# USING ( LIFEPO4 ) LITHIUM IRON PHOSPHATE BATTERIES

## *FOR AVIATION APPLICATIONS ..slide 1*

Thank you for coming to this presentation to hear how Lithium starting batteries can benefit you. Today I will dispel the myths and erroneous information that you may have been exposed to and clear up any misconceptions you have. Later on, different batteries will be shown and their performance tested.

I ask that u hold on your Q's till after the presentation

My name is Andy Reich, my battery background is in electric vehicles which have used Lithium batteries now for years and are way ahead of the aviation industry.

You have all heard the horror stories and seen all the videos of flaming laptops and cell phones and lithium cells that cannot be extinguished and how dangerous all of them are on aircraft after a few highly publicized isolated incidents, Now, all lithium batteries are considered hazardous cargo. But, they are not all the same.

BE very afraid your told. But, your told nothing else, your not told the facts. Your not told that primary cells - which are the non rechargable types - , laptops and cell phones use a different lithium chemistry and if they are shorted or crunched in a passenger seat hinge, yes they will have smoke and possible flames. No surprise there. But, what do the regulators do ? They ban and restrict everything that has the word Lithium in it.

The lithium cells and batteries are not the problem, it's the people mishandling them. It's the ground personnel hooking up a GPU to a citation with a lithium battery where clearly there is no need to do so. . So, now, everybody is scared of Lithium. So, lets find out…

* How many here today are scared of Lithium raise your hand ? *..ok.. How many are scared to raise their hands ? * … And of course those who have an investment in the status quo are also not in favor of allowing lithium to be approved for certified aircraft.

thank goodness for experimental.

**So**..We'll start off talking about the <u>inherent safety</u> of iron phosphate type of lithium chemistry. I repeat .. the inherent safety 3***– read table –2***

The important advantage of LiFepo4 over other Li types is the thermal and chemical stability, why u ask ?.

As compared to the LiCo type, who's cathode structure changes from multiple charge/discharge cycles, the phosphate cathode in the lithiated and unlithated state are structurally similar, which gives stability to the cell. The carbon anode – a lithiated graphite – is much safer as there is less chance of lithium dendrite formation which can

cause internal cell shorting which is more commonly found in the other more volatile chemistries.

These cells have a carbon anode and po4 type cathode. This cathode material is held together because of the olivine crystal structure **slide 3** and strong covalent bond between phosphorus and oxygen. This stabilizes the fully charged cathode instead of releasing O2. The only thing that transfers is the Li ions. So, There is no chemical reaction that is transferring the charge. That's why they are safe.

So, quite simply stated; LiFepo4 has a lower +3 valence state in the charged cathode, this prevents O2 release and any possible thermal runaway. The Oxygen stays bonded, no free O2… therefore, nothing happens, even at temps at 160 celcius / 320 **F slide 4 & 5 .. explain sandia**

Even in an overcharged state, this type lithium battery is not combustable, no exothermic reactions…ie, fireballs

No lithium remains in the cathode of the fully charged cell, compared to a cobalt type that keeps 50% saturation and is much more volatile.

All the excitement happens up here, here is where fireballs and fireworks happen, it's here's where all the news stories happen, all the govt regulations are based on this area.

SO.. Has any govt. regulatory agency ever told you about the inherent safety of LiFEpo4 type batteries ?? .no of course not, that would mean issuing regulations based on facts .. we cant have that happening now can we ?? nooo, they lump all Lithium into the same basket.

Same with shipping regulations, which is not part of this presentation

OK ……..

Now that you know the facts, your not scared anymore .. right ??

Ok, then, lets talk about performance differences in lithium cells.

Not all lifepo4 material is equal. There are low capacity / hi rate cells, and hi capacity / low rate cells.

A good Lithium Starting battery will use hi discharge rate cells. The higher the better. **Slide 6**

That's why lithium batteries can be so small. Compared to lead, Lithium has 3 x's the energy density and power density. Rule of thumb, 1Ah of Lithium = 3Ah of lead.

Here are some examples of Impedance values for batteries being sold today.

**Slide 7** This 5Ah battery in the orange & black plastic case shows a value of 19 milliohms. See the needle…

**Slide 8** The battery in the black case shows 10.3 milliohms. Advertising 4.7Ah / 14Ah pb equivilent

**Slide 9** This 3rd battery in the unique see thru clear case shows 11 mohms for 4.4Ah capacity

Hi rate cells have low impedance values. This measurement is important to rate the cells ability to carry hi current loads and not heat

up on discharge. This is known as the C-rate. This is why I always ask a customer what engine and starter he has and if he knows the cranking starter current. Show clamp ammeter . This info helps decide the proper size lithium battery to start the engine.

Higher impedance lithium batteries exhibit a higher voltage drop under load. So, keep this in mind when choosing a lithium battery. Or any battery for that matter. Batteries that have a higher internal resistance, will heat up quicker and suffer from voltage sag under heavy loads. These batteries have a lower C rate. **Slide 10**

The prize for hi internal resistance of course goes to lead acid batteries, The disadvantage with PbA chemistry is the changing internal resistance of each cell that increases as more current is discharged, while the acid electrolyte, anode and cathode components undergo a chemical transformation that has to be reconstituted during charging. This non linear chemical change is called the Peukart effect of lead acid batteries, **slide 11** where cell voltage drops off exponentially as more current is drawn and internal resistance continues to increase. This voltage drop plagues lead acid batteries to supply the rated power consistently to a load. As the voltage drops, the current must increase to maintain power. This is especially troubling to starting turbine engines. Compare this to a NiCd and lithium discharge curve **and 12**

At this point .. I'm scared of PbA batteries.

One company - Aero lithium batteries have impedance values listed for each size on their website;

**OK .. Some**

***CHARACTERISTICS of LIFEPO4 TYPE LITHIUM BATTERIES slide 13..energy densities***

- higher energy density, 100+ wh/gram .. compared to lead at 40, **slide 14** higher watt hrs per wt. & volume, (btw) we don't talk about Nicd or NiMh any more because they are heavy, and have low C rates. Notice the area representing Lithium cells, the phosphate type rate higher than the typical ' Ion ' type..
- higher efficiency, electricity is generated from movement of ions rather than from a chemical reaction as in a lead battery. **Slide 15**
- superior performance to lead for energy density and power density, .. see Rogonee graph
- tolerant of overcharging / overheating .. 16V .. we've covered that, very thermally stable..300c needed / 600F **slide 16**
- Another very big characteristic No need for trickle charging, a charged Li battery will stay charged for a year on the shelf or in an unused airplane. Assuming no parasitic drain.
- Never jump start a Lithium battery. It will become unbalanced and shorten its life. It can only be balance charged from a low

charge state. If battery has built in balancer circuit, lithium chargers are available from AeroLithium.

- Wide temp range , -20 to +60C... in freezing temps, successive cranking attempts get faster. Over 60C limits batteries capacity but does not harm it.
- Ideal charging voltage is 14.0 – 14.4V, 28 – 28.8V
- Flatter discharge curve is ideal for starting turbine engines, u get a faster spin which = cooler start
- Can be made into hand carry portable Ground Power Units

***CELL and BATTERY PACK CONSTRUCTION;***

Cylindrical and flat type, **slide 17**

Cylindrical cells are more stable and tolerant of harsh conditions , overcharge, and temp variations

Cylindrical cells have a safety vent built in to relieve internal pressure , here's the makeup of a cylindrical cell **slide 18**

Smaller cylindrical cells have higher discharge rate and cool better than bigger sizes

Packs should be assembled with air spaces between cells **slide 19**

Flat prismatic cells sandwiched together are prone to swelling up, have low heat dissipating ability and generally lower discharge rates, less tolerant to overcharging and high temperatures.

Always consider the actual lithium Ah in sizing batteries, not some kind of Pba equivalent that attempts to exaggerate the true capacity.

Packs should be built with copper connections between cells and copper or brass terminals.

The AeroLithium battery packs use polycarbonate case material whose upper temp limit is 121C / 250F and the see-thru case is nice to see what your getting and for visual inspections. **Slide 20**

**Charging System Basics:**

**An engines electrical system is said to be a 12 volt system, but this is slightly misleading. The charging system in most aircraft will generally produce a voltage between 13.5 and 14.4 volts while the engine is running. It has to generate more voltage than the battery's rated voltage to overcome the internal resistance of the battery. The current needed to recharge the battery would not flow at all if the charging system's output voltage was the same as the battery voltage. ..A greater difference of potential (voltage) between the battery's voltage and the alternator's output voltage will allow more current & a faster charging rate. A Lithium battery will draw less charging current and charge quicker than the typical sealed lead acid aviation battery because it doesn't get discharged as much starting the engine as lead acid. .. so, no worries there about overcharging.**

This is why a LiFepo4 battery is a very good drop in replacement, it has the same voltage range as lead acid.

***Protection Circuitry..this is the big question of our time.;*** **slide 21**

Does a lithium battery need a BMS, which stands for battery management system ? .. Well, If your driving an electric car / scooter, and the battery is used for deep discharge cycling, answer is yes. If your starting an engine and battery only gets a shallow discharge , then is immediately charged up again, then, the answer is, no….Why ?

Because, the protection functions never kick in anyway.

<u>These are the functions of bms's – overvoltage, balancing,( for both packs and cells ) undervoltage, short circuit protection, temp sensing, current limiting, SOC maybe</u>

We are going to talk about the functions most applicable to a starter battery

1st and foremost, the one that everyone fears is overcharging. We've all heard that overcharging a lithium battery will result in a fireball, right ?

Remember, those are video's and stories involving other lithium chemistries,?.. not the one we're talking about today.

So, lets ask; when would this overcharging/ overvoltage condition happen ? How many times have u read about LA batteries being overcharged in flight ? Is overcharging a regular occurrence ? Are people constantly replacing their batteries because of overcharging damage due to faulty alternator / regulator / and overvoltage relays ? …. That wouldn't be a very safe airplane to fly no matter what kind of battery you had. The Lithium battery is not going to overcharge anymore than a LA battery. So, what we're really talking about is a total system breakdown that would allow the alternator / generator to put out full voltage and current it is capable of ?

We would also have to assume there is no provision to switch the alternator offline either… now, how many people have a plane like that ?

So, The airplanes regulator will prevent any pack overvoltage events.

There are 2 ways a battery can be overcharged; Total pack overvoltage and individual cell overvoltage.

Individual cell OV is a more likely possibility. But, This usually happens when a pack is deeply discharged and charged over many cycles as, in an EV, and the series of cells inside start to wonder from a unified charged state **slide 22** . In a Li starter battery, there are 4 groups of cells in series.

Ideally we would like to keep these cells evenly charged. Electric vehicles do this with a balancing circuit**.**

SHOW BMS .. here is an example…This would keep the cells balanced automatically all the time. Or , you can get a balancing charger if you ever do any ground ops that would drain down the battery. Slide 23. when draining down, it is highly recommended to

use a low voltage alarm to warn you when a cell has reached the LV limit. Slide 24. As I will so demonstrate, there is also an alarm that signals you if you leave the master switch on 60 seconds after engine shutdown. It is also hooked to the hobbs meter to turn that off as well. ...Show it...

There is also a panel display showing voltage bars of each cell. Kind of nice to have..

So, unevenly charged cells are a function of balancing. .. Which is our 2nd BMS function

Now personally, I've had a plain Li battery in my car for 2 years now w/o any protection circuits in it. Maybe I just use really good cells..

However , all this being said; Would I prefer to have some balancing and cell OV protection for my Li battery in my airplane, Sure.. just for peace of mind, not out of fear. The balancing function will make your Li battery last 10+ years.

Aerolithium 4th generation batteries will have the balance circuit, cell OV an short circuit protection in them as an option,

usually for the bigger sizes.

OK, so, these are the 2 main protections that we are concerned with. Overvoltage, and Balancing

3rd protection is undervoltage or, over discharge protection.

This is mainly an 'on the ground' event. Although a charging system breakdown in flight could happen, with an alternator belt break or other failure. In which case you would not want a low voltage cutoff protection, instead have the battery freely discharge all the way down to maintain electrical power till landing.

So, w that in mind, its better to have a low voltage alarm for forgetting to turn the master switch off or for ground maint work instead of inside the battery.

Now, it IS ok to deep discharge a lithium battery, Li has a good deep cycle ability, It can go down to 9 - 10V., but, it then will require u to balance charge it back up again. This is the big diff w lead. Lithium needs its own charger, either a balancing type or if a bal circuit inside, a regular Li charger.

In No case, should a Lithium battery be jump started or attached to a ground power unit. This goes back to the point of; the battery is not dangerous, but the mishandling of them can be.

If jump starting is needed, the Li batt must be replaced with a backup battery and the low batt balanced charged up. An unbalanced condition will result with the big inrush of charging current from the engine and greatly shorten battery life. A plane equipped w a charged li battery will never need a ground power starting assist . No need, a properly sized Li batt is easily capable of starting a turbine engine at 1/3rd the weight of a "recommended ' Lead A battery.

Short Circuit is the 4th function – can be included.

Current limiting #5 – don't need it

Temperature sensing #6 – This can be monitored by a display on the panel.

SOC display - #6 – state of charge is helpful if your in an EV to know what range left in the battery as it drains down, but, not so much for a starter battery. You can watch the voltmeter during start.

SO .. In summary; Any protection functions still need to be monitored by the pilot irregardless if a bms is used or not. I would not count on any circuitry to perform automatically any safety prosedures. The pilot is the ultimate backup to monitor conditions of the battery, same as any other system on the aircraft.

So ***slide 25***

***ADVANTAGES OF USING A LIFEPO4 TYPE LITHIUM BATTERY IN YOUR AIRCRAFT, or, why should I use a Li battery ?***

***Much less Weight , this = more payload, shorter takeoffs, CG benefits, ultralights needing to stay underweight, bush pilots***

***Size = easier to relocate and secure***

***Flatter discharge curve = holds higher voltage to starter, better for turbine engines, lasts longer in alternator loss emergency***

***Very low self discharge rate = about 10% / year, great for infrequent flyers, freezing temps, no maint charging needed,***

***will not degrade from non use like lead acid***

***Long cycle life = 5000+ cycles, 10 year life possible,***

***Deep cycle ability, 80% of charge available compared to 50% lead acid while holding a higher voltage***

***No maintenance needed***

***Cheaper to own in the long run than lead acid***

***Environmentally friendly – no heavy metals like lead or cadmium, easily recycled***

***Lithium batteries are;***

- Not approved for certified aircraft, but, you can still carry them as a backup emergency battery or ground power unit.
- A Digital panel V meter mandatory to monitor battery voltage and regulator output

- OK ***slide 26 plane***
- ***LAST BIG Q***…. there are 3 suppliers of lithium batteries available that people are experimenting with.
- SO..Which lithium battery should I get ??
- ***Now we come to the exiting part of this presentation***..

- . Lets do a demonstration and find out. ..
- We will load test 3 similar size batteries down to MCV , minimum cranking voltage of 8V and find out which puts out the most current. 8 to 10 volts is what mechanics recommend the voltage stay above when cranking an engine.
- We'll do this twice for each battery and also read the temperature
- Can I get a volunteer in the front row, to help read off the measurements please
- 1st contender, the Aerovolts 8 cell size – hold up to audience – have volunteer read A Spruce data sheet – not sure where made; claims 275amps and a 15ah PB equivalent ..... DO TEST .. beginning V .. amps.... Rest ... amps.. temp..feel it.. 5Ah, max current tested to 165Amps, not 275A as claimed ! got warm
- 2nd contender, the AeroLithium's smallest size, which claims 240A and 4.4 Lithium Ah, definitely made in usa

  Max current tested to 260A, warm
- 3rd, contender, the Shorai LFX14L1BS12 , I wonder what the BS stands for ? motorcycle battery which claims 210 amps and a 14Ah PB equivalent which is about a 4.7 lithium Ah .. place behind shield **definitely made in china..** max current tested to 190A.. *got very hot*, 16AWG lead wires

  So ... summarize results...**slide 27 sign**

  This concludes my Li battery presentation, I hope you are no longer scared and can relay this information to your fellow EAA chapter members that couldn't be here today. Thank you

References: Dynalab, A123, batteryuniversity, electropedia, Aleees, phostech, Ti, Wikipedia, MIT, Goodenough UT