Boeing officials have detailed their proposed fixes for the lithium-ion batteries aboard its 787 planes, and the changes include better insulation between the eight cells in the battery, gentler charging to minimize stress and a new titanium venting system.

But to prevent any new fire and smoke episodes like the ones that have grounded its fleet, Boeing proposed that the battery itself will be sealed inside a steel box that would serve as the last safety rampart if everything else fails.

As design engineers, you and I know that the solution is to prevent failure, not contain smoke and fire after the fact. At least Boeing designers have made an attempt at modifying the charging system. It’s difficult to zero in on a solution when investigators have not determined the root cause of a problem that has grounded all 50 Dreamliners worldwide since January. So Boeing said it can assure federal authorities, airlines and the public that its flagship aircraft is safe, and there is no chance of a battery fire.

First let’s look at the way an aircraft power management system works and we ask readers to give us their comments and possible solutions.

The following is complements of Boeing Corporation:

**Airplane power basics**
On an airplane, the electrical system produces, controls and distributes power to all the other systems that need it — flight deck displays, flight controls, in-flight entertainment and more. It’s much like the electrical system in your house, which carries electricity throughout the rooms to power your lights, television and so forth.

Unlike your house, though, the airplane generates electricity as it flies. Airplanes don’t fly on battery power. Generators on the engines make power in flight.

**The traditional airplane: electrical and pneumatic systems**
On a traditional airplane, power is extracted from the engines in two ways to power other airplane systems:

- Generators driven by the engines create electricity.
- A pneumatic system “bleeds” air off the engines to power other systems (e.g., hydraulics).
Modern jet engines are very efficient, but removing that high-energy air robs them of some energy. A pneumatic system means that the engines produce less thrust, so they must be bigger, work harder and use more fuel. The system also means more weight, fuel burn and maintenance due to the heavy ducts and equipment needed to manage that hot air.

The 787: A more-electric system

The 787 Dreamliner uses more electricity, instead of pneumatics, to power airplane systems such as hydraulics, engine start and wing ice protection. Benefits of the 787’s innovative, more-electric design include:

- More efficient power generation, distribution and use — including new remote power distribution units, which reduce wiring and save weight (approximately 20 miles, or 32 km, less wiring than on the 767).
- Better fuel efficiency — better for airlines and the environment.
- Lower maintenance costs and fewer maintenance tasks.
- Less drag and noise.

Because the 787 uses more electricity than do other Boeing airplanes, the 787 generates more electricity, via six generators: two on each engine and two on the auxiliary power unit (APU, a small turbine engine in the tail).
On the ground, the 787 can be started without any ground power: The APU battery starts the APU generators, which start the APU to power the engine generators, which then start the engines.

In flight, the four engine generators are the primary sources of electrical power; the APU generators are secondary. Power runs from the generators to four alternating current (AC) buses, where it is either distributed for use as is (235 V AC) or converted to what other systems need.

Other power sources for the 787 include the main battery, used primarily for brief ground operations and braking; the APU battery, which helps start the APU; and ground power, which can connect through three power receptacles. The main battery, APU battery and ram air turbine also are available as backup power in flight in the unlikely event of a power failure.

As with every Boeing airplane, the 787 includes many layers of redundancy for continued safe operation, and the electrical system is no exception. For example, Boeing has demonstrated that the 787 can fly for more than 330 minutes on only one engine and one of the six generators and land safely.

A word from the NTSB

Lithium Ion Battery and Battery Charger (Main and APU) Description from March 7, 2013 NTSB report:

The Li-ion battery that is used for the Main and the auxiliary power unit (APU) battery contain 8 sealed lithium ion cells that are connected together in series with thermal conductive plates and packaged within an aluminum battery box. The battery also includes the battery monitoring unit.
(BMU), Hall Effect current sensor (HECS), temperature sensors, internal non-latching contactor, battery failure detection and diode module failure detection (detection of high rate charge current). The BMU, which is installed within the battery, incorporates redundant circuits that generate battery status, balance cell voltages, and makes battery Built In Test Equipment (BITE) and failure annunciation to the battery charger. These protection circuits are designed to protect against overcharge, over-discharge, overheating, and ensure proper cell balancing.

Each battery is charged by a dedicated Battery Charger Unit (BCU). All Battery signal and failure information are provided to the aircraft system through the BCU. If an internal battery failure is detected by the BMU, an inhibition signal is relayed to the BCU and it will stop all charging of the battery and shall annunciate the battery failure at the aircraft level.

1. The main battery system also includes a Battery, BCU, and Battery Diode Module (BDM). The Bus Power Control Unit (BPCU) monitors for failure indications from the Main Battery/Battery Charger and reports any failures. The BDM includes a large power diode and a battery side interface for the battery charger. The BDM protects the battery against high charge current when the Hot Battery Bus is paralleled with another 28 V Dc source via the Main Battery Relay (MBR), Electric Brake Power Supply Unit (EBPSU) contactors, or other equipment isolation failure.

2. The APU battery system also includes a Battery, BCU, and a Starter Power Unit (SPU1), a BDM is not included or necessary for the APU Battery System. The Remote Data Concentrator (RDC) monitors for failure indication from the APU Battery/Battery Charger and reports any failures to the BPCU.

The baseline Li-ion battery is a 50 ampere-hour (end-of-life) lithium-ion (Li-ion) chemistry battery. The main and APU batteries are identical, but provide electrical power sources to two distinct functional areas. The nominal voltage of the battery is about 29.6 volts and when it is fully charged, the voltage is 32.2 volts.

According to Boeing’s System Safety Assessment document for the 787-8 Electrical Power System, Li-ion batteries are primarily made up of non-flammable components, however, the electrolyte and active material coatings on the negative and positive electrodes contain flammable components.

Over-charge of a Li-ion cell can result in the cell entering thermal runaway, which could result in the battery cell venting and the generation of smoke and fire. Cell venting with a fire is distinct from venting with smoke only; outside of an additional ignition source, over-charge is the only known failure condition that can result in venting with fire according to Boeing’s System safety Assessment. Cell venting with smoke, however, can be initiated by several failure modes, including external overheat, external short circuit of appropriate impedance, internal short circuit, recharging a battery that has been discharged to a state-of-charge that is too low, high rate charging at greater than a 1C (one times the capacity Amp hour rating of the cell), or charging at cold temperatures. Each cell has a safety vent that opens when the cells internal pressure reaches unsafe levels to eliminate unsafe conditions.

Each battery charger takes unregulated 28VDC power on its input and converts it to regulated DC power output. The output voltage level varies depending on battery state of charge (SOC), to between 22VDC at 0% SOC and 32.2V when fully charged. For all voltages, the charger current is limited to a maximum output current of 46A.

The battery charger receives inputs from the BMU such as temperature, cell balance, inhibition of
discharge and inhibition of charge, etc, and regulates charging accordingly. The battery charger, via the Bus Power Control Unit (BPCU) for the main battery and a Remote Data Concentrator (RDC) for the APU battery, provide the battery parameters (such as battery current and battery voltage) to support the Electrical Flight Synoptic Page and the battery-charger failure indications (such as battery state of charge indication for dispatch) to the Engine Indication Crew Alerting System (EICAS)

**Functional Hazard Assessment**

Boeing’s 787-8 electrical power system safety assessment also included an analysis of lithium ion battery failure modes. This analysis determined that overcharging was the only known failure mode that could result in cell venting with fire. As a result, Boeing established additional design requirements to ensure that the likelihood of occurrence of an overcharge event was extremely improbable. Boeing further determined that cell venting without fire could be initiated by several different failure modes, including external overheating, external short circuit of appropriate impedance, internal short circuit, recharging a battery that has been over discharged, a high rate of charging at greater than a 1C (one times the capacity Ah rating of the cell), or charging at cold temperatures.

**System Safety Assessment of the Main and APU Li-ion Battery Systems**

Boeing incorporated several safety features inside and outside of the battery that were designed to prevent the conditions of cell venting and cell venting with fire. These features include:

1. A dedicated battery charger that charges within very precise voltage and current limits.
2. Cell balancing circuits to ensure all the cells in a battery are charged up equally and are within safe voltage limits.
3. Battery circuits that monitor cell and battery voltages and temperatures and control the battery charger accordingly.
4. An internal safety contactor to disconnect the battery in case of any high voltage conditions.
5. A battery diode module (Main battery only, the APU battery has no other possible charge sources) that prevents charging of the battery from any other sources other than the dedicated battery charger.

1. The starter power unit is used during APU starts only.

**And now here are the changes being proposed**

**Charging system changes**

Boeing, Thales and GS Yuasa have decided to narrow the acceptable level of charge for the battery, both by lowering the highest charge allowed and raising the lower level allowed for discharge. Two pieces of equipment in the battery system – the battery monitoring unit and the charger are being redesigned to the narrower definition. The battery charger will also be adapted to soften the charging cycle to put less stress on the battery during charging.
Usually most of this can be done by simple re-programming of the MCU charge voltage min/max levels and the charging rate. Monitoring is usually done through an ADC back through the MCU.

**Improved Battery Design Features**

1. **Located in the aft electrical equipment bay**
2. **Provides power to start the APU, which can power generators to start engines if needed, also powers navigation lights**
3. **Located in the forward electrical equipment bay**
4. **Powers up airplane systems, bringing the airplane to life before the APU or engines are started, also supports certain ground operations such as refueling**

In flight, the airplane is powered by electricity produced by the engine generators. The batteries are part of the multiple layers of redundancy that would ensure power in the extremely unlikely event of a power failure.
Changes inside the battery will help to reduce the chances of a battery fault developing and help to further isolate any fault that does occur so that it won’t cause issues with other parts of the battery.

To better insulate each of the cells in the battery from one another and from the battery box, two kinds of insulation will be added. An electrical insulator is being wrapped around each battery cell to electrically isolate cells from each other and from the battery case, even in the event of a failure. Electrical and thermal insulation installed above, below and between the cells will help keep the heat of the cells from impacting each other.

Wire sleeving and the wiring inside the battery will be upgraded to be more resistant to heat and chafing and new fasteners will attach the metallic bars that connect the eight cells of the battery. These fasteners include a locking mechanism.

Finally, a set of changes is being made to the battery case that contains the battery cells and the battery management unit. Small holes at the bottom will allow moisture to drain away from the battery and larger holes on the sides will allow a failed battery to vent with less impact to other parts of the battery.

**New Battery Enclosure**
One change proposed by Boeing is to seal the batteries in a steel box, which would contain any smoke and fire.

The battery case will sit in a new enclosure made of stainless steel. This enclosure will isolate the battery from the rest of the equipment in the electronic equipment bays. It also will ensure there can be no fire inside the enclosure, thus adding another layer of protection to the battery system. The enclosure features a direct vent to carry battery vapors outside the airplane.

New titanium fixtures are being installed in the electronics equipment bays to ensure the housing is properly supported.

It looks like the designers have done everything possible to prevent another mishap, while not actually knowing what the root-cause was. So by over-designing almost every aspect of the charging, monitoring and battery system design, we trust that the engineers have a solid design in place that should be robust enough to fly.

Please give us your comments and technical expertise in this area---we would really like to begin a discussion on this issue.