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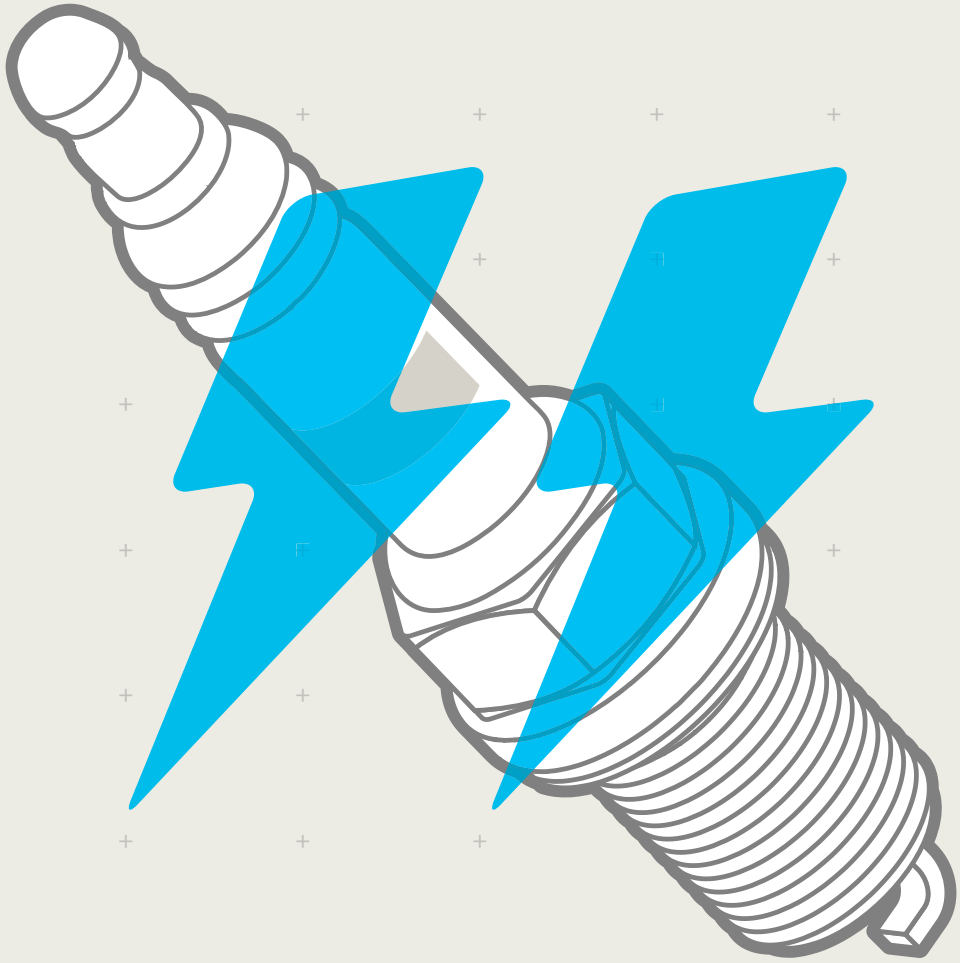
Tech

A Tale Of Two Sparks



norm HOWELL

This tale starts, as do most, with a desire to fulfill a lifelong dream. I had always wanted a very capable, fast and efficient airplane to call my own. I have been very lucky over the years to fly a pretty wide variety of airplanes in my career with the US Air Force, during my involvement with the Experimental Aircraft Association, and with my second career as an Engineering Test Pilot with The Boeing Company. But in the majority of cases, those airplanes belonged to someone else.

NORM HOWELL 1977 601P

1 | *Options include; Machen Intercoolers, High Altitude Turbos, Standard Props and Electric Air Conditioning.*

I had previously been in a partnership with other USAF members in a couple of different Mooney airplanes and a Long EZ. All of these airplanes have a very high product of speed and efficiency. No pilot wants a slow airplane (at least for travel) and smart pilots know that it is possible to have speed and efficiency in the same package with a really good design. So that's the type of airplane I wanted! I met my wife, Gretchen, while acting as a deputy Air Boss at the Edwards AFB Open House. She flew in with her own airplane, a very nice Mooney 201. "Things" developed, and we were married in 1999. We actually flew the Mooney from our wedding location at Mojave Airport, California, to the reception at our home in the Rosamond Skypark!

Gretchen and I enjoyed the 201 a great deal, but my job with Boeing was providing greater benefits than I had ever known before, and we both decided that when the time was right, we would buy an airplane with better capability. She had previously flown an Aerostar on several occasions, so when we got serious about airplane shopping, I wisely asked her what kind of airplane she wanted. Of course we could not afford a jet, but she then said "An Aerostar, but be ready when you go fly one, because it will be love at first flight!" As usual, Gretchen was right. I had been doing my homework, joined the AOA and gleaned as much tribal knowledge as I could from the association forum. In the summer of 2009, the market had turned very soft on twins (like it did in the mid 80s for singles, Gretchen bought her 201 back then for a song) and I spotted a couple of candidate airplanes at Aerostar Aircraft Corporation (AAC). I contacted Jim Christy and flew a 700 conversion, and then N425CA, the airplane pictured above.

> *Be ready when you go fly one, because it will be love at first flight!*

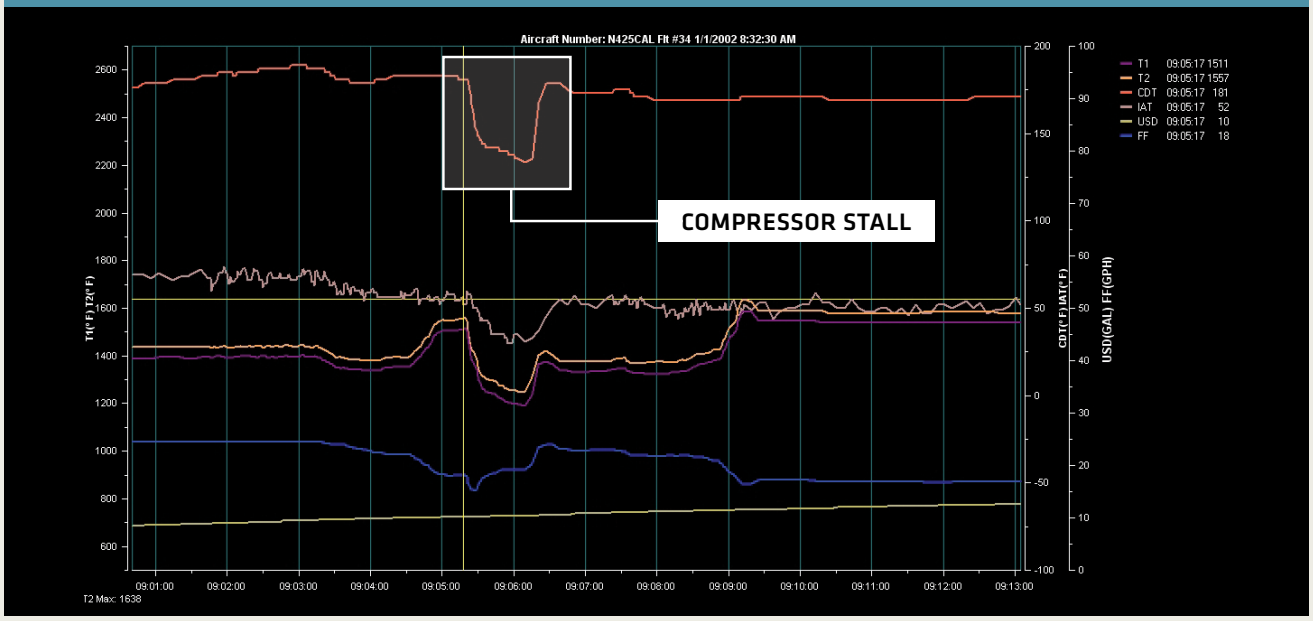
I was really impressed with 5 Charlie Alpha. Even though it did not have a lot of bells and whistles, and did not exactly have the paint scheme I would have chosen, it was a very solid airframe with little damage history and most of the systems worked. And the price was perfect. The previous owner let the annual run out the day after I flew it, so my bargaining position could not have been stronger. So, after getting some financing with Airfleet (great folks, there) I did what most everyone else reading these words has done.handed my entire wallet to Jim Christy and AAC!

2 | *Hooked another one! Norm starts out like everyone else - by handing Jim Christy all of his money!*

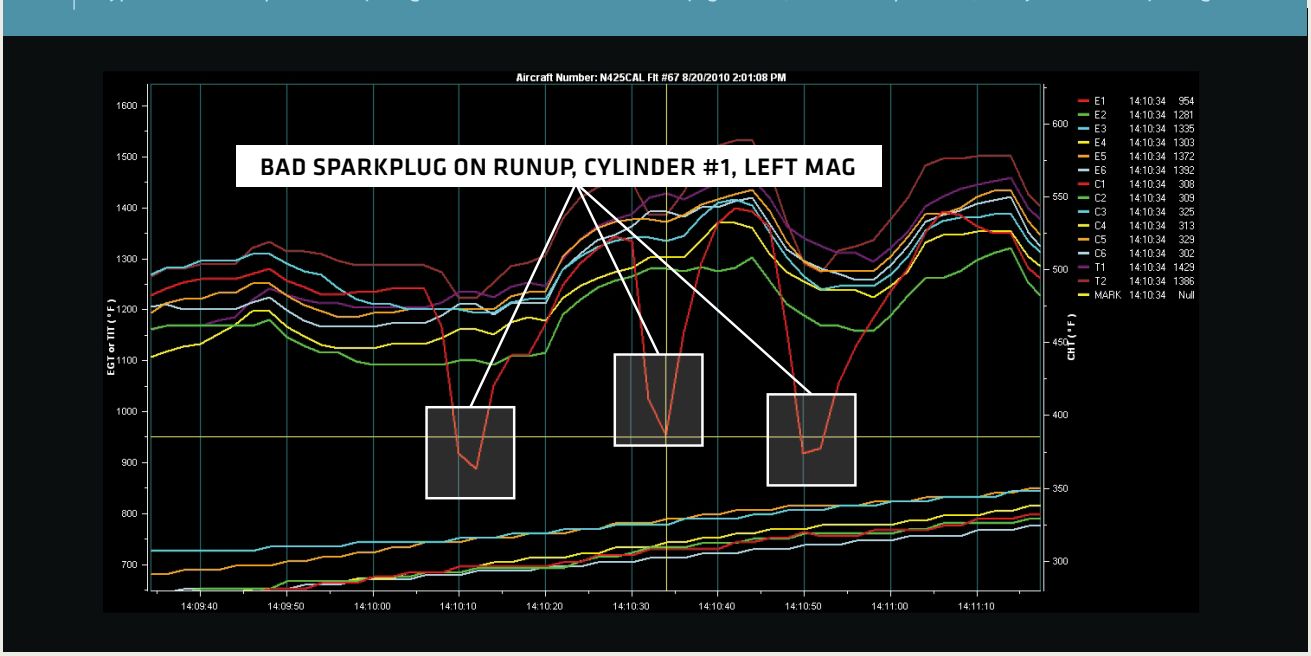
The Airfleet loan allowed for purchase and upgrades in the same package, so I elected to leave the airplane at AAC after I bought it to replace the timed-out right engine and do some avionics and interior upgrades. I put in the Plastech headliner and window shades (after winning the Plastech item auction at the AOA convention in 2009 by e-mail!), and totally upgraded the existing ductwork and air handling for the electric air conditioning. While the right engine was being replaced, I also elected to fully instrument both engines with a JPI engine analyzer system. At first I was going to install a JPI EDM 960, but the price went through the roof after JPI had to perform a huge amount of support on the first couple of units going into Aerostars. Instead, I settled on a JPI EDM-751-6C system, which is essentially two EDM 730s, side by side. The two units talk to one another and provide individual engine parameters as well as combined data such as total fuel flow, fuel remaining and waypoint information. I included TIT probes on each turbocharger, a combined compressor discharge temp before the intercooler and an induction air temp probe after the intercooler. The JPI units also record all engine data for

later analysis. The data is recorded at a 6 second interval by default, but the minimum user-selectable interval is 2 seconds, which is what I chose. The JPI engine analyzer system, with every engine parameter monitored and recorded, is the best money I have ever spent on an airplane. I pretty much knew there would be a shakedown period after I started flying the airplane and exercising its full capability. Little did I know how useful the JPI would be from the beginning. On my first flight solo, while flying the airplane from AAC, I set up for cruise at FL240 and brought the engines back from climb to my planned cruise power... 26" manifold pressure, 2200 RPM and 30 gph total. This cruise power setting is pretty familiar to intercooled 601 owners, and is about 70% power. The fuel flow is the published economy cruise from the Machen intercooler STC performance tables. I was pulling the props back slowly from 2500 RPM to 2200 RPM when... The left engine manifold pressure suddenly dropped to 20 inches, the engine surged some and the airplane yawed to the left. Oh great, I thought, my first solo landing in my new plane will be engine-out!! But after looking at the engine instruments for a few seconds, it became clear that the turbos were still putting out something, because the MP was still above ambient. So I undid what I just did, and slowly pushed the left prop control forward. At 2300 RPM the left engine MP jumped back up to 26" and the plane yawed back to the right. Power was restored! So I knew the problem was not catastrophic, but was likely a turbo controller or other imbalance in the induction system. The data trace below confirmed the actual problem; a compressor stall, shown by the sudden drop in compressor discharge temperature. I flew the airplane back to AAC and the troubleshooting began. As it turns out, the left bleed air valve switch in the cockpit had been wired backwards years ago, and the switchlight cover had been electrically reversed as well to make the indication appear correct to the pilot!! No one at AAC had ever seen this one before. The airplane had been holding cabin pressure for years on only the right bleed air system, and the pressure rise across the left compressors (with the bleed valve actually closed) combined with low mass flow rate through the turbine caused the stall. AAC fixed the bleed valve wiring issue and the problem was solved. In fact, the pressurization worked much better than before! So the value of the JPI system had been validated on my very first flight. Now, letís try to solve some other issues by using the data recordings. On most of my flights I would have poor mag checks on runups, with at least one spark plug on one mag fouling out per engine, every flight. I would lean like a Scotsman for taxi, and after failing a mag check, I would run the engine up at 2100 RPM, leaned out, "to burn off the fouled plug".

4 *Data trace shows sudden drop in compressor discharge temperature, due to stall. Engine is an IO-540-S1A5, Turbo normalized, high altitude turbos, Champion massive electrode spark plugs.*

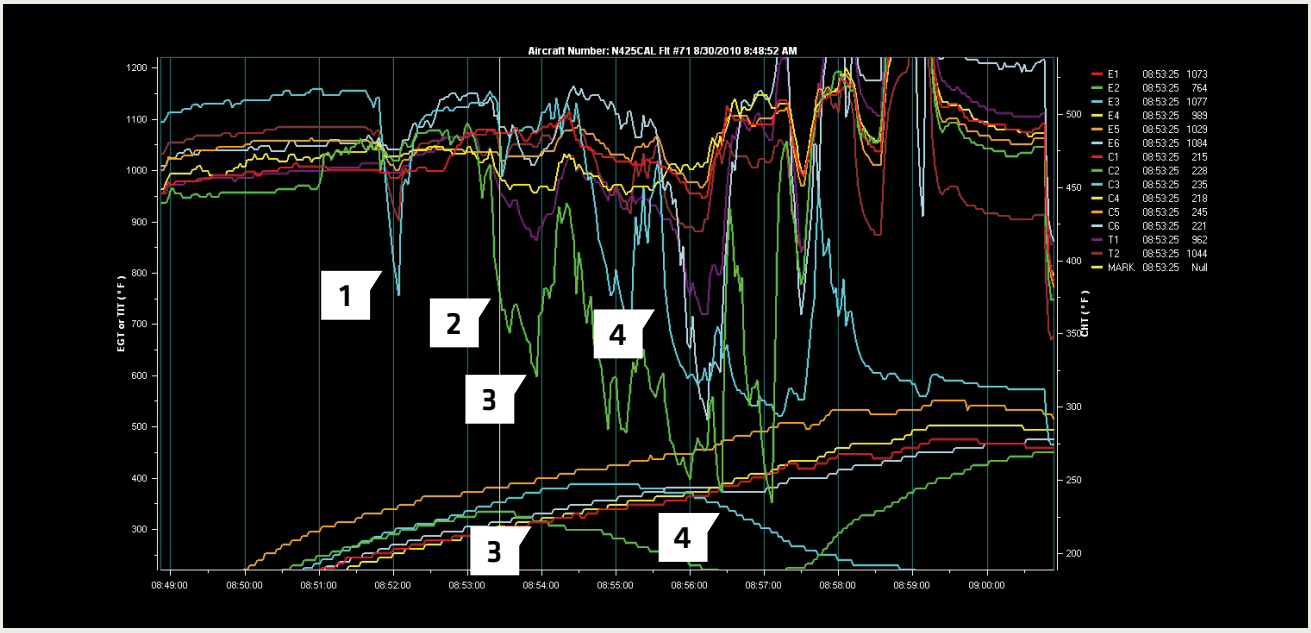


5 *Typical bad run-up on the left engine. Data trace shows lack of ignition (sudden drop in EGT) on cylinder #1, left mag.*



These poor runups were frustrating because I knew both engines had mags with fewer than 150 hours on them, and the ignition harnesses and plugs had been cleaned and inspected at AAC on high-quality equipment. I figured the problem was due to poor starting technique or some other pilot-operation issue. With leaning during runup and an extended engine warm-up period, I could get a satisfactory mag check, but the problem was not getting any better. Finally, I had the mother of all bad runups, as shown below.

6 *So many problems happened with this runup that we have to do it with key numbers.* ***(1)*** *#3 cylinder, bad sparkplug, left mag, blue data trace is EGT and the red trace dragged down behind it is the associated turbo #2.* ***(2)*** *#2 cylinder, bad sparkplug, right mag, green data trace is EGT, purple trace dragged down behind is turbo #1* ***(3)*** *Now both sparkplugs in cylinder #3 fail to spark, notice associated drop in CHT (lower green trace)* ***(4)*** *Then BOTH sparkplugs fail in cylinder #2 with associated drop in CHT. (lower light blue trace) Back to the hangar. No flying today!*



I had several discussions on this issue with Jim Musgrove, a Boeing colleague in my office who is also one of the most well-respected aviation maintenance technicians (AMT-IA) in Puget Sound. Jim had been working with an owner-client of a Seneca twin whose problems had progressed beyond my experience to include a rough running engine while airborne. After Jim told me about the Seneca owner, he asked what kind of spark plugs I had. I said "Champion, massive electrode, RHB37E, but I would like to go to fine wire plugs". He told me that was a good idea and to let him take a look at the removed massive-electrode spark plugs when I had them out of the airplane. I had wanted to go to fine wire plugs because of the lessened fouling potential and the possibility of a little more efficient operation. RAM Aircraft Corp in Waco, Texas, had characterized a 2.2% improvement in cruise efficiency on their products using fine-wire plugs (see www.ram aircraft.com/Maintenance-Tips/Spark%20Plugs-Fine-Wire-vs-Massive.htm) and that was good enough for an efficiency freak like me. At about this time Aero Accessories had finalized production and approval of their Tempest brand spark plugs... the price at $49 each handily beat brand C fine-wires at $90 each...so as soon as a set of URHB36S fine wire plugs were available from Aircraft Spruce I bought 'em. Now, the following information may seem a bit techni-

:: design comparison between the two plugs ::

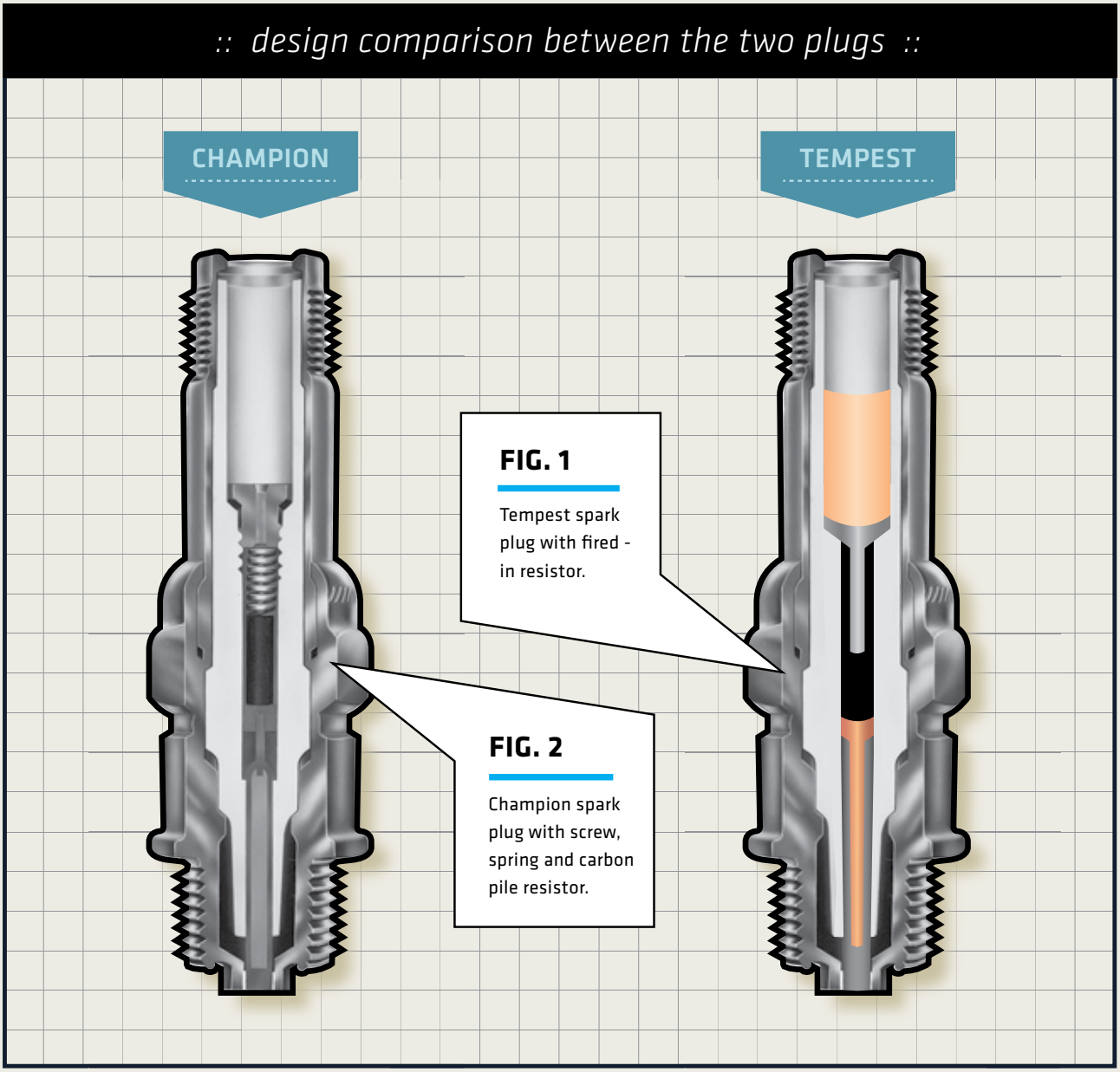


FIG. 1

Tempest spark plug with fired - in resistor.

FIG. 2

Champion spark plug with screw, spring and carbon pile resistor.

cal for Aerostar owner/operators who have not wrenched on their own plane, but among the Preventative Maintenance procedures authorized by 14 CFR 43, Appendix A for pilot owner/operators to perform on their Part 91 airplanes is spark plug removal, cleaning and gap-setting. So the maintenance procedures and information following may be implemented by any pilot owner or operator of an Aerostar! I removed the old Champion massives, gave them to Jim and we discussed the problems he has been seeing with other owner-operators of these plugs. By way of background, Champion spark plugs are constructed with a center resistor carbon pile, spring, and screw stackup. Tempest plugs, on the other hand, have a fired-in resistor that is integral to the plug. See the cross sections at left. This is the problem we are seeing: a number of Champion spark plugs have not held stable resistance values across the center electrode over what would otherwise be normal service lives and condition. Nominally, the resistance is about 1000 ohms on the center electrode. However, the Seneca owner (and others) found much higher center electrode resistances after the plugs have been in service for some time. This has been leading to operating problems such as poor runups and engine roughness in flight. Jim measured the removed spark plugs from my Aerostar for center electrode resistance and provided the following results:

:: *Aerostar Engine Spark Plugs* ::

Ted Smith Aerostar 601P N425CA Spark Plug History

Left Engine												
4/22/2011	100 Hr/ Annual		Hobbs 993		New Tempest URHB36S Fine Wire Spark Plugs installed							
			TT TSMOH									
5/31/05	Installed 12 each Champion RHB-37E spark Plugs					Hobbs 883.5						
						TSMOH 1321.0						
	1431.1	TSMOH										
	1321	TSMOH										
	110.1	**Time on spark plugs over 5 years and 11months**					Manufactured in 2004					
	Resistance c											
Manf date	1J04	1J04	1J04	1J04	1J04	1J04	1J04	1J04	1J04	1J04	1J04	1J04
Resistance	Inf	50K	500K	250K	4K	12K	3K	60K	Inf	90K	6K	1.5K

New Champion Spark Plug center electrode resistance is nominally 1000 ohms.

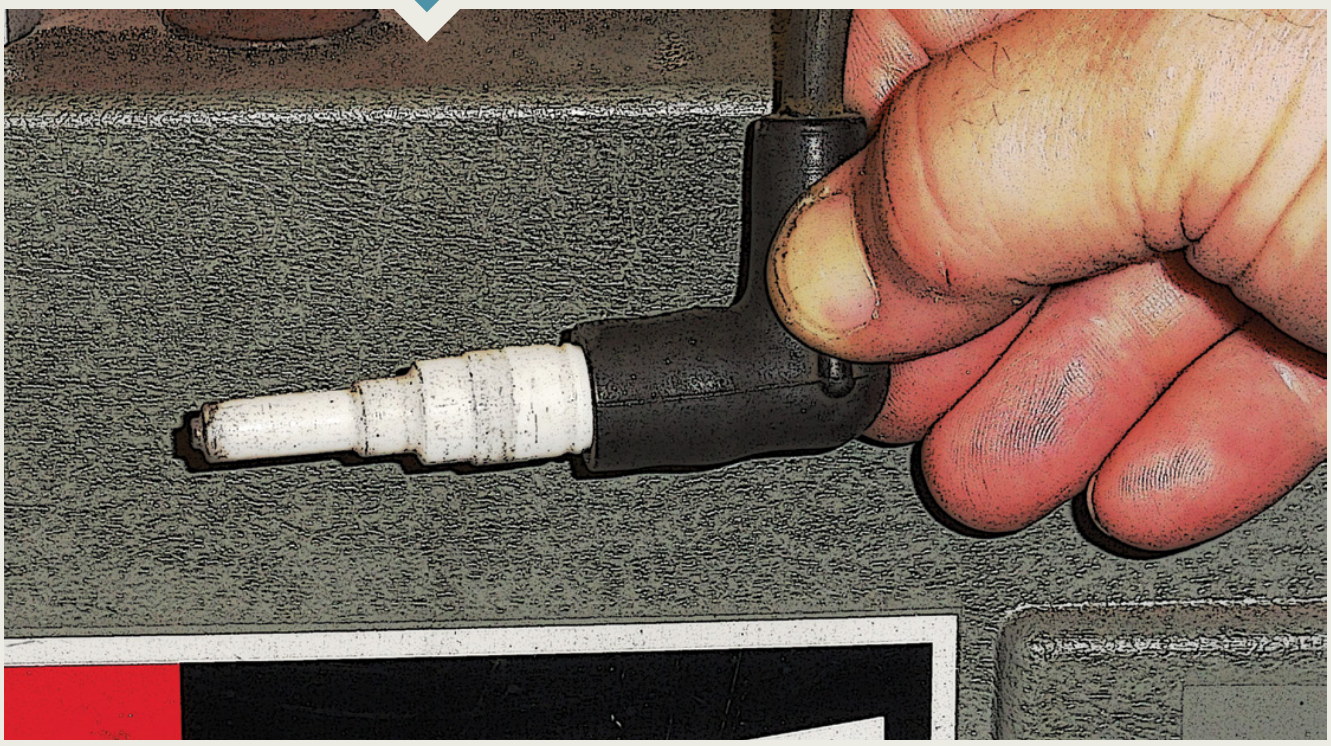
Right Engine												
4/22/2011	100 Hr/ Annual		Hobbs 993.6		New Tempest URHB36S Fine Wire Spark Plugs installed							
			TT TSMOH 26.4									
2/1/04	Installed 12 each Champion RHB-37E spark Plugs					Hobbs 883.5 (on a different airframe)						
						TSMOH 876.5						
Hobbs 981.2; 3//3/10 Engine built up no mention of spark plugs												
0.00 TSMOH, Total time in service 2289.1 and recording tach ; No mention of spark plugs												
2/1/04; TT 2203.7 & Recording Tach TSMOH 876.5 (Note) Logs state, "removed old spark plugs and installed new units"												
	2289.1	0.0 TSMOH										
	2203.7	new spark plugs installed										
	85.4	Time on spark Plugs @ installation on R/H engine of N425CA										
	26.4	Time on spark Plugs @ installation of new tempest Plugs? on 4-22-11										
	111.8	**Total time on Champion spark plugs over 8 years & 2 months installed but 14 years old**									Manufactured in 1997	
Resistance												
1L97	1L97	1L97	1L97	1L97	1L97	1L97	1L97	1L97	1L97	1L97	1L97	
1K	1K	1.2K	3K	1.5K	5K	1.1K	2K	1K	1.1K	1K	1K	

Generally articles say that anything up to 3K 3,000 Ohms is ok
So basically all of the older But one 1L97 (manufactures in 1997) could be cleaned and used again.
It is interesting that all but one of the 1J04 plugs Manufactured in 2004 are well over the limit.

A Tale Of Two Sparks

This was astonishing. 11 out of 12 plugs from my left engine measured at least three times the nominal value of 1000 ohms across the center electrode. Two of them measured infinite resistance and had evidence of connector well flashover inside the terminal well. However, none of them were rejected prior to this point because they ALL tested satisfactorily on a spark plug tester! In addition, the left engine plugs were 6 years old, but had only 110 hours on them. In contrast, the right engine plugs were several years older, had a little more time on them and 10 out of 12 were OK. Champion does not publish any service criterion for center electrode resistance in its Aviation Service Manual (ASM - free download here: http://www.championaerospace.com/assets/AV6-R-Nov2004.pdf). They only specify a "satisfactory spark" jumping the specified gap while being tested on a CT-475AV Cleaner/Tester (sometimes referred to as a "bomb tester"). All of the other reconditioning and servicing instructions in the ASM are concerned with physical cleaning and inspection of the spark plugs. However, other sources have published a criterion for center electrode resistance. Specifically, John Schwaner of Sacramento Sky Ranch recommends a maximum resistance of 5000 ohms (http://www.sacskyranch.com/eng37.htm) and there are other sources who recommend 3000 ohms or so. It is important to note that there are no hard and fast rules for center electrode resistance, so the decision to retain those plugs in service if all other inspection criteria from approved data sources (such as the ASM cited above) are met rests with the individual performing the preventative maintenance. Having said all that, the question then becomes: Why doesn't the Champion bomb tester detect a high resistance plug by failing to throw a spark at the firing end, assuming it is properly calibrated per the Champion ASM? Perhaps the design of the lead that connects to the terminal well may be a factor.

8 | *Tester lead on Champion cleaner-tester part # CT-475A. The lead is ceramic with a center electrode and has much higher resistance to connector well flash over than a normal aircraft ignition lead. This may be why high resistance spark plugs will test as "good" on the machine.*



Measuring the center conductor resistance on an brand new Champion Massive Electrode spark plug. Meter shows a nominal resistance of about 1000 ohms.

Notice the lead is a solid ceramic piece, with the electrode down the center. The tendency for connector well flashover using this lead is much less than what exists in the airplane because the silicon airplane ignition leads do not provide nearly the same insulating value as the solid ceramic. The tester built by ATS (model SPCT100, see it here http://www.aircraftspruce.com/catalog/topages/atsSparkPlugCleaners.php) has a test lead which is much more like the ignition lead in an airplane. High resistance spark plugs tested on an ATS machine are more likely to flashover at the connector end in the same manner as the airplane. Jim has noted that conducting such a test in a darkened room on a high resistance plug provides a rather spectacular light show at the connector end! Of course, sparks outside the cylinder don't do any good at all for the Aerostar pilot. Even though the following are just suggestions for good preventative maintenance practice, I believe that Champion's eventual publication of an inspection criterion for its spark plug center electrode resistance values in the ASM is just a matter of time. So, the next time you have your spark plugs out of the airplane, test the center electrode resistance as shown above.

Any plugs with values higher than 3000 ohms should be subject to very close scrutiny, along with the associated ignition leads. As an example, I tried this procedure on 7 unused Champion REB37E spark-plugs removed from a radial engine that was going to a museum. One of those plugs showed infinite resistance, brand new! Since it was of questionable utility at this point, I removed the terminal well screw, spring and carbon pile: (FIG 10.1) And this is what I found (10.2).

FIG 10.2

Maybe this is why 1 : Loctite sealant is clearly visible on the mating surface of the screw. This plug may have started firing under vibration and heat, however. The carbon resistor still had the nominal 1000 ohm resistance.

:: *Disassembled and Unused Champion Spark Plug* ::

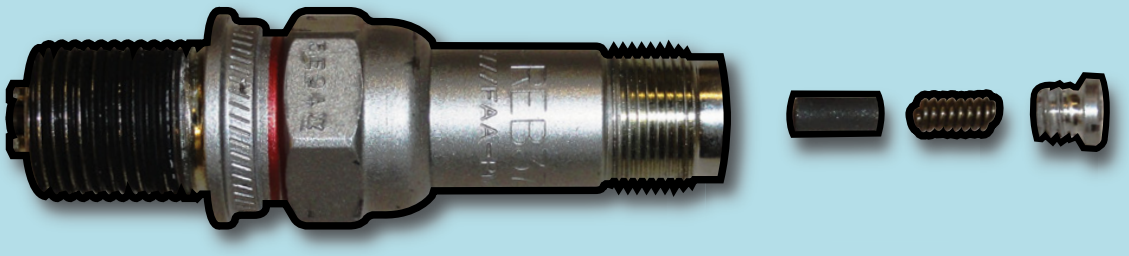
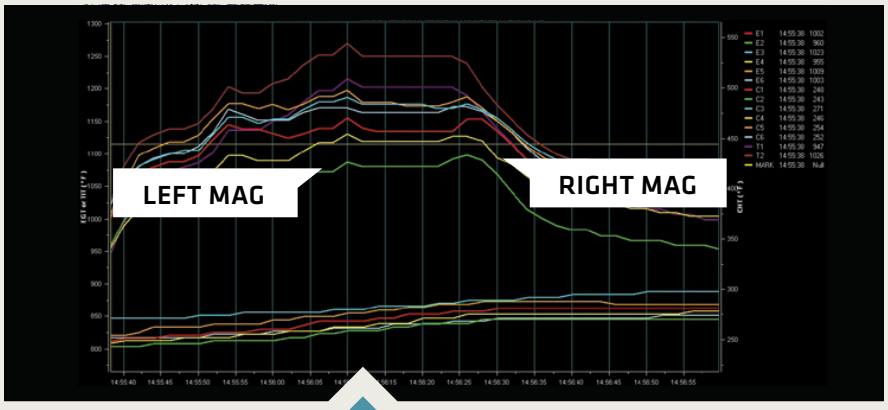


FIG 10.1 This plug showed infinite resistance of the center electrode without any engine time.

This plug, in service, may have been problematic from the beginning... or maybe not. At any rate, the check of spark plug resistance as a preventative maintenance practice should be well within the capabilities of any pilot owner/operator, and won't really consume that much time. And what of my Aerostar? Well, after replacing the Champion massives with Tempest fine-wire URHB36S plugs, I have not had a single "fouling" problem on runup. Here is a much better graph of such a runup, at right:



12 | *A good runup with Tempest fine wire spark plugs. Arrows point to slight, even EGT rise on all cylinders while running on one magneto. Let's go flying!*

I believe the "plug fouling" I had experienced before was actually connector well flashover during runup. I also believe that if I had kept the previous plugs in service and limped the airplane through runups, that eventually I would have a rough running engine in flight, just as others have with the same causal factors. Gretchen does not like rough running engines! Although Tempest does not have a long service history at this point, it would appear that the design of their spark plugs is intended to preserve the resistance values of the electrode over time. In addition, their pricing for plugs ($22 vs $25 for massives, $49 vs $90 for fines) makes my own personal choice for spark plugs a no-brainer.

My preference is pretty clear at this point. I am sold on Tempest fine-wire plugs for my Aerostar, and will plan to check their resistance values in addition to the normal service visual inspections, cleaning and gapping anytime they are out of the airplane. Happy flying to you in the worldís best piston twin airplane!

POINTS TO TAKE AWAY;

1. Some Champion aviation spark plugs appear to increase their resistance above the new value of about 1000 ohms some time after being placed in service.
2. High resistance spark plugs can cause problems with runups, misfiring, rough engine operation and stress on other ignition components.
3. The published reconditioning data does not address this issue, and the normal spark plug electrical tests may be ineffective in detecting high resistance due to the design of the testing machine.
4. High resistance spark plugs may not wear out their electrodes as quickly due to weak spark energy, therefore they may not be retired as quickly due to electrode wear.
5. A simple measurement of center electrode resistance may provide additional clues for operating problems or provide a cue for a decision to continue a spark plug in service.
6. Some Aerostar operators use a practice of retiring massive-electrode spark plugs every two years regardless of condition.
7. Tempest spark plugs may prove to be a more robust design, but no conclusion can be drawn without an extensive service history.
8. An engine analyzer with data recording capability is the absolute best accessory any piston engine airplane can have.

AUTHOR biography

NORM HOWELL

the story behind the pilot

FORMAL EDUCATION:

BS, Aeronautical Engineering, USAF Academy, 1982. Graduate, USAF Test Pilot School, 1992 (Master's Equivalent). Master's Studies, Mechanical Engineering, CSU-Fresno, 1995. Currently enrolled, MS, Aeronautical Science, Embry-Riddle, 2006

COMPANY / ORGANIZATION:

Boeing, Test and Evaluation, Puget Sound ASW&ISR Flight Operations, Tukwila WA

CURRENT POSITION:

Senior Experimental Test Pilot, 737/757/767/CT-133

BRIEF DESCRIPTION OF DUTIES:

Responsible for flight execution of engineering flight test for military derivatives of the above airplane models

BRIEF DESCRIPTION OF PREVIOUS AVIATION EXPERIENCE:

First Flight, Boeing P-8A Poseidon, 2009. Senior Experimental Test Pilot, C-17, Blocks 10 thru 17, 1998 to 2008, numerous awards and firsts including 7 world aviation records. Last Flight, YC-15, July 1998. First Flight, Cirrus SR-20 Prototype, March 1995. First Flight, Cirrus ST-50 Prototype, December 1994. Experimental Test Pilot, F-16, 1993-1994, HARM Targeting System, Tri-Service Standoff Attack Missile, GE-129 Performance, LANTIRN Terrain Following Radar tests.

OTHER INFORMATION OF INTEREST:

Own two GA airplanes, a Mooney 201 and an Aerostar 601P, Gretchen and I have owned or co-owned 7 GA airplanes over the years and were responsible for 12 others in a southern California flight school during 1982-1983. SETP Associate Fellow, member of EAA since 1979, EAA Flight Advisor, AOPA member. 2006: Selected as the 2006 recipient of the SETP Iven C. Kincheloe Award for Outstanding Contributions to Flight Test for over 8 years of continuous duty on the C-17 follow-on flight test program. 2005: Published "Messier-Bugatti Wheels and Brakes Tests on the C-17" in Cockpit, 3rd Q 05; Presented paper on same topic to SETP Fall S & B, 2005 Ray Tenhoff Award. 1997: Presented "EAA Flight Advisor Program" at SETP Fall S & B. 1997: Presented "Spinning the Spin Doctors" at the SFTE Symposium in Reno, NV. 1995: Published "Have Pacer II" paper in conjunction with TPS class, paper developed a new GPS speed course method, which has been incorporated into USAF TPS textbooks.