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## Airworthiness considerations of supply chain management from Boeing 787 Dreamliner battery issue

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### Abstract

With the globalization of the economy, the aviation market competition intensifies and the aviation product development mode has correspondingly changed. The aircraft manufacturers pack more and more works to the suppliers to join the development work. The role of suppliers becomes more and more important during the development. Therefore, the problems of suppliers are following which have a significant influence on the aircraft design, manufacture and EIS which is means through the whole lifecycle of the aircraft.

On January 16, 2013, an ANA flight made an emergency landing in western Japan after a cockpit message warned of battery problems and a burning smell was detected in the cockpit and cabin. At the same time, the FAA issued an emergency airworthiness directive ordering all U.S.-based airlines to ground their Boeing 787s until yet-to-be-determined modifications are made to the electrical system to reduce the risk of the battery overheating or catching fire. This is the first time that the FAA has grounded an airliner type since 1979. This event caused that Boeing shares has fell 2.6%. It is not the only accident of Boeing 787. Similarly, for other aircraft types, such as the Airbus A380, had to delay delivery due to supplier problem. It can be conclude that the supply chain management has an important impact on the aircraft development. From the perspective of airworthiness, this paper analyze the suppliers management of Boeing 787 Dreamliner battery issue and some advices are given to provide references and learnt lessons to the aircraft industry.

The main content of this paper is as follows:

First of all, the context and the purposes of this study was introduced in Chapter 1; the airworthiness regulation of CAAC, FAA and EASA about applicants' supplier management are introduced. All requirements covering supplier managements would be concluded.

Secondly, this paper focus on the whole process and solution of Boeing 787 battery issue and analyze the airworthiness problem of supplier management.

Boeing 787 uses the lithium-ion battery which was produced by Yuasa and assembled by Thales who are integrate it into avionic system. Thales is the tie 1 supplier and Yuasa is the tie 2 supplier. This paper will introduce the whole

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process and the final resolution given by Boeing. Based on the airworthiness regulation, the airworthiness problem of supplier management reflected from Boeing 787 battery issue would be analyzed, especially in the tie 2 supplier management show compliance with the airworthiness requirements.

Thirdly, on the basis of precious analysis, the actual airworthiness regulation would be concluded and supplier management of some international company would be presented as example. It is shown that development mode change has brought more problems of supplier management.

Finally, this paper proposes how to fully meet the airworthiness requirements to suppliers management. Some ideas and suggestions are given to avoid the similar events and support aviation industry

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*Keywords:* Airworthiness, Supplier chain management, Boeing 787 Dreamliner battery issue

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## 1. Introduction and airworthiness requirements

With the globalization of the economy, the aviation market competition intensifies and the aviation product development mode has correspondingly changed. The aircraft manufacturers pack more and more works to the suppliers to join the development work. The role of suppliers becomes more and more important during the development. Therefore, the problems of suppliers are following which have a significant influence on the aircraft design, manufacture and EIS which is means through the whole lifecycle of the aircraft.

### 1.1. Introduction

The efficient of the supplier management will lead the aircraft manufacture to realize more target on reducing the cost, bring more interesting functions for customers, developing market together etc. But whatever they make and however they take, the safety objective is and always be the top and the prior commitment. Airworthiness is the best and necessary means to reach this objective both for the manufactures and authorities. This paper is focus on the airworthiness consideration of supply chain management in design and production phases with the Boeing 787 battery case.

### 1.2. Airworthiness requirements

The airworthiness requirements are addressed in the regulations. All of them are almost come from Part 21 regarding suppliers management. The airworthiness regulation of CAAC (Administration of Civil Aviation of China), FAA (Federal Aviation Administration) and EASA (European Aviation Safety Agency) about applicants' supplier management are stated in the following tables (please see the Appendix A for the details).

The common authorities' requirements for suppliers, in fact, are required the prime manufacturer's (the applicant) to take the safety responsibility in aircraft level, not focus on system and equipment level which is provided by the suppliers. Besides the quality system requirements about suppliers which the three authorities are all concerned, EASA require the applicant's design organization shall extend to the suppliers' design organization through the interface between them to build a full design assurance system which is cover all the appliances, parts of the aircraft. Follow these requirements, the applicant must cover design activities under his own DOA (Design Organisation Approval) and to do not ask for Supplier to hold a DOA, as a result, they have to understand and support their suppliers in-depth to take the airworthiness responsibility in aircraft level. CAAC will address the same requirements in the coming amendment regulations in the future.

Table 1. Supplier management requirements stated in the regulations

| Authorities regulation           | CCAR-21<br>CAAC   | FAR-21<br>FAA  | Part 21<br>EASA   |
|----------------------------------|---|--|---|
| No. and Titles in the regulation | 21.143<br>Quality control system and data requirements; | 21.143<br>Quality control data requirements; prime manufacturer. | 21.A.129<br>Obligations of the manufacturer<br><br>21.A.139 Quality System<br>21.A.157 Investigations<br>21.A.165 Obligations of the holder<br>21.A.239 Design assurance system<br>21.A.243 Data<br>21.A.257 Investigations |

So far, the applicant keeps more focus on the first tie suppliers than the other sub-tie suppliers. But many problems shows that the accident comes from the parts which is produced by them with the aircraft development mode changed that more and more design activities are packed to the suppliers. Which means there are many gaps exist in the design system to prevent the applicant fully understand from the hidden troubles with unsafe conditions. Boeing 787 (B787) dreamliner battery issue is a representative accident hereafter.

## 2. Boeing 787 case

### 2.1. Boeing 787 innovation supply mode

In 2004, Boeing launched the development program of its latest commercial airplane design, B787 (Dreamliner), which was made very high percent from composite materials compared to the traditional material (aluminum) used in airplane manufacturing.

The new airplane design became Boeing's the most successful product launch. Boeing not only introduced a transformational and extraordinary airplane design, but also revolutionized the way it used to develop a new model. It devised a new supply chain model in which suppliers were responsible to invest their own money to design, manufacture, and integrate major sections of the airplane, based on general specifications provided by Boeing.

Boeing has gone the extra distance with the 787 program -- retains only about 33%-35% of the total B787 work share:

- Deliberate effort to reduce parts count to enable "snap" three-day assembly of the B787.
- Suppliers moving up the value chain & assuming more of a system integrator role, providing more integrated components and managing their own sub-tier suppliers.
- This is the first time Boeing has outsourced the entire wing design and manufacturing to external suppliers.

- This is the first time Boeing applied lean manufacturing process in B787 program to improve absence management while merging its short and long-term disability program administration with leave-of-absence offering.

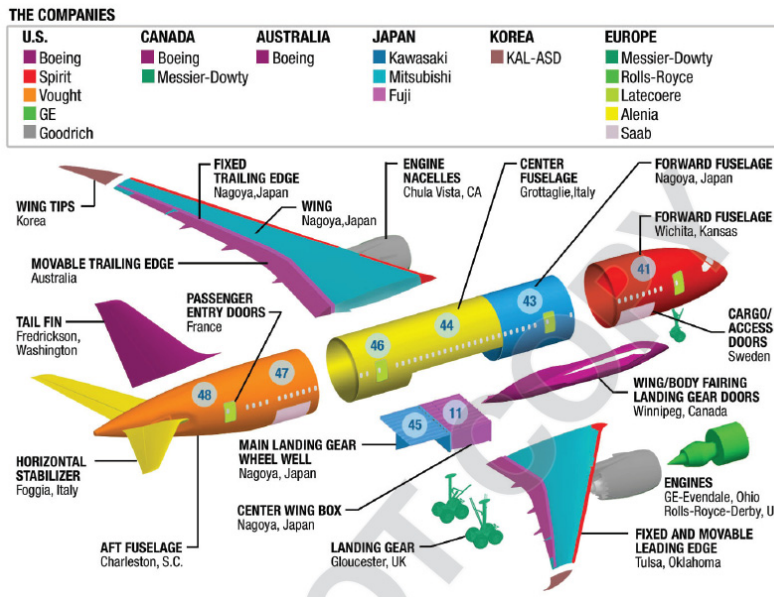


Fig.1. B787 work sharing

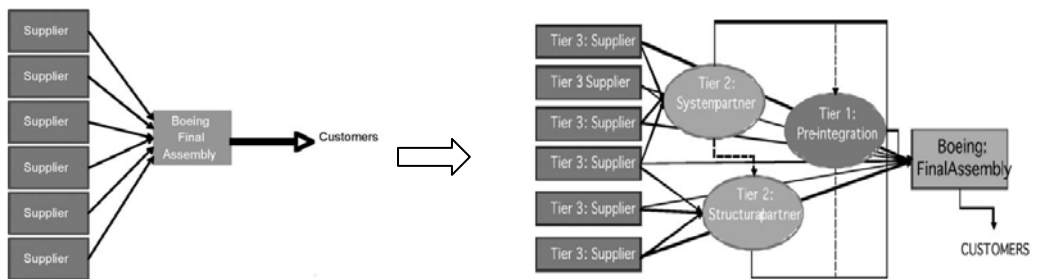


Fig.2. B787 have been developed and produced by using an unconventional supply chain new to the aircraft manufacturing industry

### 2.2. Boeing 787 battery events

The first B787 was entered into service in the fall of 2011 by ANA, Japan. But in the year of 2013, a series of battery events were coming:

On January 7, 2013, A Japan airlines (JAL) B787 was under fire caused by the battery overheating of the Auxiliary Power Unit in the rear fuselage on the ground at Boston's Logan International Airport. The inspection found that not only the battery and the shell was badly damaged, but the airframe 0.5m away from the heating point was also damaged affected by the leaking material and heating air from the battery.

On January 9, 2013, United Airlines reported a problem in one of its six B787s with the wiring in the same area as the battery fire on JAL's airliner; subsequently, the U.S. National Transportation Safety Board (NTSB) opened a safety probe.

On January 16, 2013, an ANA flight made an emergency landing in western Japan after a cockpit message warned of battery problems and a burning smell was detected in the cockpit and cabin. After that, Japan airlines and ANA announced to ground all the B787s belonging to them.

At the same time, FAA issued an emergency airworthiness directive ordering all U.S.-based airlines to ground their Boeing 787s until yet-to-be-determined modifications are made to the electrical system to reduce the risk of the battery overheating or catching fire. This is the first time that FAA has grounded an airliner type since 1979.

As of January 17, 2013, all 50 of the aircraft delivered to date have been grounded. On January 18, Boeing announced that it was halting 787 deliveries until the battery problem is resolved.

On January 24, 2013, NTSB announced that it had not yet pinpointed the cause of the Boston fire; FAA will not allow U.S.-based Dreamliners to fly again until the problem is found and corrected.

On February 4, 2013, FAA said it will permit Boeing to conduct test flights of 787 aircraft to gather additional data.

On April 5, 2013, FAA approved Boeing's modification solution and test result.

On April 23, 2013, The Boeing Company, GS-Yuasa and Thales will testify and answer questions from NTSB Board members and technical staff about the design, testing, certification and operation of the lithium-ion battery on the Boeing 787 and the battery fire incident.

On April 27, 2013, FAA approved B787 return to service after changes were made to battery systems.

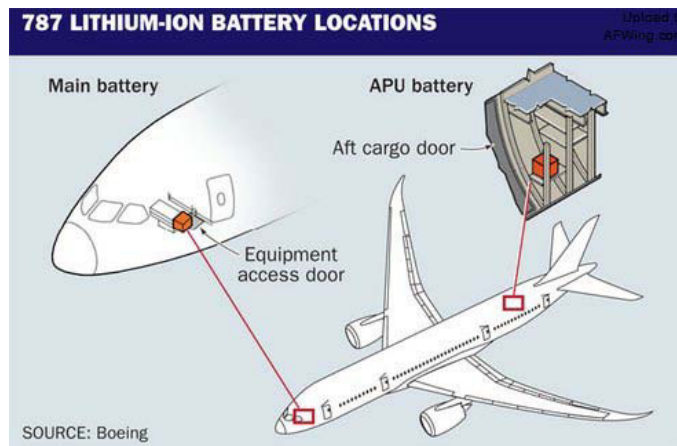


Fig.3. B787 Lithium-ion battery locations

The two lithium-ion batteries installed in B787 are all cause problems to set the aircraft in unsafe conditions. These batteries which was produced by GS Yuasa (a Japanese Company) and assembled by Thales (a French Company) who are integrate it into avionic system. Boeing outsourced the avionic system to Thales as the first tie supplier, Thales, in turn, subcontracted the design and production of the battery to Yuasa who was the sub-tie supplier for Boeing.

According to the airworthiness requirements, Boeing should provide a description of inspection procedures for the avionic system produced by suppliers including methods used to ensure acceptable

quality. On the other hand, Boeing shall make available to FAA the information regarding all delegation of authority to suppliers to make major inspections of the avionic system.

As for the technical problem, Boeing 787 is the first big civil aircraft installed lithium-ion battery for electric power source. Because of the lack of applicable technical standards and certification regulations, both Boeing and FAA faced big difficulties that ever have. FAA issued 9 special conditions (SC) for the battery installed in B787. This paper will not involve in the technical solutions, but focus on the suppliers management.

During the investigation period, the authority found that —among other things—no record of the final production-standard charging system having been tested with the actual GS Yuasa-made battery. According to the NTSB report, Securiplane, the charging system developer, tested the unit with a simulated electric load instead of an actual battery. The company apparently took this precaution after having earlier suffered a fire at its facility during battery testing. Another found in the investigation show that the battery was not worked well as Boeing or Thales released documents statement. Especially in the condition of discharge, it couldn't keep invariable rate with high variable range and countercurrent which is shouldn't happened.

B787 development introduced an innovation supply systems with innovation technology. Boeing should have held all systems and suppliers close to their assembly lines to facilitate cooperation between suppliers and Boeing. But from the NTSB report we may see that there are some gaps between Boeing and GS Yuasa due to the no-contract relations. Because of the way the supply chain for the B787 which is outsource work packages to the suppliers who are required to share more risk and the profits with Boeing together. But the financial burdens will inevitably shift up and down the line as each company protects its own interest. And the further more, due to the lack of tightness between them particularly in the design and verification activities, the result could be short-term chaos, a delayed product and more important the unsafe hidden troubles in which everyone suffers.

Nevertheless, we can't conclude irresponsibly that Boeing has really mismanaged the suppliers. On the contrary, we are happy to see that Boeing is conscientious to solve the problem with fast action to remain the airworthiness responsibility.

### **3. Supply Chain Management Practices by Airbus**

Airbus, as a multinational consortium prior to July 2001, had already adopted a strategic partnership model with well-defined work-share arrangements. He also reported is to have established “risk-sharing partnerships” with more than 30 of its major suppliers covering \$3.1 billion or 25% of total program non-recurring costs. However, this needs closer scrutiny, to see what it actually means. Airbus also continues to exercise control over all system and detail engineering interface definitions.

Airbus suppliers work “ in parallel ” (bilaterally with Airbus), with limited lateral communications among them. Unlike Boeing, Airbus “ has no strong partners ” for major risk-sharing activities or as contributors to development spending. He has increased its outsourcing in the A350 program, but has still kept in-house core technologies, such as composite technology and wing design. However, Airbus is currently pursuing new partnering arrangements under its Airbus Power “competitiveness” Industrial Plan. As part of the plan, supplier relationships would also change (Airbus wants partners to commit to long-term cost reductions). Airbus also reducing its supplier base from 3,000 down to 5,000.

On the other hand, according to European regulations ( Part 21, Subpart J, Design Organisation Approval ), the applicant should build design assurance system to get DOA and must extend or cover his design organisation to the first tie suppliers. Airbus require Suppliers shall be selected according to their capability to meet Airbus business needs, including regulatory requirements. And also Airbus requires

equipment suppliers including engines, nacelles and landing gear to hold a Production Organisation Approval (POA) or equivalent granted by a recognised authority acceptable to EASA.

This make Airbus are well understand the capability of suppliers who have to follow Airbus design system by the design organisation interface document. And also the production organisation.

This is not means that Airbus' supplier management is better than Boeing's. It is just describe the difference between the two leader company in civil aviation industry which is supposed to provide useful reference for the others.

#### **4. conclusion and proposal**

From the above statements, we may have the conclusion that the approach of aircraft prime manufacturer control the first tie suppliers directly and supposed to control the other ties supplier through them to remain the aircraft airworthiness responsibility need to be assessed whether it could meet the airworthiness requirements under the innovation supply systems like B787 both for the aircraft maker and the authorities. And the aircraft prime manufacturer should control the suppliers directly whose product will affect the aircraft safety directly whatever the suppliers are in which ties or levels.

Since the new mode of the supply system is just used in the industry, the best possible fix for the supply chain problems is to build experience and to weed out those elements of the supply chain that cannot live up to the required specs. But before we may build enough experience, the proposals hereafter are supposed to be considered both for industries and the authorities.

##### *4.1. Be familiar with the suppliers' design system more deeply*

For work packages of outsource including design works, the purchaser need to know more information about the supplier's design system which is means the design process, teams, developing procedures as well as the verification approach and results. The purchaser may establish the requirements chain, cascaded from top aircraft level down to the final parts level through the interface between the purchaser and suppliers in different levels. The prime manufacturer should be very familiar with the products whose failure will directly result in safety issues or use novel technology that ever used before, even in the level of parts whatever the providers as which tie-supplier, such as the lithium-ion battery.

##### *4.2. Develop the suppliers with more certification responsibility*

Following the regulations, all the airworthiness responsibility in aircraft level are the duty of the prime manufacturer. It has few problem when they do almost all the design works. It show that the safety trouble are coming after the innovation supply systems was introduced that many design works outsource to the suppliers. This kinds of supply system requires the suppliers share risk and benefit with the aircraft maker together to reduce cost and developing time. So when the suppliers get more sharing of benefit they should take duty to show compliance with the certification requirements even in the level of aircraft with the prime manufacturer at the same time.

##### *4.3. Take more audit on the suppliers*

As previous mention, the suppliers should provide technical support in certification requirements, both the authority and the prime manufacturer should take more audit on the suppliers' developments. In fact, on February 26, 2008, FAA issued a report regarding the overseeing aircraft manufacturers' suppliers risk

assessment. The report gave three findings as following after they found weaknesses throughout FAA's oversight system for manufacturers and their suppliers:

First, FAA has not ensured that manufacturers are providing oversight of their suppliers. Manufacturers are the first line of defense in ensuring the products used on their aircraft meet FAA and manufacturers' standards. Yet, during the 24 months preceding our review, manufacturers had not audited 6 of the 21 critical part suppliers we visited.

Second, FAA does not require inspectors to perform enough audits of suppliers to determine how well manufacturers' quality assurance systems are working. FAA's guidance for overseeing manufacturers' quality assurance systems only requires inspectors to perform, at most, four supplier audits, regardless of how many suppliers the manufacturer uses.

Third, the systemic deficiencies we identified at the 21 supplier facilities we visited indicate that manufacturers and FAA need to strengthen their oversight of these facilities. For example, nearly half (43 percent) of the suppliers had deficiencies in their tool calibration and employee training programs. Deficiencies in these areas could impact the quality of the parts these suppliers produce.

So both for the prime manufacturer and authority should strengthen audit on the suppliers.

#### 4.4. Build suppliers' problems database

The prime manufacturer may build suppliers' problems database and share it with the authority which is at least include the reason, the problem solution, final result and the position as well as the action of the suppliers. The target of building is not aims to punish them but expected to build experience base on the fault. The suppliers may disagree with it understandably to worry about the database will harmful to their market reputation and profit. Nevertheless, we may assume that the B787 batteries event might not be happened if GS Yuasa had information that the same accident was occurred before by himself or other company. And by the other point of view, the responsible position and action of Thales and GS Yuasa are good to their public reputation but not harmful. Because nobody want to see the accident are taken place due to their product failure, we have possible confidence to realize this building which is important supporting of the applicable experience on truly innovative product.

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## Appendix A. The supplier managements related requirements stated in the regulations in detail.

### A.1. CAAC requirements

#### CCAR-21-R3 《Certification Procedures for Civil Aviation Products and Parts》

| No. and titles of the regulation                       | Statements of Regulations  |
|--|--|
| 21.143<br>Quality control system and data requirements | <p>(a) Each applicant must submit data to the authority, describing the inspection and test procedures necessary to ensure that each products produced conforms to the type design and is in a condition for safe operation, including :</p> <p>(1) ....</p> <p>(2) A description of inspection procedures for raw materials, purchased items, and parts and assemblies produced by manufacturers' suppliers including methods used to ensure acceptable quality of parts and assemblies that cannot be completely inspected for conformity and quality when delivered to the prime manufacturer's plant;</p> <p>.....</p> <p>(b) Each prime manufacturer shall make available to the authority information regarding all delegation of authority to suppliers to make major inspections of parts or assemblies for which the prime manufacturer is responsible.</p> |

### A.2. FAA requirements

#### FAR 21 《Certification Procedures for Products and Parts》 (1-1-08 Edition)

| No. and titles of the regulation                                 | Statements of Regulations   |
|--|---|
| 21.143<br>Quality control data requirements; prime manufacturer. | <p>(a) Each applicant must submit, for approval, data describing the inspection and test procedures necessary to ensure that each article produced conforms to the type design and is in a condition for safe operation, including as applicable—</p> <p>(1) ....</p> <p>(2) A description of inspection procedures for raw materials, purchased items, and parts and assemblies produced by manufacturers' suppliers including methods used to ensure acceptable quality of parts and assemblies that cannot be completely inspected for conformity and quality when delivered to the prime manufacturer's plant;</p> <p>.....</p> <p>(b) Each prime manufacturer shall make available to the Administrator information regarding all delegation of authority to suppliers to make major inspections of parts or assemblies for which the prime manufacturer is responsible.</p> |

### A.3. EASA requirements

#### Part 21 《Certification of aircraft and related products, parts and appliances, and of design and production organisations》 (12.08.2012 Edition)

| No. and titles of the regulation            | Statements of Regulations  |
|---|--|
| 21.A.129<br>Obligations of the manufacturer | Each manufacturer of a product, part or appliance being manufactured under this Subpart shall:<br>.....<br>3. where the manufacturer acts as supplier to another production organisation, report also to that other organisation all cases where it has released products, parts or appliances to that organisation and subsequently identified them to have possible deviations from the applicable design data.  |
| 21.A.139 Quality System                     | (a) The production organisation shall demonstrate that it has established and is able to maintain a quality system. The quality system shall be documented. This quality system shall be such as to enable the organisation to ensure that each product, part or appliance produced by the organisation or by its partners, or supplied from or subcontracted to outside parties, conforms to the applicable design data and is in condition for safe operation, and thus exercise the privileges set forth in point 21.A.163<br><br>(b) The quality system shall contain:<br>1. as applicable within the scope of approval, control procedures for:<br>(i) document issue, approval, or change;<br>(ii) vendor and subcontractor assessment audit and control;<br>(iii) verification that incoming products, parts, materials, and equipment, including items supplied new or used by buyers of products, are as specified in the applicable design data; |
| 21.A.157 Investigations                     | A production organisation shall make arrangements that allow the competent authority to make any investigations, including investigations of partners and subcontractors, necessary to determine compliance and continued compliance with the applicable requirements of this Subpart.   |
| 21.A.165 Obligations of the holder          | (h) establish an archiving system incorporating requirements imposed on its partners, suppliers and subcontractors, ensuring conservation of the data used to justify conformity of the products, parts or appliances. Such data shall be held at the disposal of the competent authority and be retained in order to provide the information necessary to ensure the continuing airworthiness of the products, parts or appliances;   |
| 21.A.239 Design assurance system            | (c) The design organisation shall specify the manner in which the design assurance system accounts for the acceptability of the parts or appliances designed or the tasks performed by partners or subcontractors according to methods which are the subject of written procedures.  |
| 21.A.243 Data                               | (b) Where any parts or appliances or any changes to the products are designed by partner organisations or subcontractors, the handbook shall include a statement of how the design organisation is able to give, for all parts and appliances, the assurance of compliance required by point 21.A.239(b), and shall contain, directly or by cross- reference, descriptions and information on the design activities and organisation of those partners or subcontractors, as necessary to establish this statement.  |
| 21.A.257 Investigations                     | (a) The design organisation shall make arrangements that allow the Agency to make any investigations, including investigations of partners and subcontractors, necessary to determine compliance and continued compliance with the applicable requirements of this Subpart.  |