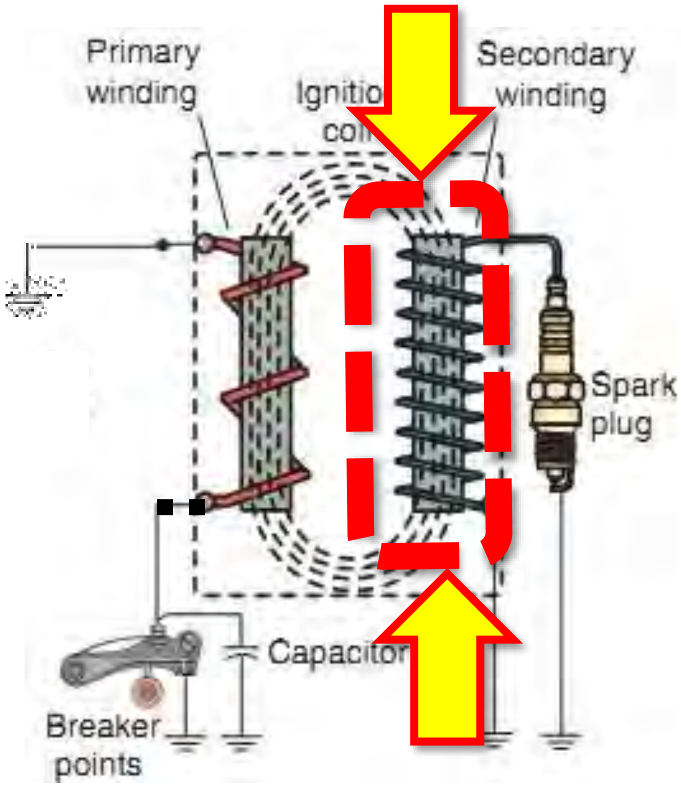
When the cam opens the breaker points, it interrupts the flow of current in the primary coil winding, and causes the magnetic field in the coil's core to collapse suddenly



The collapse of the core's magnetic field induces a voltage spike in the primary that may be 200 or 300 volts when the engine is operating at takeoff or cruise RPM



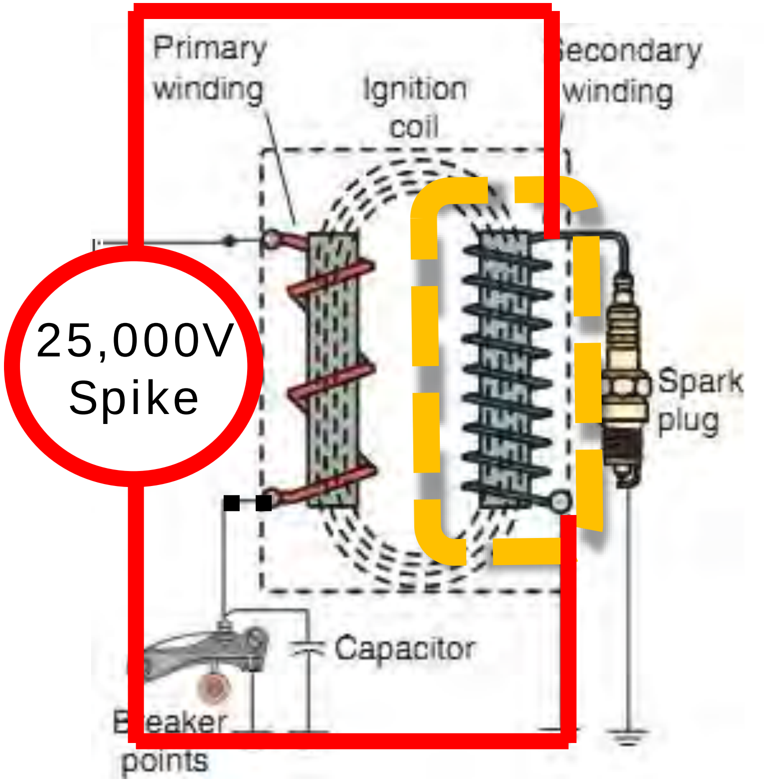
The secondary winding of the coil consists of typically 18,000 turns of very fine magnet wire wound around the same core as the primary



The two coil windings act as a step-up transformer…

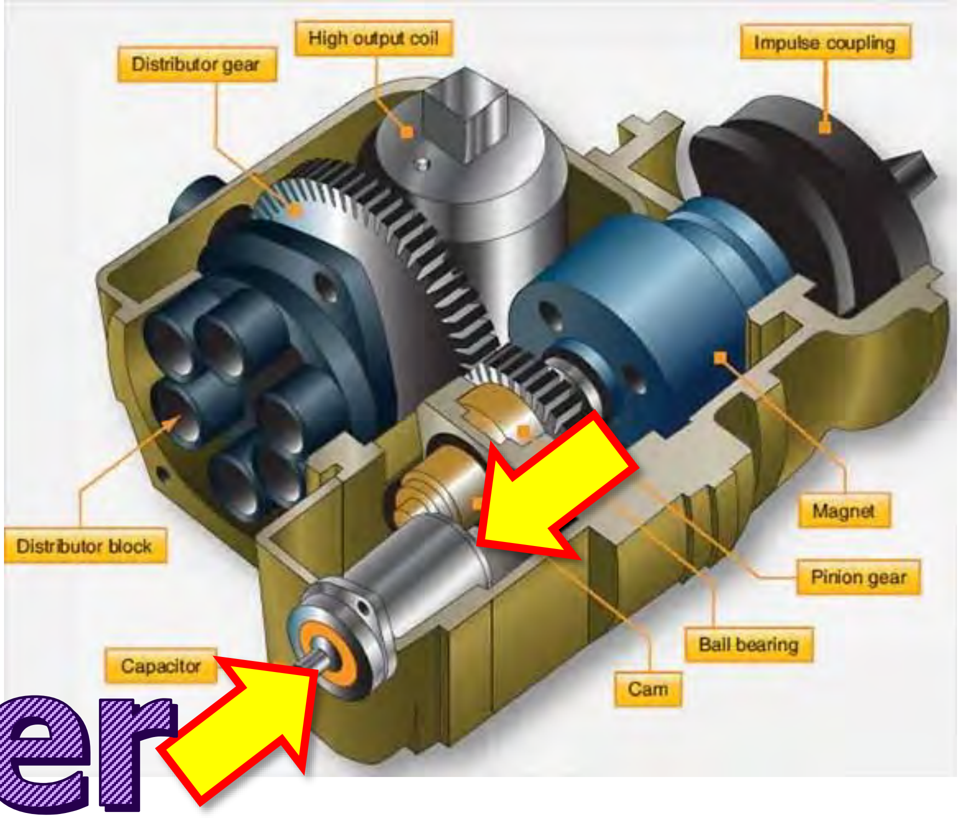
18,000/180 = 100X

100 X 250V = 25,000V

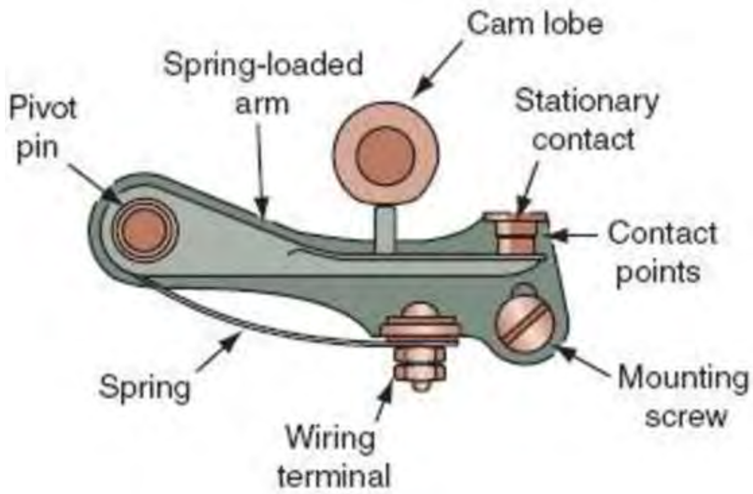


That's enough to fire a spark plug!

The Condenser (Capacitor)



The breaker points are opened by mechanical action of the cam

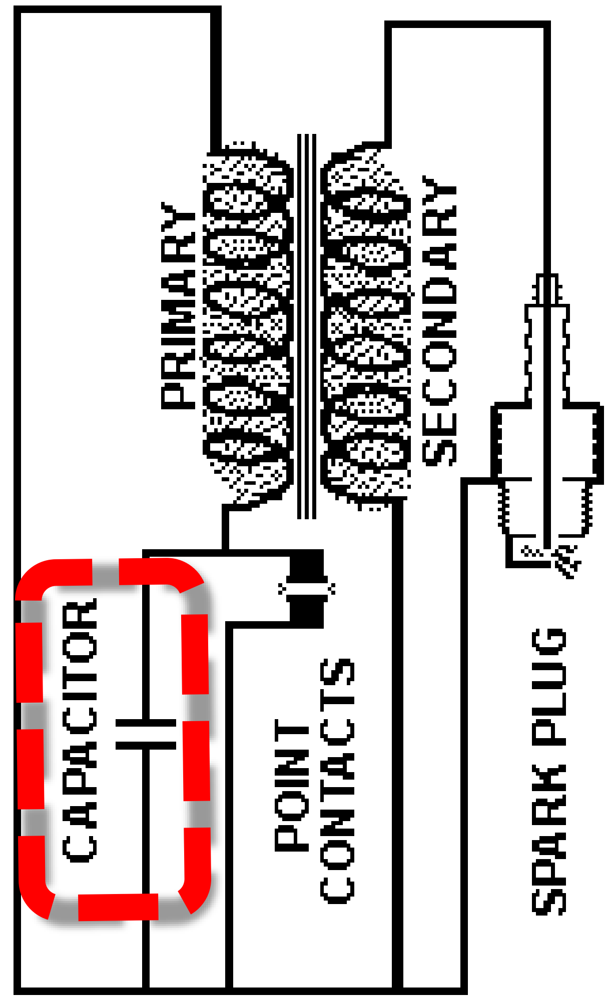


During the first microseconds that the cam is opening the points, they're so close together that the 250V spike in the primary coil winding could arc across them

Arcing across the points would be a bad thing…

- Points would erode and pit
- Collapse of the magnetic field would be slower, causing a weaker spark

To prevent such arcing, a condenser (capacitor) is connected across the breaker points

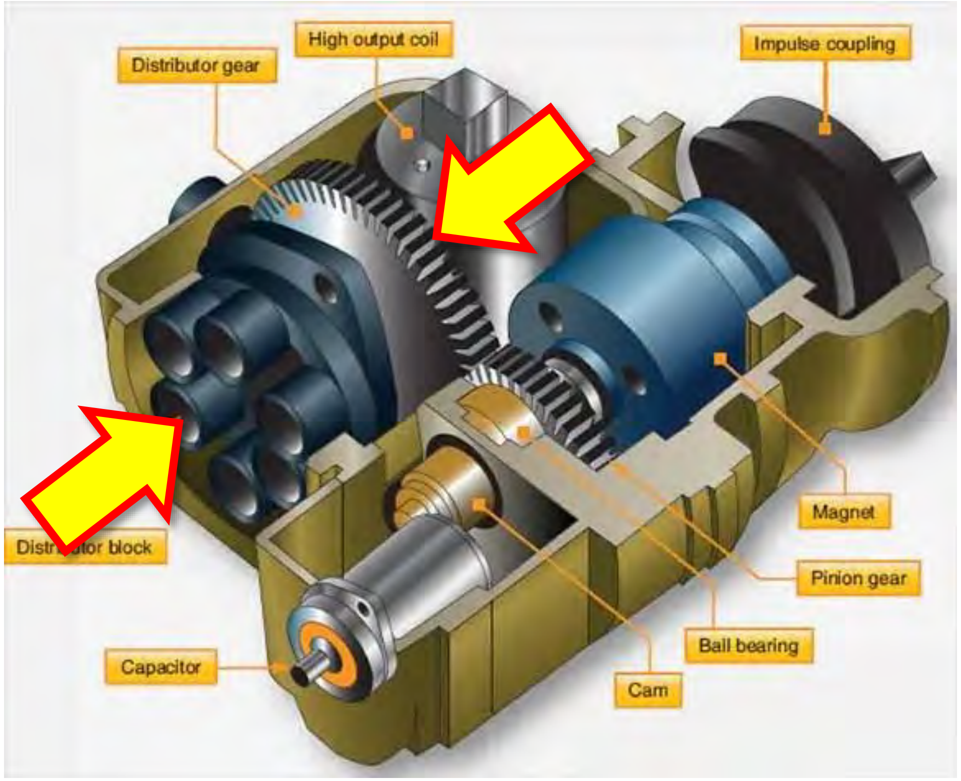


At the moment of point opening, the initial voltage spike charges the condenser for 50 microseconds or so instead of arcing across barely-separated points

By the time the condenser is charged, the cam has separated the points far enough that the 250-volt spike in the primary coil cannot jump the gap

The result is a predictable waveform and much longer-lasting points

If the condenser goes bad (as they sometimes do), mag performance degrades, and the points don't last long

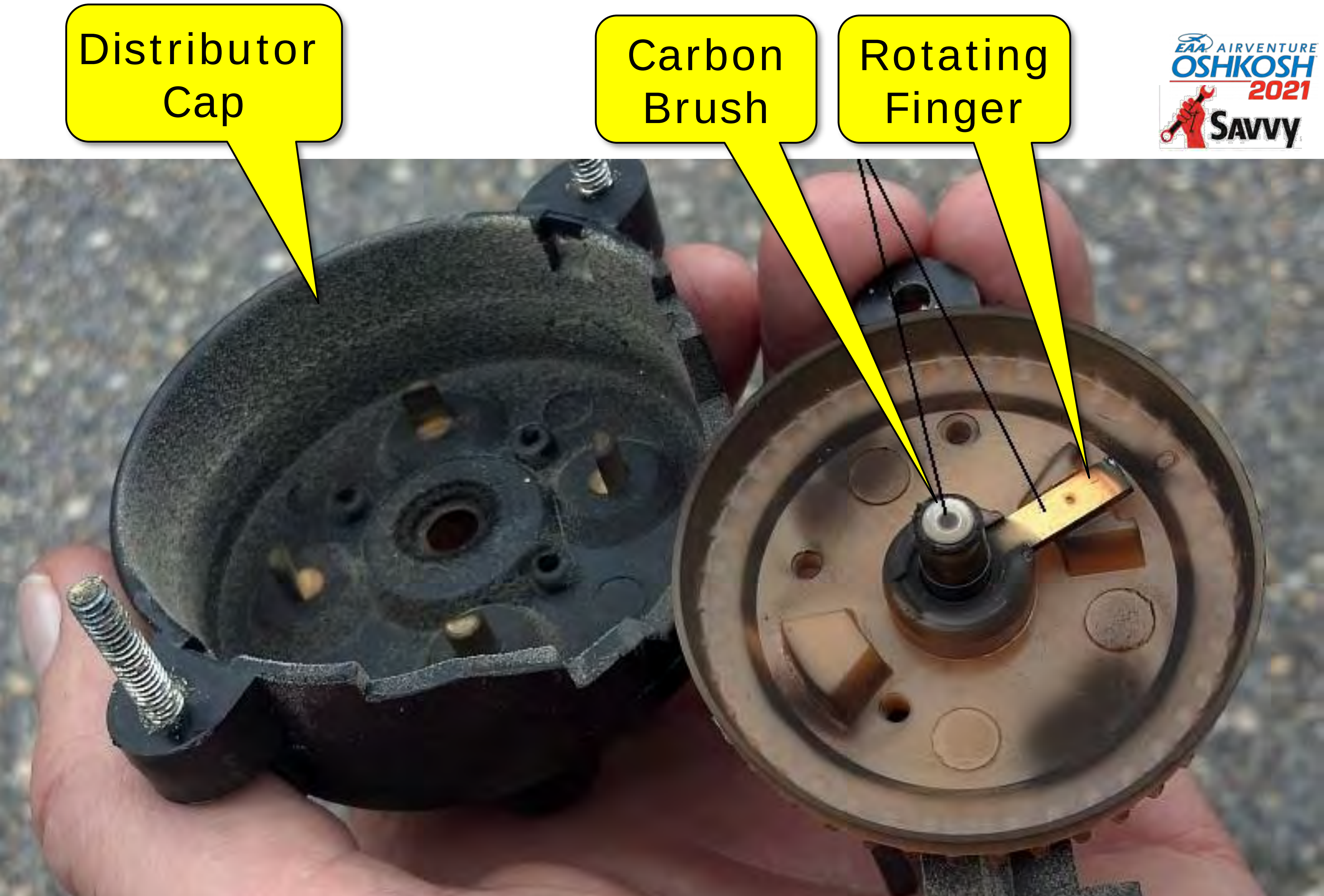


The Distributor

The high-voltage pulses produced by the secondary winding of the coil must be directed to the spark plug of each cylinder in sequence

The magneto accomplishes this by means of a mechanical distributor

The high-voltage lead of the coil is connected to a rotating wiper on a large distributor gear that turns at one-half crankshaft speed inside the distributor block, passing close to electrodes connected to the 4 or 6 spark plug lead wires


Distributor Cap
Carbon Brush
Rotating Finger
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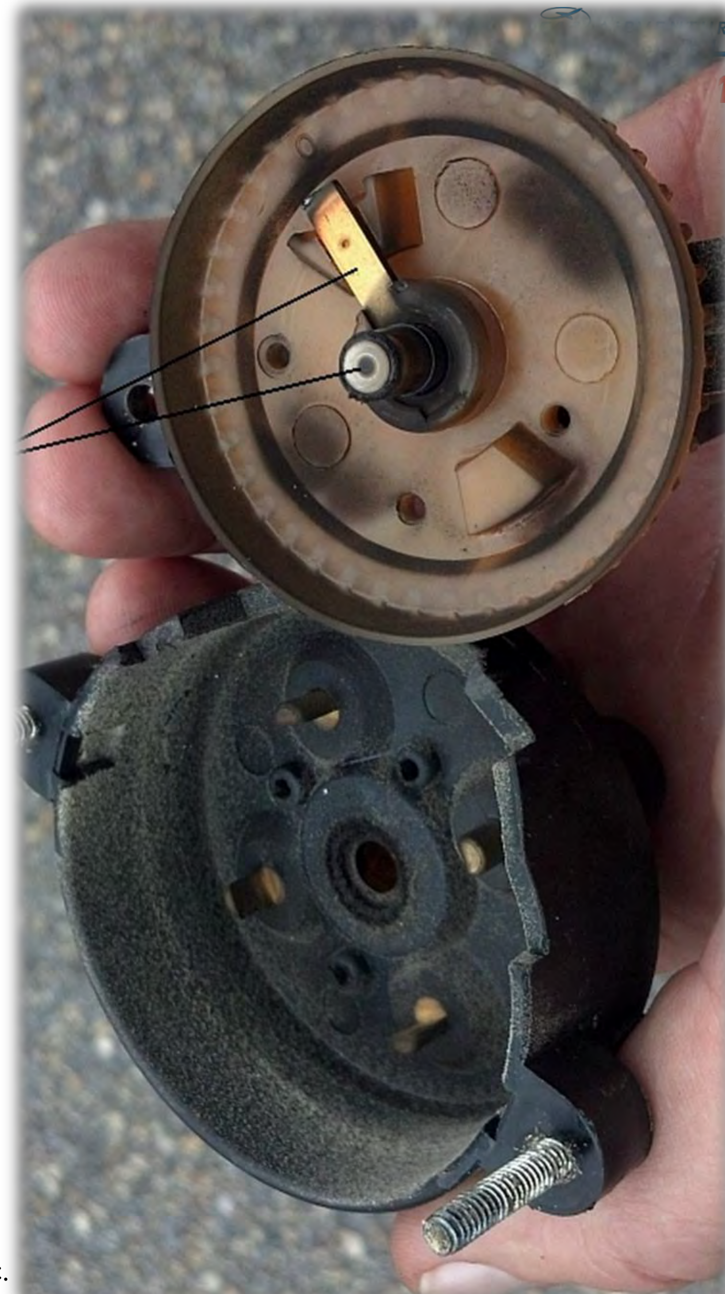
Savvy

The wiper doesn't actually touch the electrodes, it just comes really close

That's why it is known as a "jump gap distributor"

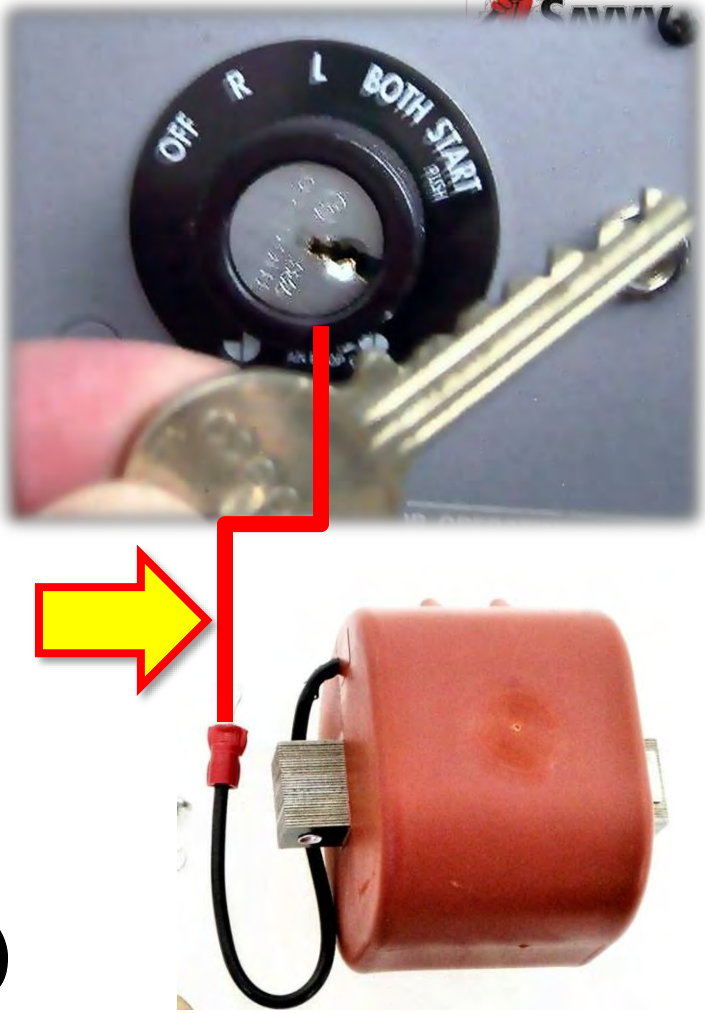


The distributor block is made of dielectric (non-conductive) material capable of withstanding tens of thousands of volts

It is essential that the inside of the distributor block remain scrupulously clean and dry

The P-Lead

The "P-lead" is a wire that runs from the ungrounded end of the magneto coil's primary winding to the cockpit mag switch



(The "P" stands for "primary")

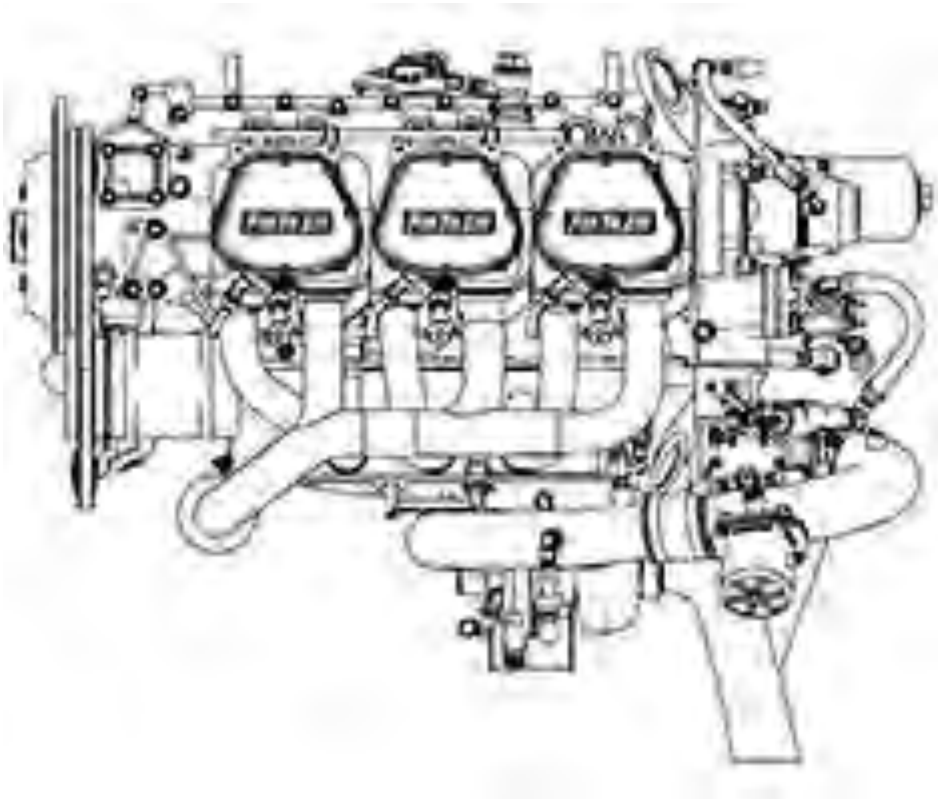
The P-lead is normally a 16-gauge shielded wire, with the shield grounded to the magneto case

Shielding of the P-lead is essential because an unshielded P-lead would act as an antenna and cause interference with avionics

A broken P-lead center conductor results in a dangerous "hot mag" condition in which the ignition switch is unable to shut off the magneto

A broken P-lead shield results in noisy radios and impaired nav performance

Starting the Engine



Getting the engine started presents a couple of problems:

- Magneto can't generate enough energy when engine is cranking at 50 RPM
- Normal ignition timing (20° to 28° BTDC) is way too advanced to permit starting

To get the engine started, we need to:

- Coax the magneto into generating enough energy to produce a hot spark
- Retard the ignition timing enough that the engine won't kick back during start

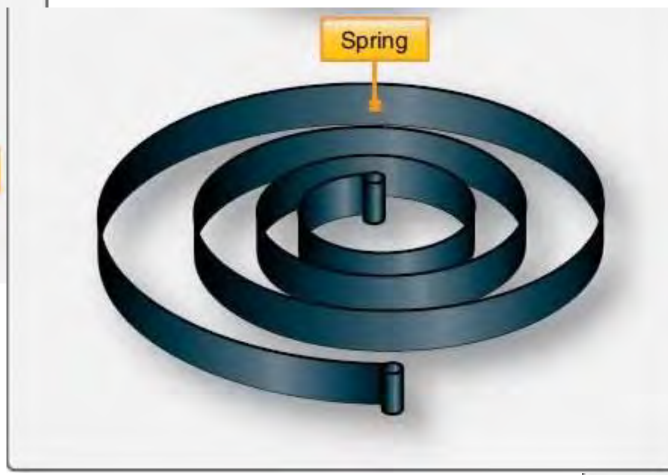
Two different methods are commonly used to accomplish these things—one mechanical (impulse coupling), and the other electrical (retard breaker)

Which you use depends on what kind of airplane you fly

Impulse Coupling

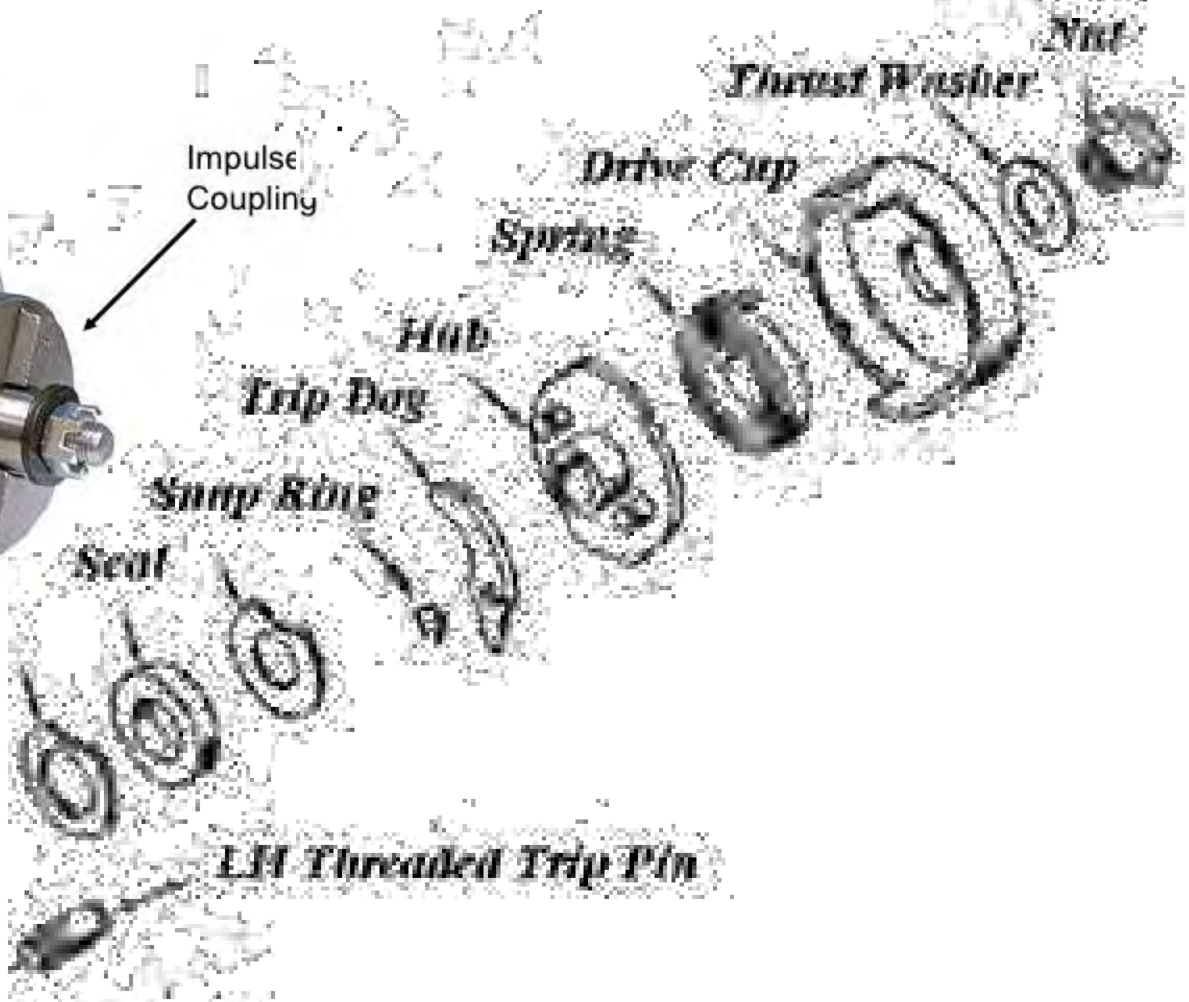
Flyweight assembly drives the magneto

Spring connects the body to the flyweights

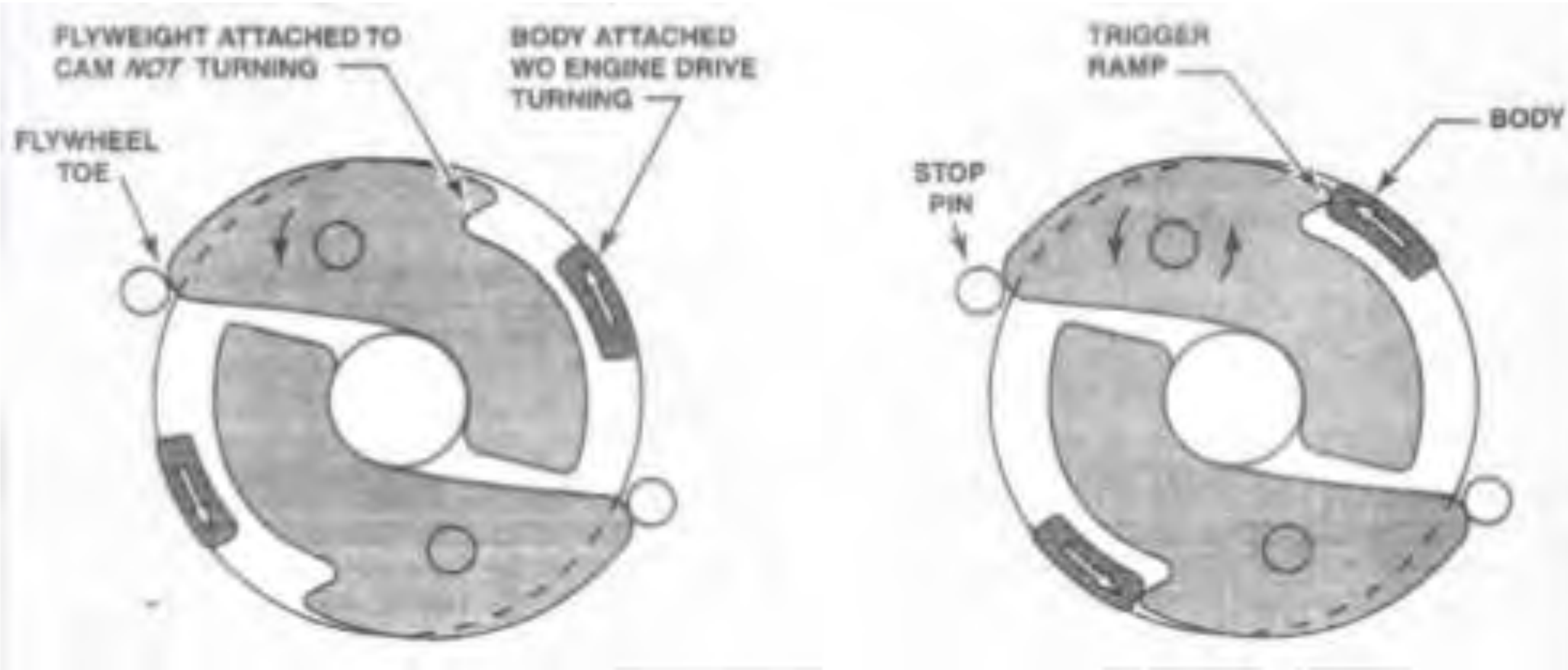


Body is driven by the engine

Impulse
Coupling



Nut
Thrust Washer
Drive Cup
Spring
Hub
Trip Dog
Snap Ring
Seal
LH Threaded Trip Pin

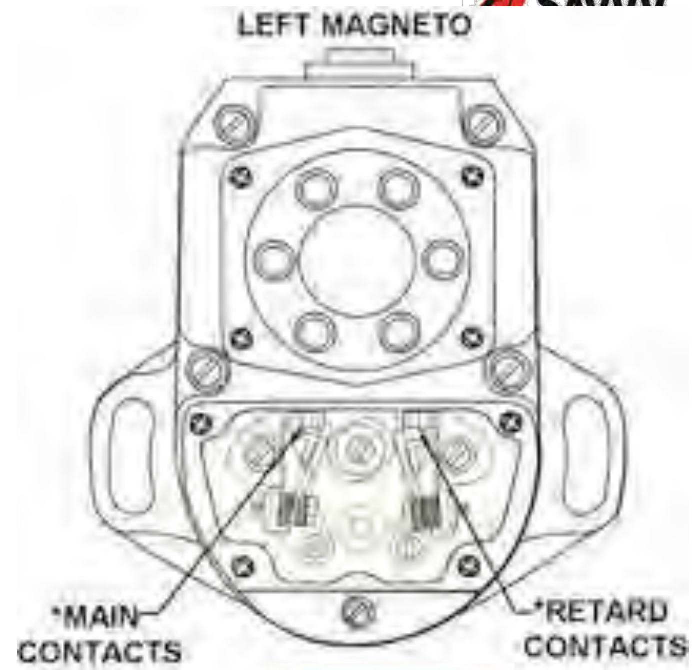


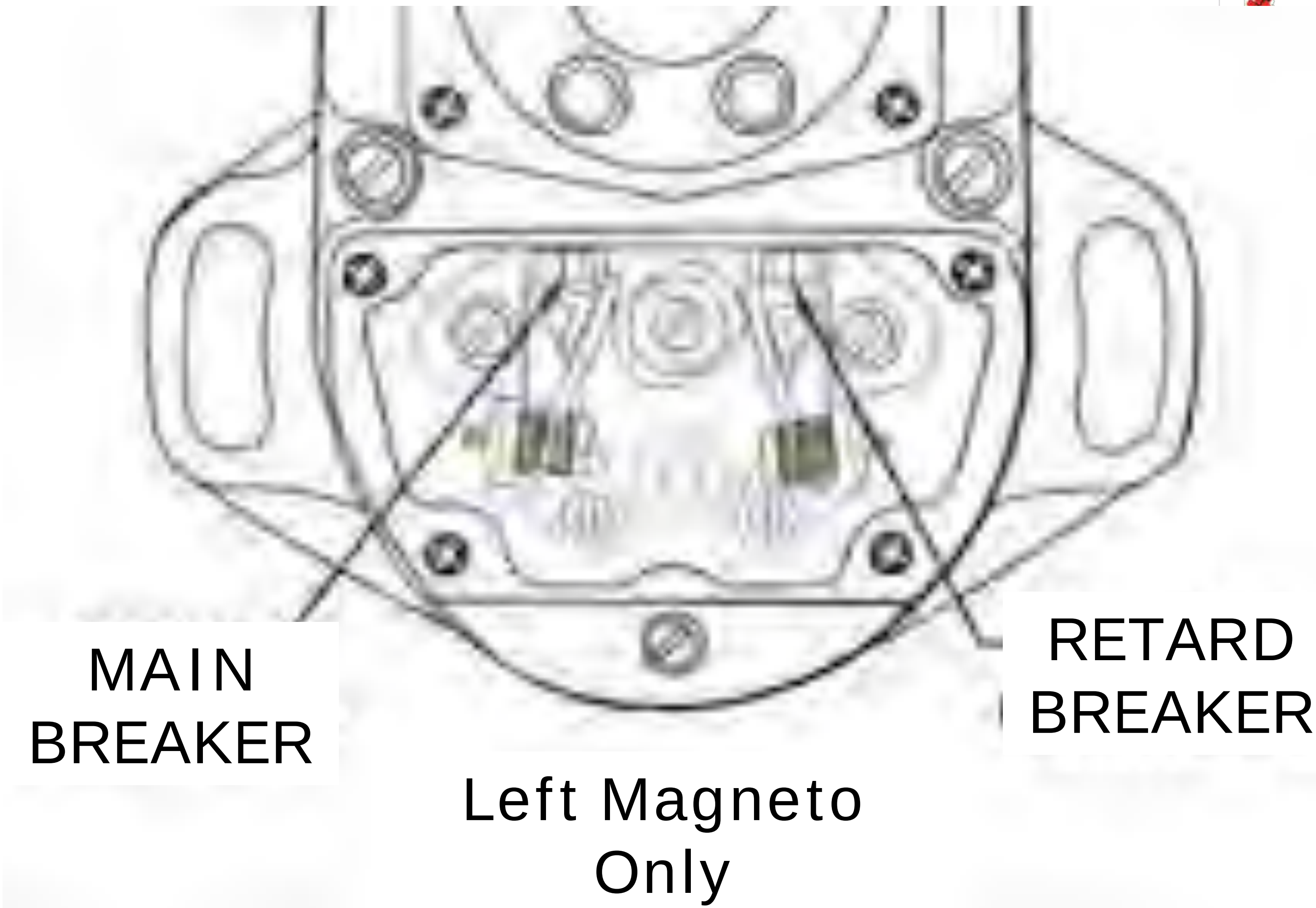
FLYWEIGHT ATTACHED TO CAM *NOT* TURNING
BODY ATTACHED WO ENGINE DRIVE TURNING
FLYWHEEL TOE
TRIGGER RAMP
BODY
STOP PIN

- Many moving parts
- Need to be inspected each 500-hour magneto inspection
- Can cause a catastrophic engine failure
- Several ADs against impulse couplings—both Bendix and Slick—that have to be taken seriously

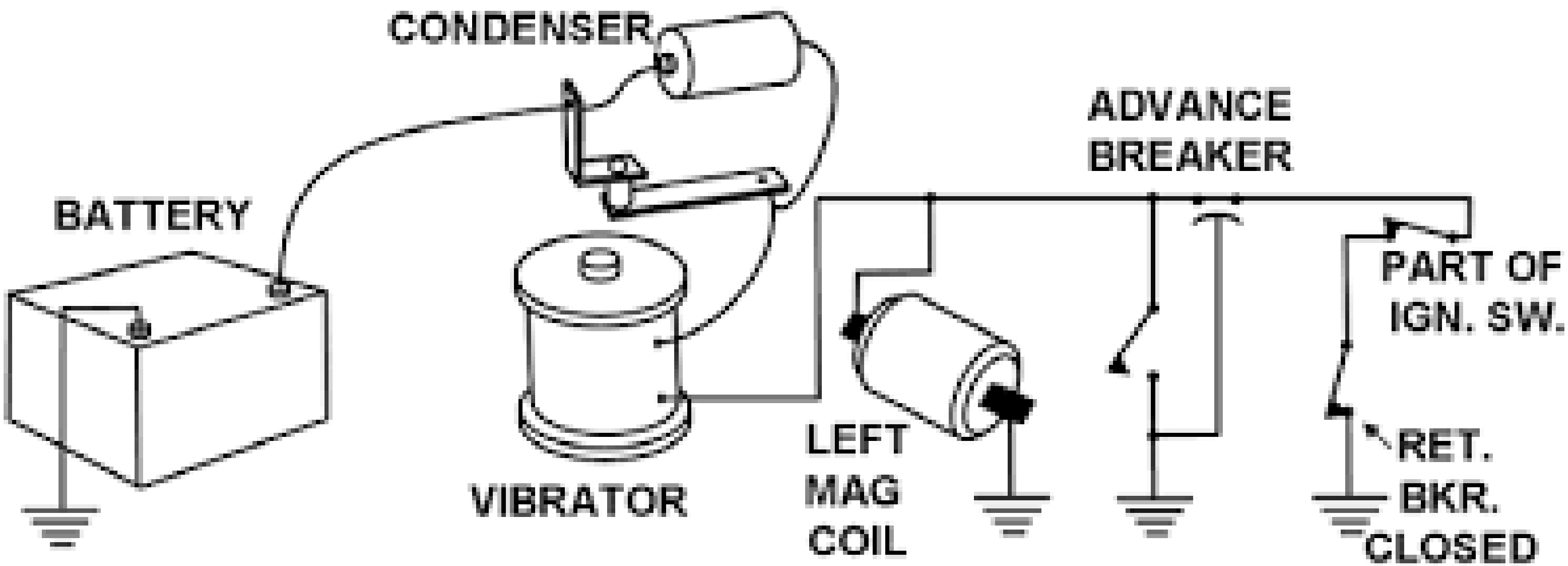
Retard Breaker

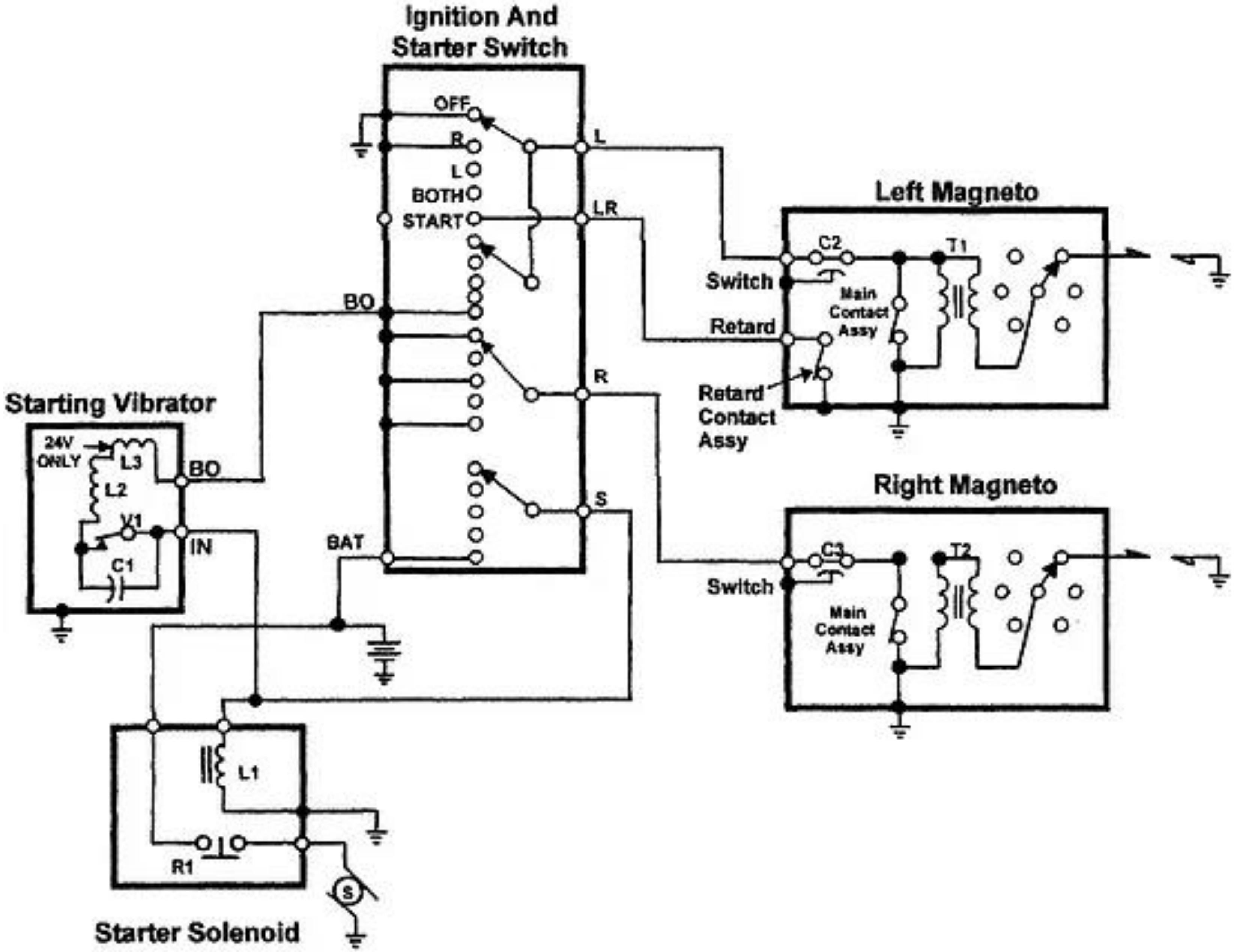
"Shower of Sparks"




MAIN
BREAKER
RETARD
BREAKER
Left Magneto
Only


STARTING VIBRATOR
PART NO
10-176485-241 C
VOLTS D.C.
24
AMPS D.C.
DATE MFD.
325
Bendix®
SCINTILLA DIVISION
THE BENDIX CORPORATION
SIDNEY NEW YORK, U.S.A.
WARNING
USE WITH SERIES
S - 200
S - 400
S - 500
S - 600
S - 700
MAGNETOS
R
L
GRD


CONDENSER
ADVANCE
BREAKER
BATTERY
PART OF
IGN. SW.
VIBRATOR
LEFT
MAG
COIL
RET.
BKR.
CLOSED



Ignition And Starter Switch
OFF
R
L
BOTH
START
L
LR
R
S
BO
BAT
Starting Vibrator
24V ONLY
L3
L2
V1
C1
BO
IN
Starter Solenoid
L1
R1
S
Left Magneto
C2
T1
Switch
Main Contact Assy
Retard
Retard Contact Assy
Right Magneto
C3
T2
Switch
Main Contact Assy

The retard breaker system…

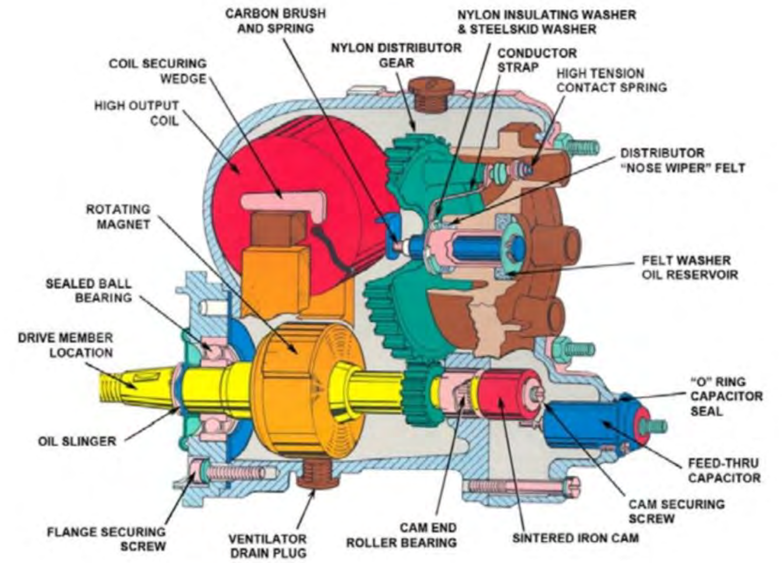
- Eliminates the mechanical risks associated with worn impulse couplings
- Produces easier starting because the spark plug fires a dozen times or so during each ignition event, rather than just once

One disadvantage is that it depends upon battery power to start, so you can't hand-prop the engine with a dead battery

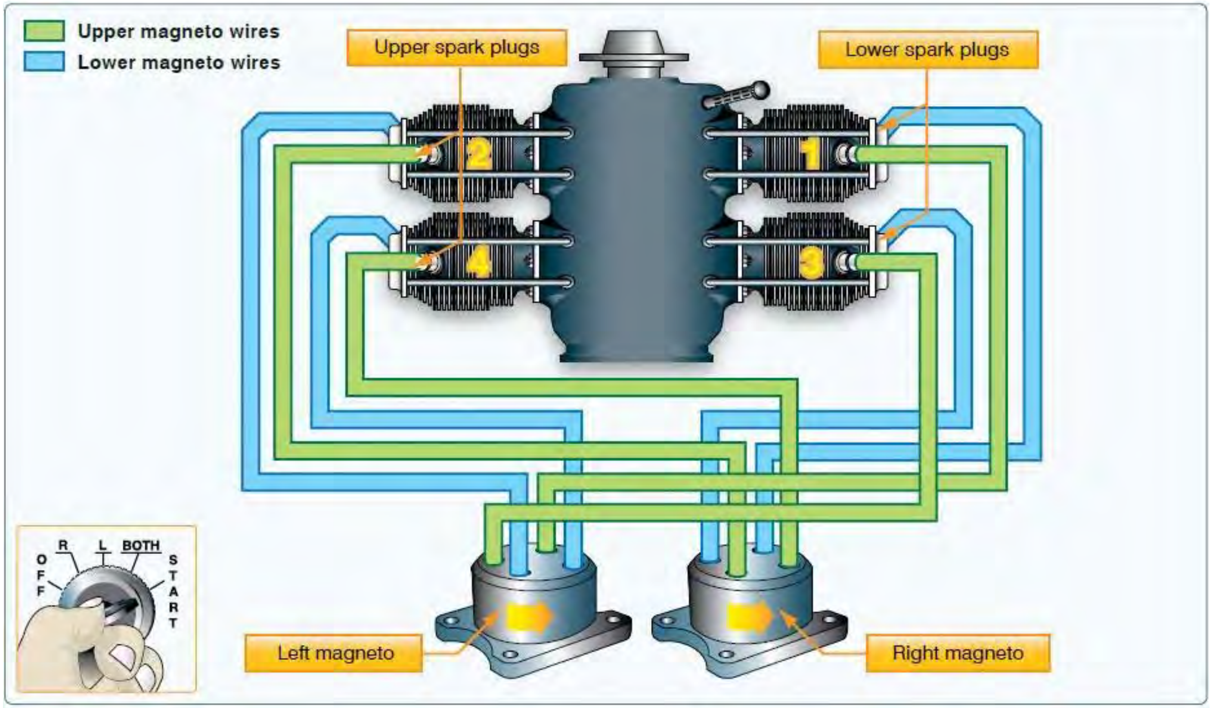
SlickSTART Magneto Booster

Shower-of-sparks for engines that use impulse couplings

Magneto Failures and Mitigation



Both the FARs and predecessor CARs require that certificated spark-ignition reciprocating aircraft engines have fully redundant dual ignition systems



§33.37 Ignition system.

Each spark ignition engine must have a dual ignition system with at least two spark plugs for each cylinder and two separate electric circuits with separate sources of electrical energy, or have an ignition system of equivalent in-flight reliability.

There's a good reason for this:

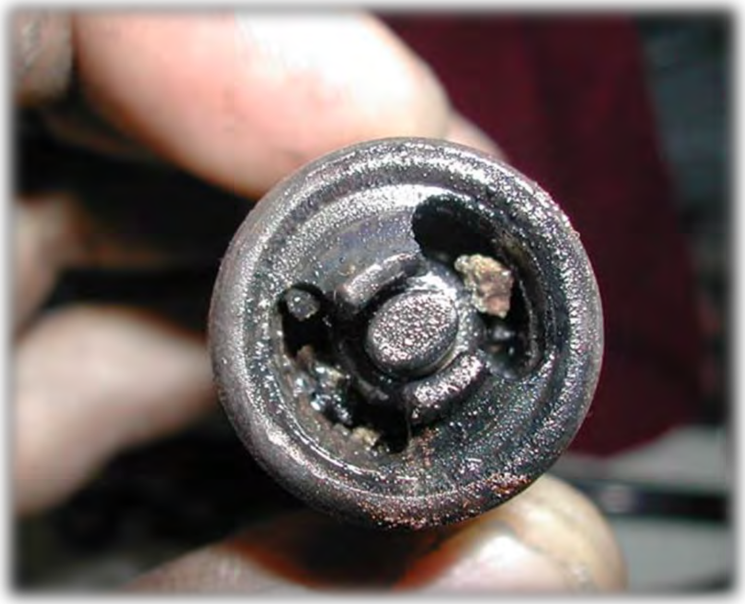
Magneto-ignition system failures are relatively commonplace

Without a properly functioning ignition system, the engine could quit, the airplane could fall out of the sky, and people could get hurt

How often do ignition systems fail?

Spark plug failures happen a lot, but usually they're not even noticeable…

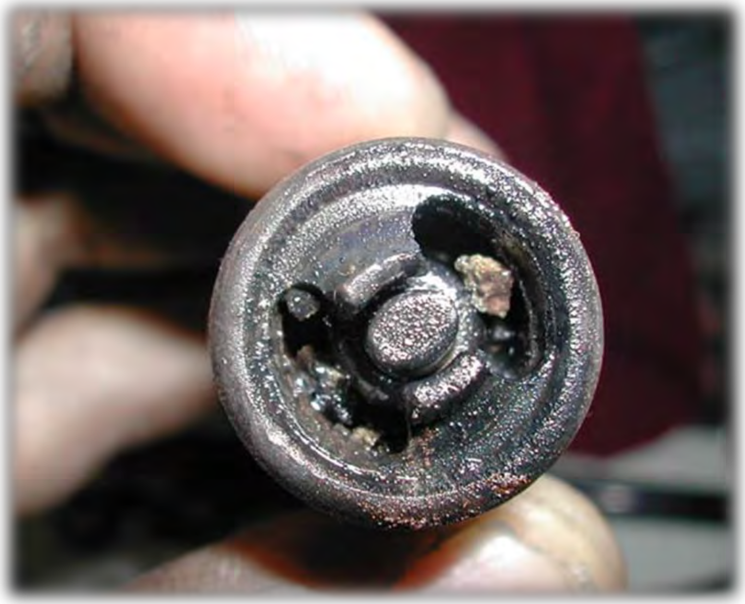
…precisely because we have two spark plugs in each cylinder, and one is enough to keep the cylinder producing power



Usually, the only sign that a spark plug has failed in-flight is that the EGT on the affected cylinder rises by 50°F or so

Unless you have an engine monitor and keep it in "normalize mode" you'll probably never even notice

Often these failures are caused by some crud getting lodged in the spark plug electrodes, and sometimes those failures self-resolve



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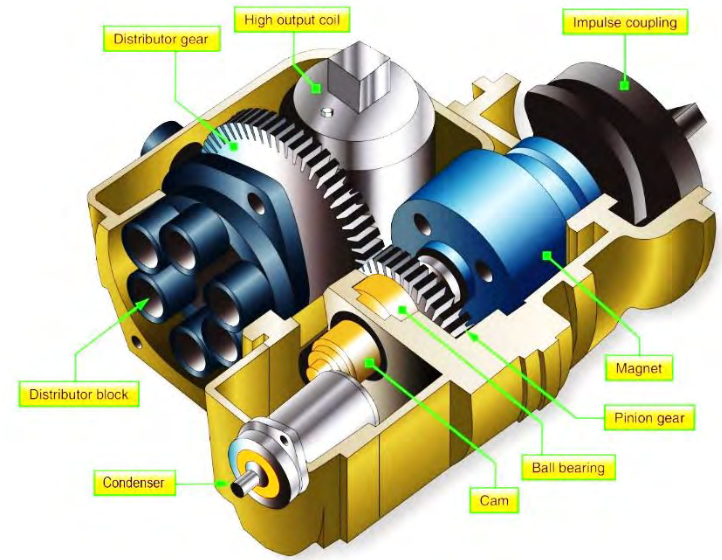
Lead-fouled fine-wire spark plug

Even when they don't self-resolve, spark plug failures often aren't caught until the next pre-flight mag check when the failed plug causes an excessive mag drop

Magneto failures happen less often, but when they do happen the consequences can be much more serious…

…or not, depending on the failure mode

If the mag just quits cold—say, because the breaker points fail, the coil opens, or the condenser shorts—then the consequences are relatively benign…



All cylinders continue to make power in single-ignition mode, all EGTs rise in unison, and you fly to your destination and get the bad mag fixed

No big deal

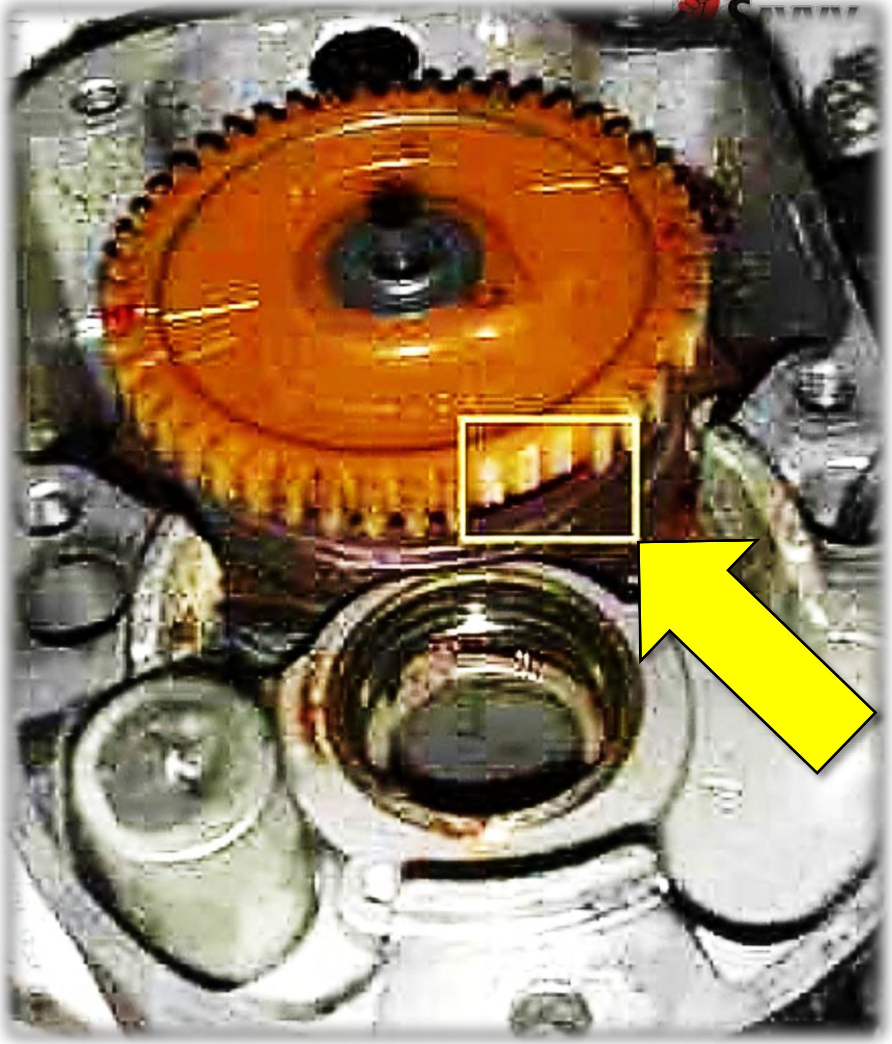
On the other hand, a failure that affects the magneto's timing can be a very big deal…

…particularly if the timing is advanced (i.e., the spark plugs fire too early)

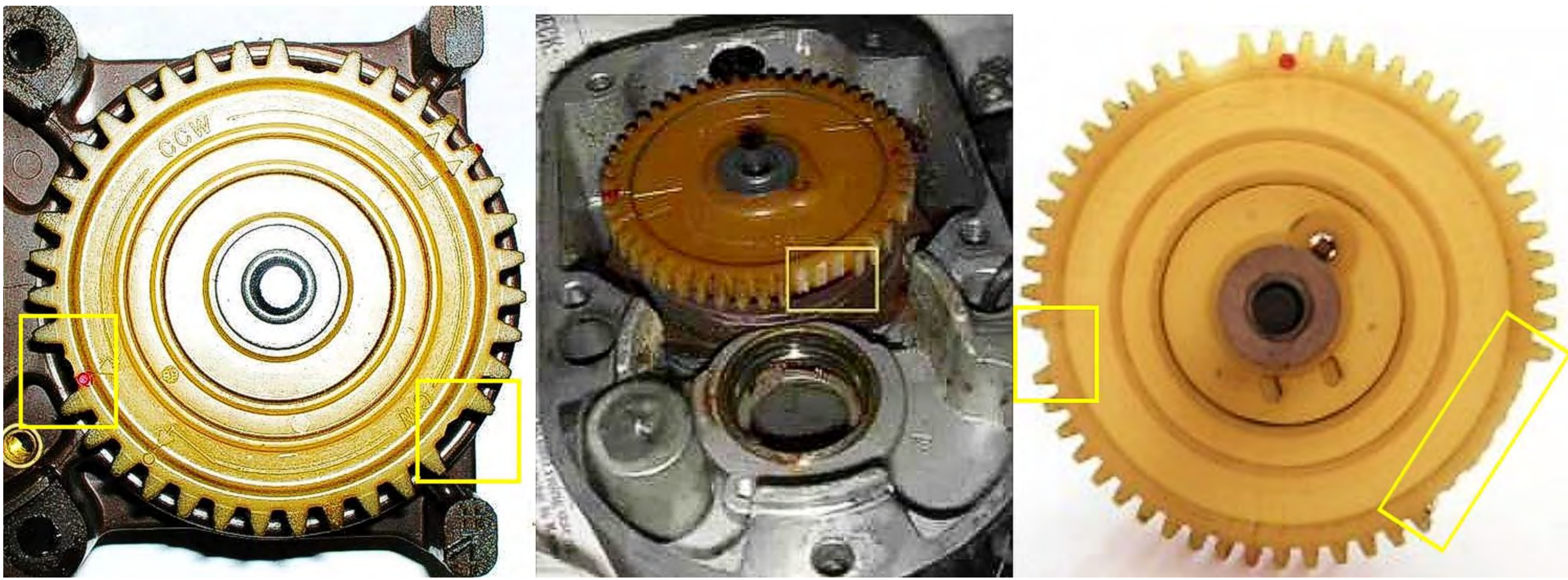
A mag that fires 5° early can send CHTs right through the roof

One that fires 10° early can melt holes in pistons and cause cylinder heads to separate

One of the worst kind of mag failures occurs when the mag's plastic distributor gear fails by shedding teeth



We've see these failures occur with disturbing frequency



When this happens, the magneto can start firing random spark plugs at random times

All hell breaks loose!

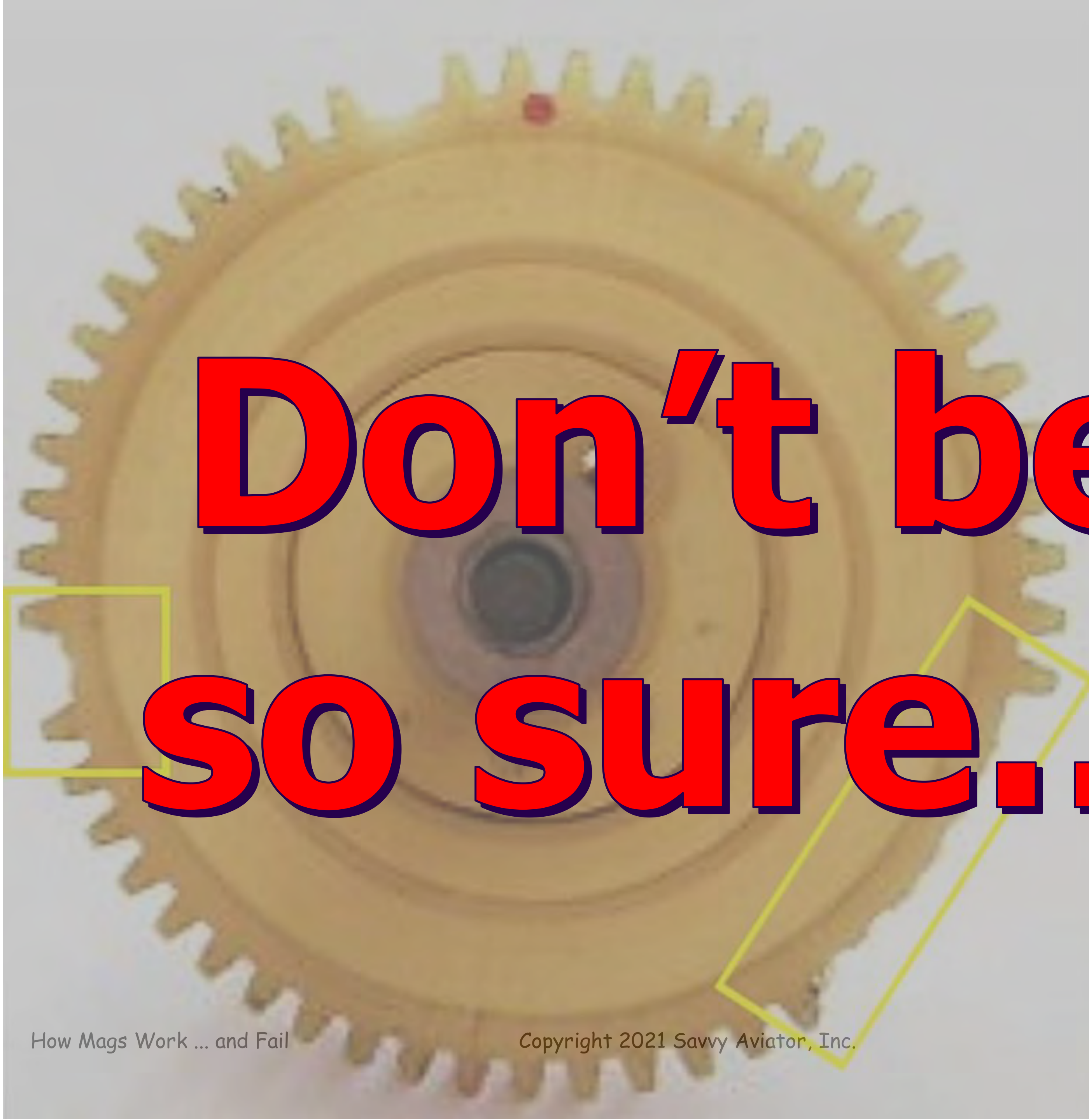
The engine starts running change-of-underwear rough

I counted six such magneto distributor gear failures during a two-year period in a fleet of roughly 300 piston GA airplanes

That works out to an average of one failure per year per 100 planes

Not to worry, though, that's why the FAA requires that our engines have two magnetos

Even if one mag goes berserk, we've still got a healthy one to get us home, right?



Don't be so sure…

I investigated those six magneto distributor gear failures quite thoroughly

They happened to all sorts of pilots, ranging from newbies to veteran multi-thousand-hour CFIs, and they occurred in phases of flight, ranging from pattern altitude to FL210

<u>NOT ONCE</u> DID THE PILOT HAVE THE PRESENCE OF MIND TO IDENTIFY AND SHUT OFF THE MISFIRING MAGNETO!

That was even true of the failure that occurred at FL210, where the experienced pilot had nearly a half-hour to troubleshoot the issue as he was descending power-off to an emergency landing

In every one of these six cases—high-time or low-time pilot, high altitude or low altitude—the pilot declared an emergency, pulled the power way back, and landed at the nearest airport

Fortunately, all the emergency landings were uneventful…

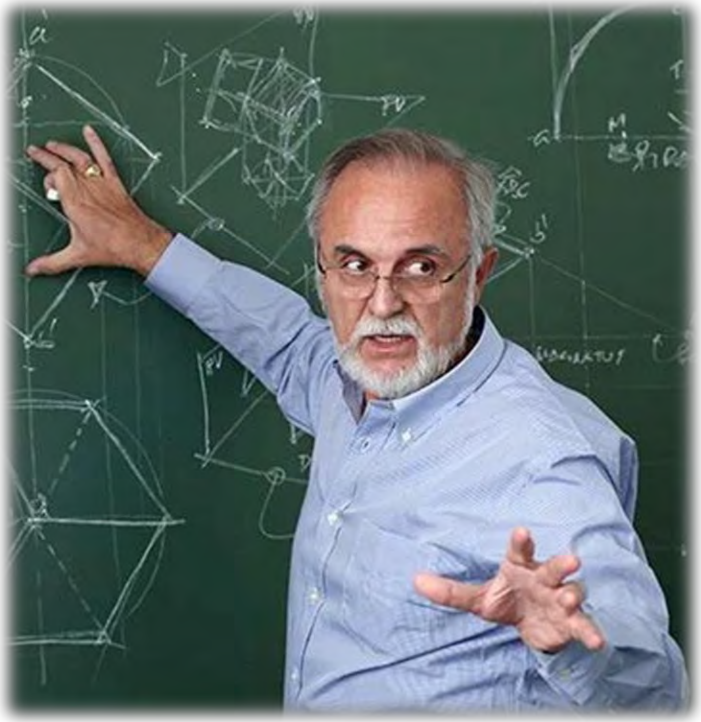
…disregarding the state of the pilots' underwear

Had these pilots been taught to deal with such a failure by identifying and shutting off the bad magneto, their engines would have resumed smooth operation and their airplanes could have continued uneventfully to the planned destination…

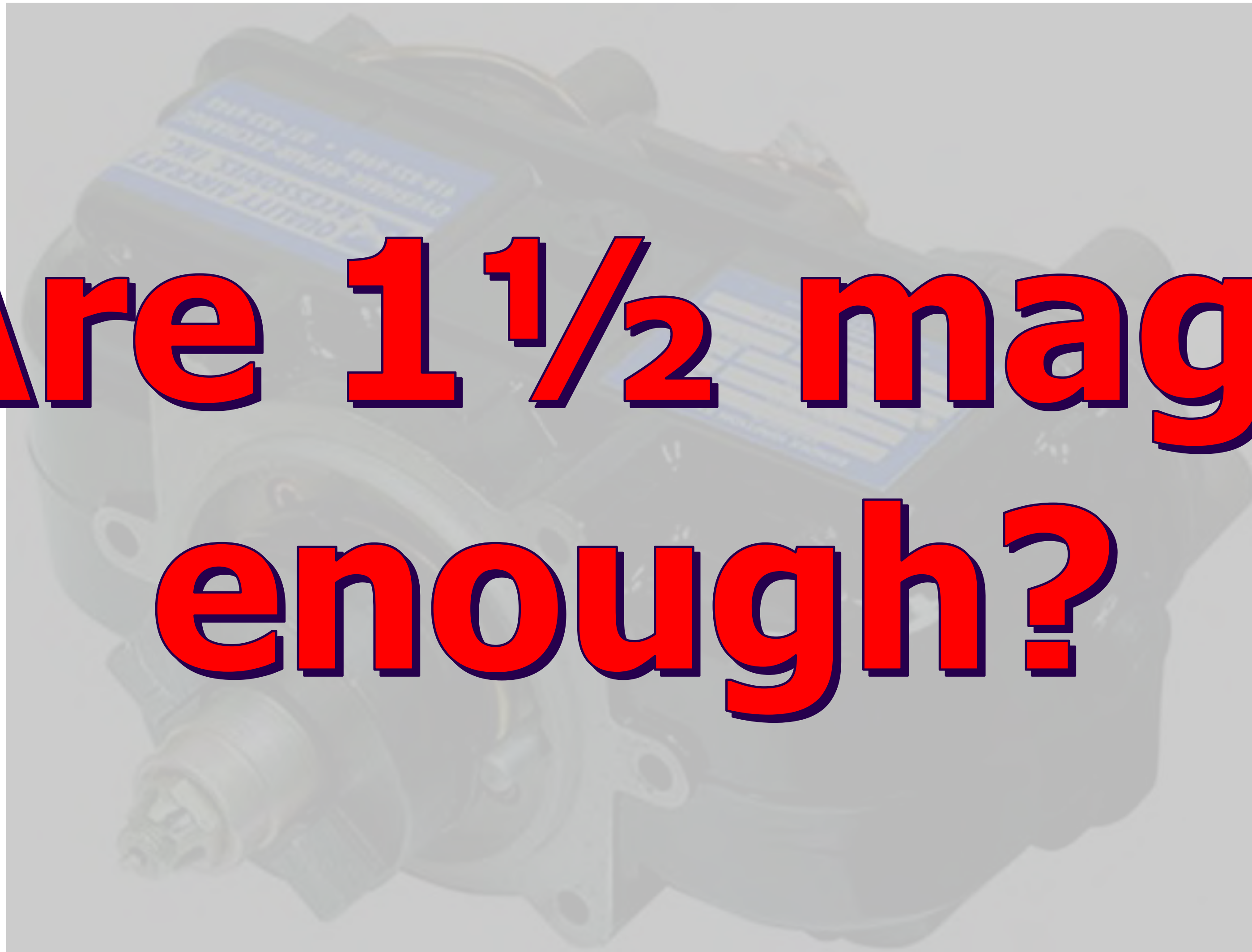
…but none of them did!

With a failure mode like this, having a good mag does you no good unless you shut off the bad one

Clearly, we have a pilot education issue



Are 1½ mags enough?



The Bendix D3000 dual magneto is used on many Lycoming engines

If your Lycoming engine model number ends in a "D" suffix—e.g., O-360-A1F6D or TIO-540-F2BD—it has one of these puppies

In essence, this is two magnetos packaged into one housing, with a single drive shaft, mounted on a single pad on the accessory case

Frankly, this probably wasn't Lycoming engineering's best idea

Many owners and mechanics have had bad experiences with dual mags, some declaring that they would not fly any single-engine airplane that was dual-mag equipped

The issue with the dual mag is that there are a number of single-point failures that can affect both magnetos simultaneously, compromising the redundancy required by FAR §33.37

Magneto clamp

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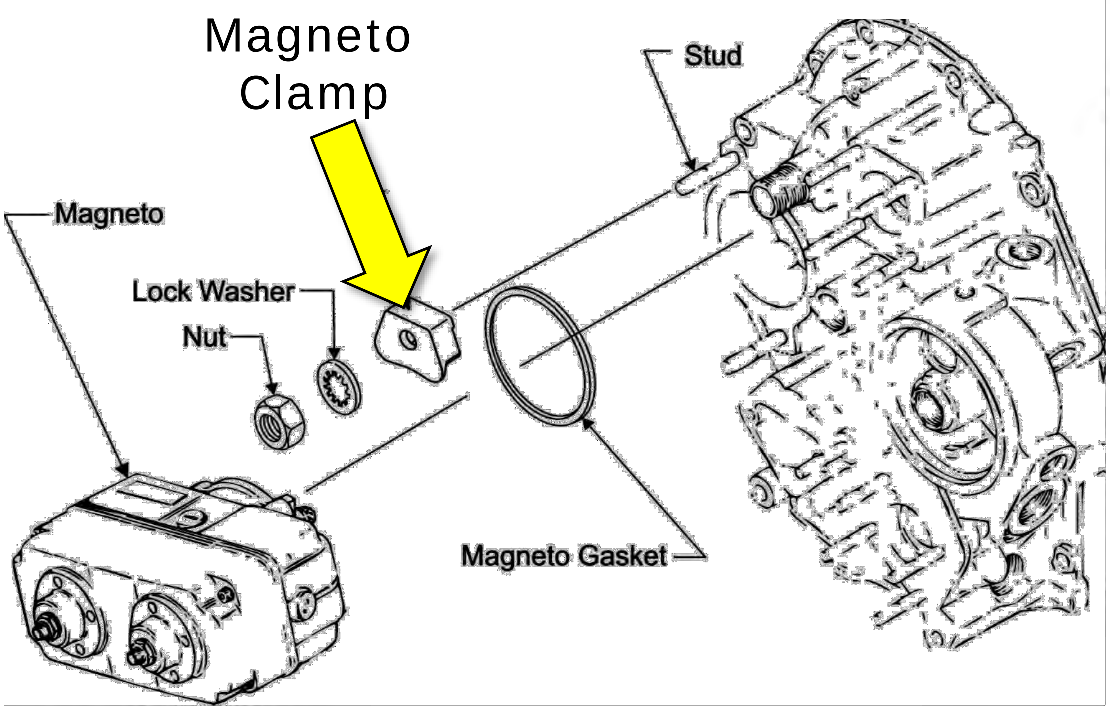
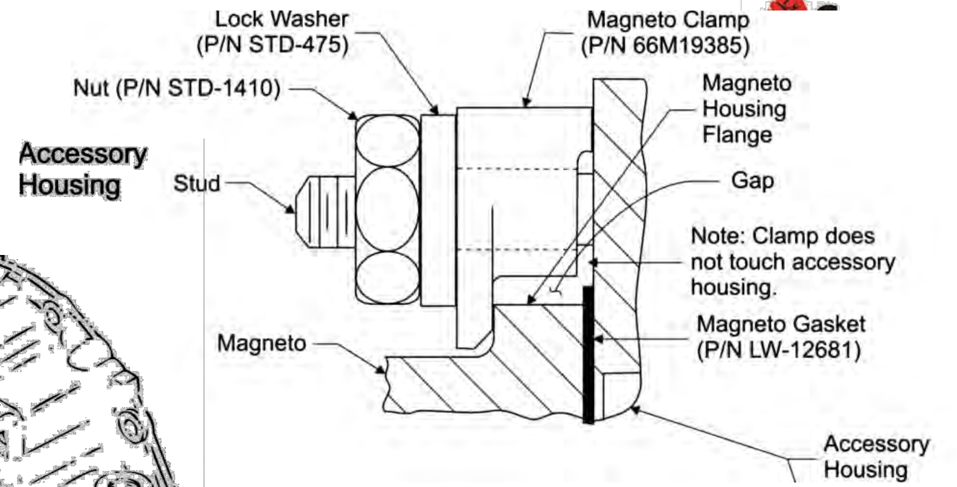
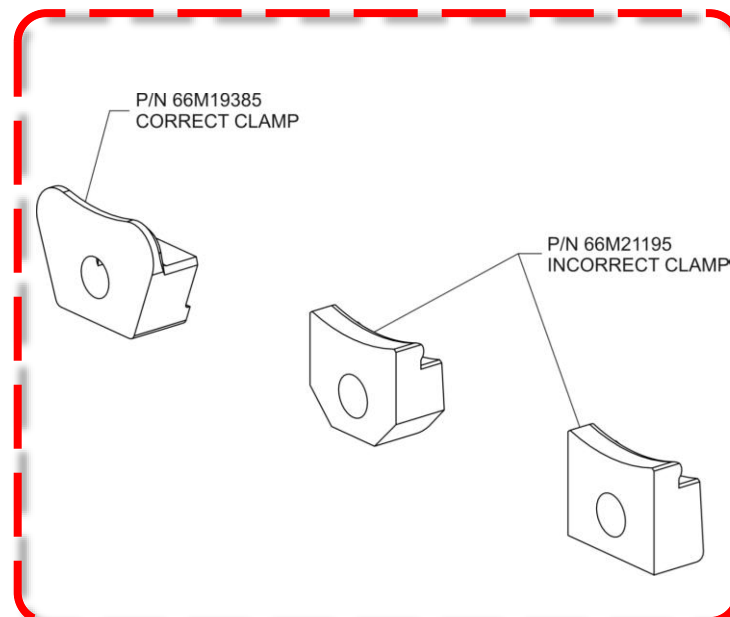
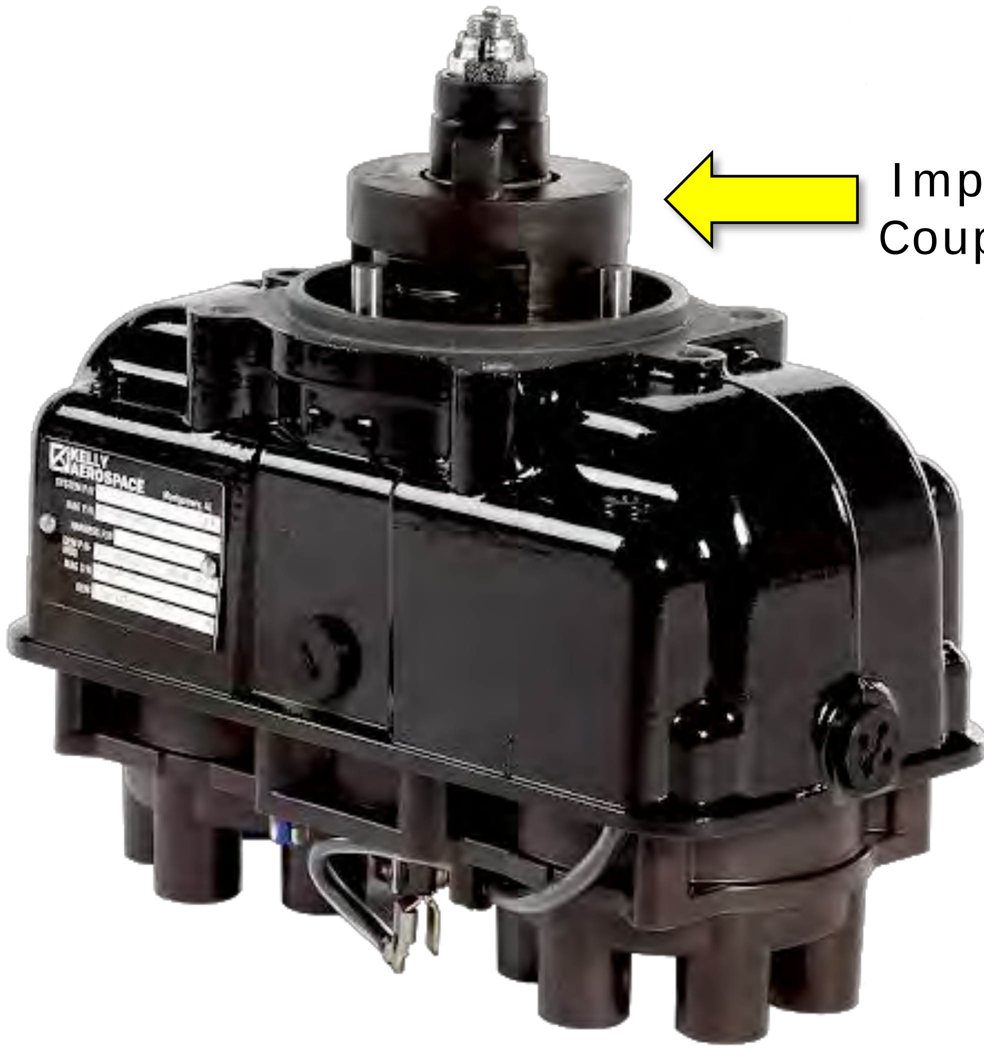


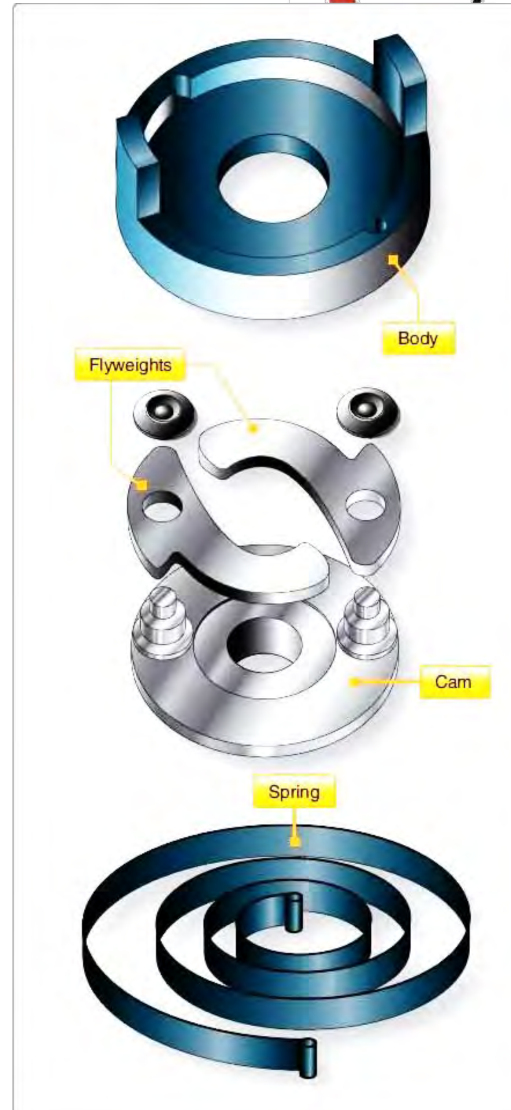




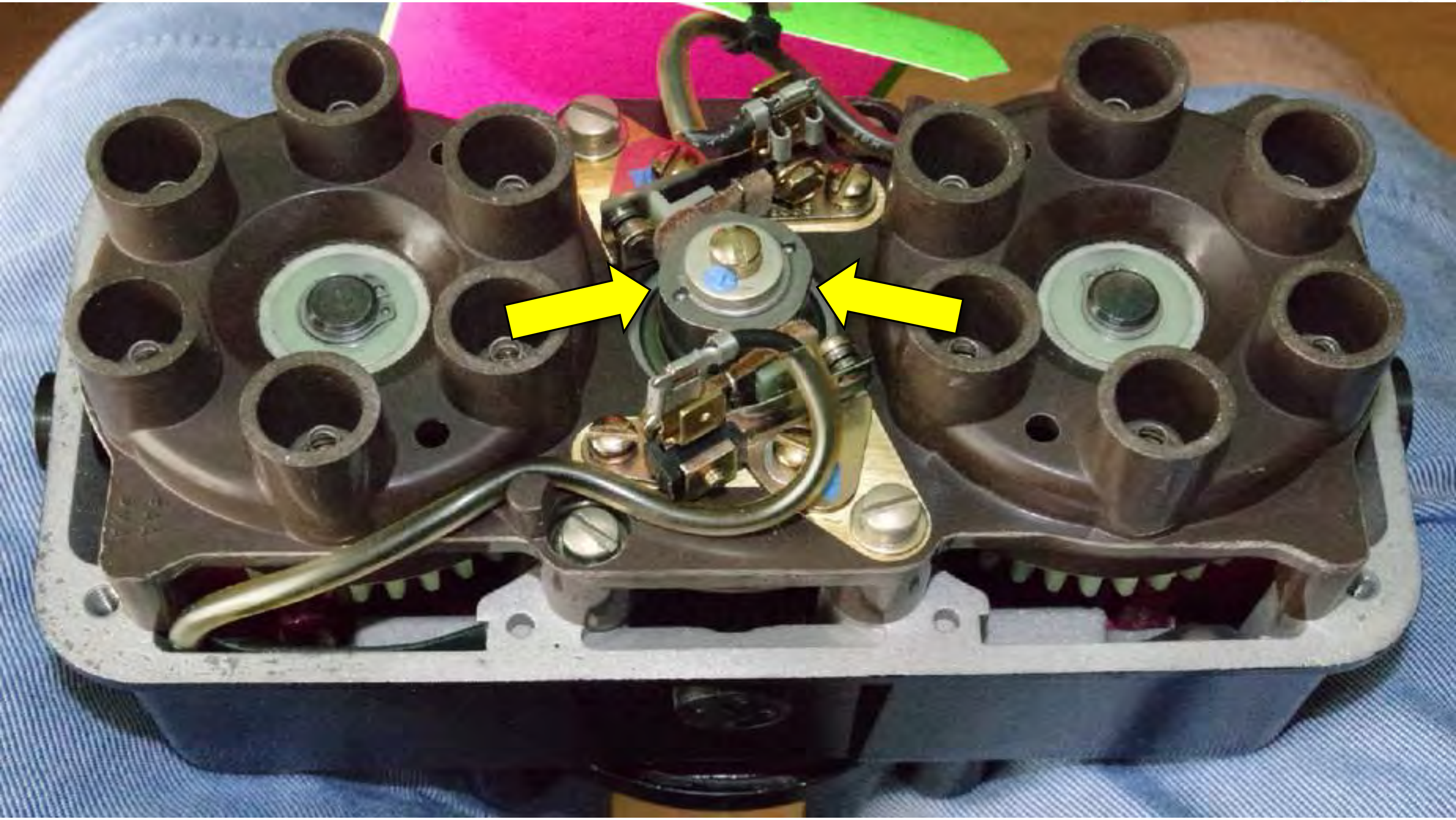
Impulse coupling



Impulse
Coupling



Cam



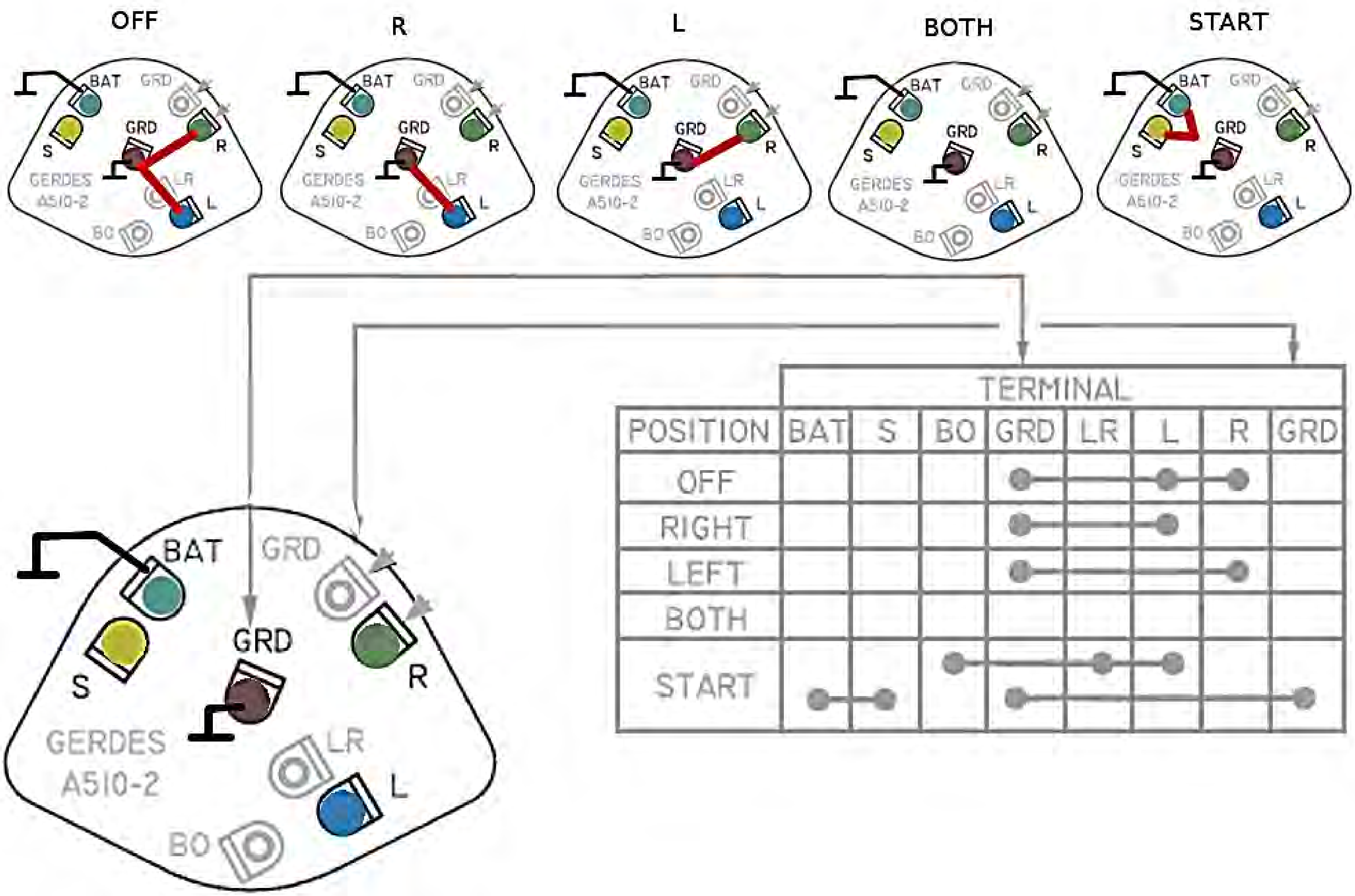
Although the dual magneto complies with the letter of the FAA's two-source requirement, it just doesn't provide the same level of redundancy as two conventional mags

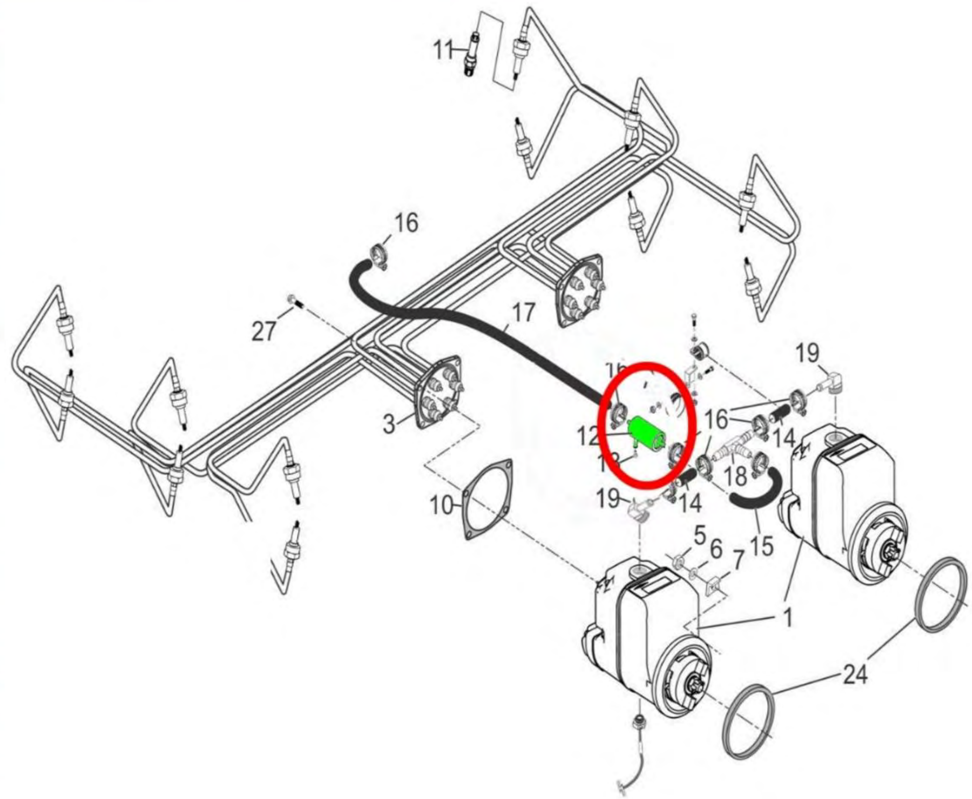
More single-point failures

Mag switch


MAGNETOS
R
L
BOTH
OFF
START
ELECT
FUEL PUMP
BCN LT
LAND LT
ELECTRICAL
PITOT HEAT
NAV LTS
TAXI LT
5
5
10
10
5
10
5

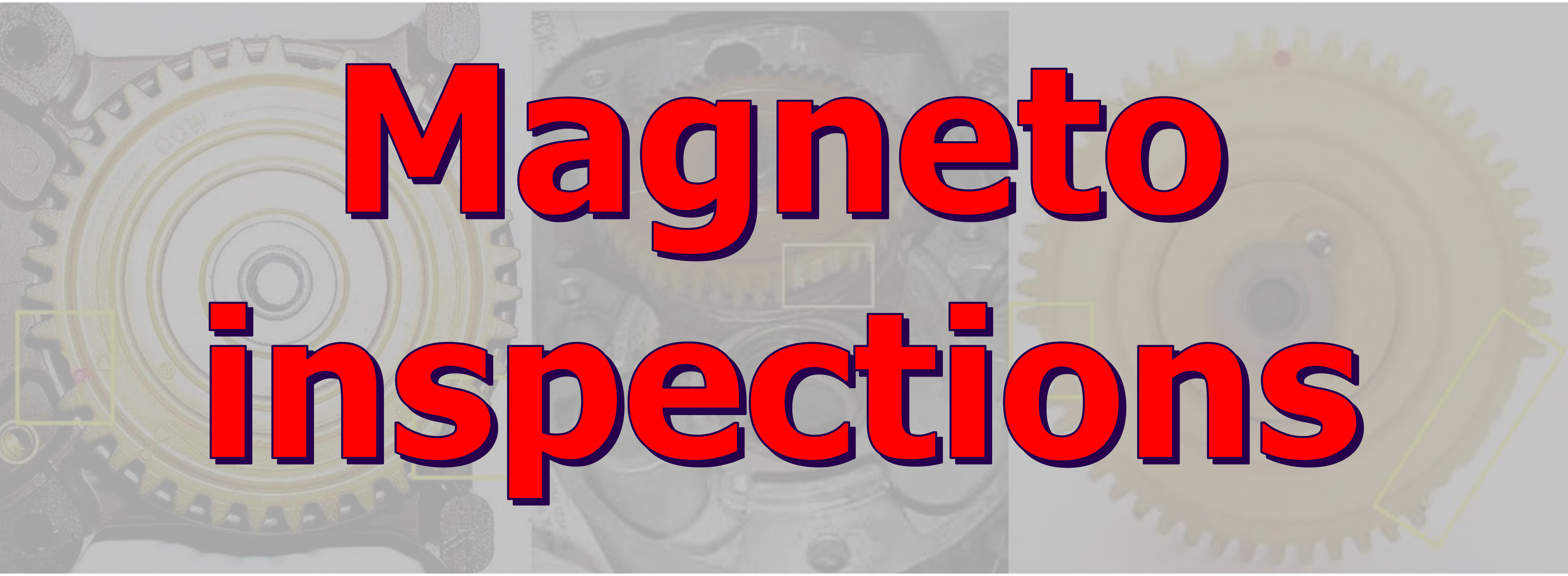
Mag switch


OFF
R
L
BOTH
START
BAT
GRD
S
R
L
LR
BO
GERDES
A510-2
TERMINAL
POSITION
BAT
S
BO
GRD
LR
L
R
GRD
OFF
RIGHT
LEFT
BOTH
START



Pressurization filter

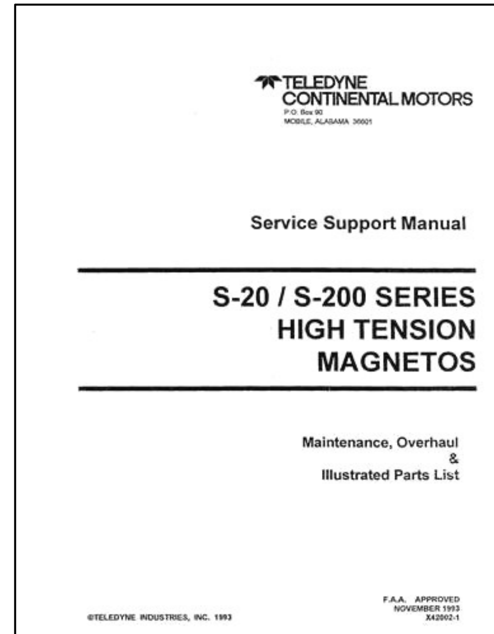
Magneto inspections



Magnetos normally receive only a cursory inspection during annual or 100-hour inspections

- The mag-to-engine ignition timing is checked and adjusted if necessary
- Perhaps the breaker points are checked for condition (or perhaps not)

Both Bendix/Continental and Slick/Champion recommend that their mags be removed from the engine and opened up for a thorough disassembly inspection every 500 hours


TELEDYNE CONTINENTAL MOTORS
P.O. Box 90
MOBILE, ALABAMA 36601

Service Support Manual

S-20 / S-200 SERIES HIGH TENSION MAGNETOS

Maintenance, Overhaul & Illustrated Parts List

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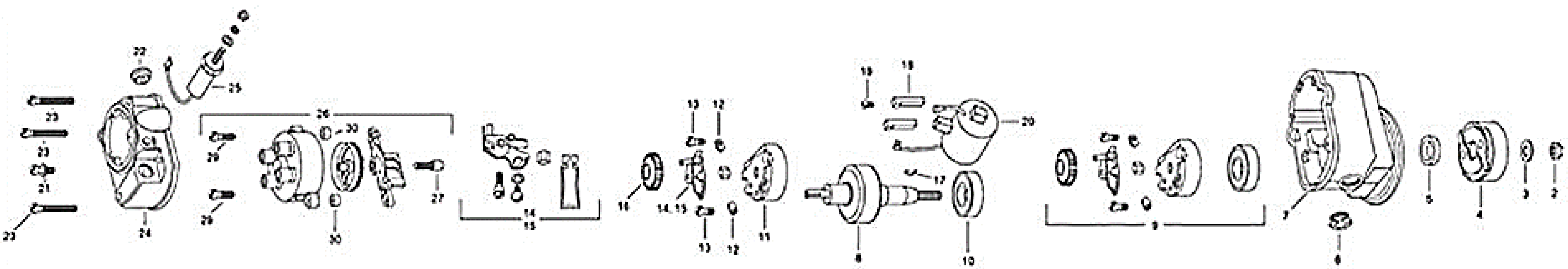
Although the 500-hour inspection is not compulsory for Part 91 operators, I have become convinced of the importance of doing them religiously

Although I'm a big believer in doing maintenance strictly on-condition, there's no way to assess the condition of a magneto without disassembling it



Although I would normally consider a component that is part of a fully redundant system to be a run-to-failure item, pilots don't do well in the face of magneto failure modes that cause the engine to go berserk

The 500-hour inspection

- inspect the magneto's breakable plastic parts (such as the distributor gear)
- replace various consumable items (such as the carbon brush)
- lubricate internal parts (such as the cam, gear, and felts)
- inspect the condition of the breaker points and reset the point gap to specifications
- reset the mag's internal timing ("E-gap")

Some A&Ps have the knowledge, special tools and inclination to perform these important 500-hour inspections themselves

Others prefer to send the mags out to a good magneto specialty shop

If your shop sends your mags out, make sure they ask for a 500-hour IRAN rather than an overhaul

IRAN

Inspect and Repair as Necessary

Mo 1000 #7	The EGT Myth
Mo 1300 #7	How Healthy Is Your Engine?
Tu 0830 #7	To TBO and Beyond…
Tu 1000 #7	Leaning The Right Way
Tu 1300 #7	Destroy Your Engine in 1 Minute
We 0830 #7	Cylinder Break-In: Do It Right
We 1130 #7	What Is Preventive Maintenance?
We 1430 #7	Cylinder Work: Risky Business
Fr 0830 #7	It's Baffling
Fr 1000 #7	Where Fuel Meets Air
Fr 1300 #7	Benefits of Running Oversquare
Sa 1000 #7	How Mags Work…and Fail
Sa 1300 #7	**Predictive Maintenance**

to attend my **free monthly maintenance webinars** on the first Wednesday of each month

(sponsored by EAA and Aircraft Spruce)

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to participate in my **free monthly podcast "Ask the A&Ps"**
with my colleagues Colleen Sterling A&P/IA and Paul New A&P/IA sponsored by AOPA

to receive my <u>monthly e-newsletter</u> and <u>weekly maintenance stories</u>

I'm happy to autograph your book

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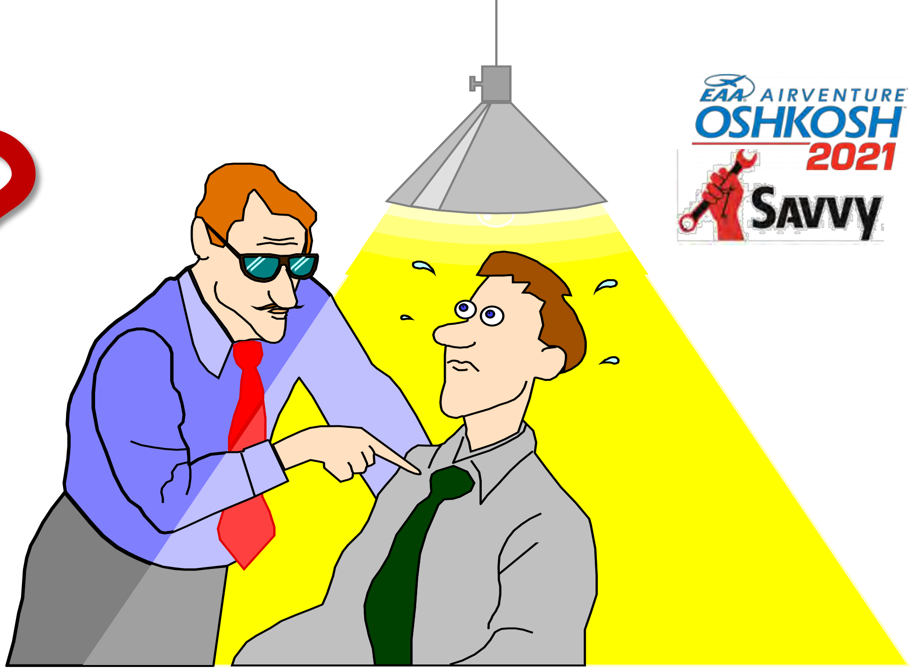
Savvy

Aircraft Spruce & Specialty Co. SINCE 1965

Available at amazon

PLEASE POST YOUR REVIEWS!

Questions?



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