Research on harmful substances and air quality control of civil aircraft components

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Abstract. This article provides an overview of harmful substances within as well as released from common civil aircraft components. The current domestic and foreign controlling status in these fields were compared, as a result, huge blank still need remains to be filled for domestic civil aircraft. Therefore, several assumptions on commanding the harmful substances and air quality of domestic civil aircraft components were proposed. Domestic civil aircraft manufacturer was supposed to establish industry control standards, which should later be implemented to all levels of subordinate suppliers, and strictly gate-keep the quality of components. By taking measures in advances, China is more likely to open a broad international market of exporting domestic civil aircraft.

1. Introduction
Domestic civil aircraft manufacturing industry has developed rapidly in recent years. Aircraft ARJ21-700 is accelerating delivery and operation, C919 has made its first flight and CR929 has stepped into the joint design stage. The delivery quantity of China-made civil aircraft is increasing year by year, of which the main customers are domestic airlines, signifying Chinese civil aircraft manufacturer begin to seize the share of international civilian machine manufacturing enterprises in the domestic civil aviation market. Actually, the international trend puts forward higher requirements for the development of Chinese civil aircraft manufacturing industry. However, different from the lack of relevant acceptance standards in China, foreign countries, especially European and American countries, have set detailed and strict import standards for many imported products including aircraft. Generally, control of harmful substances within as well as released from common civil aircraft has always been a focus of concern for countries, airlines and passengers. In order to successfully break through barriers with European and American countries, domestic civilian aircraft manufacturers must be proactive and give full consideration to the environmental needs of the international market, as well as develop relevant strategies early to avoid hinders from European and American countries in the export of products on the grounds that the harmful substances in the cabin of Chinese civil aircraft exceed the standard[3].

2. Control status of harmful substances in civil aircraft components
At present, materials used for aircraft can be mainly divided into two categories: metal materials and composite materials, among which metal materials mainly include aluminum, titanium, steel, aluminum lithium and other alloy materials, while composite materials can be summarized into several categories such as resin, rubber and fiber[2]. In order to meet the specific performance requirements, some trace harmful substances may inevitably be introduced into aircraft production materials. By contacting with aircraft parts, passengers may ingest harmful substances from these parts through skin, respiratory tract and other routes, which will have a certain impact on their health. In addition, if these harmful substances
are not properly recycled, they will cause unpredictable long-term pollution to soil, water sources, and etc. Therefore, it is necessary for domestic civil aircraft manufacturing industry to control the harmful substances in the parts body, so as to avoid adverse effects on the health of customers and environment, which will also lead to a better preparation for entering a higher international entry threshold in the future.

2.1 Introduction of harmful substances in civil aircraft components

The harmful substances in various parts of civil aircraft mainly include the following categories:

(1) Chromate in surface film of aluminum alloy

Chromate exists mainly in two forms in nature: trivalent chromium and hexavalent chromium. Among them, hexavalent chromium is an ingestion/inhalation poison, which can invade the human body through digestion, respiratory tract, skin and mucous membrane and may cause cancer under long-term exposure. In addition, if the sewage containing hexavalent chromium is directly discharged without treatment, it will also be absorbed into human body after going deep into the soil and water. Moreover, hexavalent chromium can not be naturally degraded and will accumulate in organisms for long range, which is one of the heavy pollutants[5].

Chromic acid anodizing and chemical conversion coating (alodine) are common surface treatment processes for aircraft aluminum alloy parts. Both of these processes will apply hexavalent chromate oxidation film on the surface of aluminum alloy and produce wastewater containing hexavalent chromate which is difficult to post-processing. Although Boeing has used boric acid anodizing as an alternative process for aluminum alloy surface treatment more than ten years ago, Airbus and domestic civil aircraft manufacturers have not abandoned the hexavalent chromate surface treatment process due to objective reasons such as different production modes and insufficient technical maturity.

(2) Harmful heavy metals in electronic components

Many components of electronic products often contain mercury, lead, cadmium, hexavalent chromium and other heavy metal substances. These heavy metal substances show significant biological toxicity and can cause persistent and cumulative damage to various organs and brain of human body[8]. It is worth mentioning that these heavy metal substances will cause great pollution to human body and environment after being discarded, too. Although the use of such substances has decreased with the development of flexible polymer electronic devices, they can hardly be replaced in various components for their excellent properties.

(3) Chlorofluorocarbons (CFCs) in fire extinguishing agents

For the sake of aircraft safety, fire extinguishing devices must be arranged in the area where fire may occur[9]. Trifluoromethyl bromide (Halon 1301) and difluorochloromethyl bromide (Halon 1211) are widely used as fire extinguishing agents for engine/APU cabin, cargo hold and manned cabin of aircraft due to their high fire extinguishing efficiency, low toxicity, good diffusion performance and no residue[10]. Although Halon fire extinguishing agent is used in almost all active aircraft, its potential harm to the environment is still the focus of international environmental protection organizations and aerospace field. As chlorofluorocarbons, Halon-type fire extinguishing agent will stay in the ozone layer for long term after release, continuously depleting ozone molecules in the atmosphere, causing irreversible damage to the ozone layer. The Montreal agreement signed in 1994 strictly controls the production, use, transportation and storage of Halon fire extinguishing agents except for essential uses. Although a variety of Halon substitutes have been developed, it remains the best choice for aircraft engine, APU cabin and cargo hold due to light weight and other irreplaceable disadvantages.

2.2 Control status of harmful substances in civil aircraft components

With the popularity of green concept, various industries around the world, such as ships, automobiles, rail transit, electronic appliances, and foreign civil aviation industries, have issued environmental control standards and regulations, aiming to reduce environmental load and related hazards to human body[14]. In order to reduce the potential impact of harmful substances in civil aircraft products on the environment or its customers, relevant international organizations, associations and major aircraft
manufacturing companies are committed to formulating and strictly implementing relevant industry standards.

As a non-profit organization composed of global aerospace companies, the international aerospace environment group (IAEG) developed and released aerospace and defense declared substances List (AD DSL) in March 2015, establishing standards for material declaration of suppliers in the aerospace and defense industry supply chain. This list is used by suppliers to report the chemical substances contained in the production, operation or maintenance of their products, mainly involving their current use, product content limit or declaration requirements, which may have potential impact on the industry or its customers. The Aerospace Industries Association (AIA), however, released the first revision of the Hazardous Material Target List (HMTL) in 2016, which is based on the hazardous substances management plan in the national aerospace standard NAS 411 and Task 108 in the US Department of defense military standard MIL-STD 882E, building a hazardous substances target list to support and strengthen the management of risks associated with the use of hazardous substances in products and services.

In fact, the laws and regulations involved in the production, sale, storage, transportation, treatment, transfer (including import and export) of chemicals and products in different regions or countries are different. Airbus mainly follows the EU Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), American Toxic Substances Control Act (TSCA), Fluorinated Greenhouse Gas (F-GHG) and Ozone Depleting Substances Directive (ODS), and etc. It has made a good demonstration in the regulating of hazardous substances in aircraft components. On the one hand, Airbus strictly reports and tracks the controlled substances used to meet the technical performance, safety and airworthiness requirements of its products according to the information provided by suppliers. On the other hand, the company is also involved in the study of potential alternative technologies for controlled substances, which can reduce risks to human health and the environment, and are expected to be implemented as alternative technologies if they are proved feasible. As a world-class aero-engine and equipment manufacturer, the main goal of Safran group in hazardous substances commanding is to manage and eventually replace hazardous substances. It supervises the toxicity and ecotoxicity of substances and materials used in the whole life cycle of products in accordance with EU REACH regulations. United Technologies Corporation (UTC), however, emphasizes that employees ought to reduce their exposure to hazardous chemicals, especially carcinogens, reproductive toxins and endocrine disruptors (CRES).

In contrast, although there are relevant methods and standards for the physical and chemical properties test of materials in domestic aerospace industry, such as non-destructive testing, corrosion test and metallographic inspection, there still remains blank in the control of prohibited and restricted substances in aerospace products, components and the relevant standards. Relative technical specifications are also scarce. The national defense science, technology and Industry Commission has issued the national military standard, GJB 1059.3-1990, i.t. free phenol test for ablative materials using test methods of phenolic resins in 1990 and aviation industry standard HB 7736.4-2004, i.t. Determination of volatile content, which is Part 4 of test methods for physical properties of composite prepreg. In GJB 1059.3-1990, the method of distillation, separation and titration is used to determine the free phenol in phenolic resin, of which the accuracy and precision are not high. HB 7736.4-2004 uses thermogravimetric method to determine the total volatile content in the composite, which does not determine the specific volatile matter and the thermogravimetric method has the disadvantage of low accuracy. Besides, the types of harmful substances in the above standard tests are extremely limited. In addition, with the wide use of new materials in recent years, the above standards can not be applied to the analysis and determination of new materials.

3. Air quality control of civil aircraft
In fact, volatile harmful substances will also reduce the cabin air quality and affect the comfort and health status of cabin personnel in addition to the inherent harmful substances in aircraft components. Generally, the air environment in civil aircraft cabin has the following characteristics: (1) the air circulation can only rely on the air conditioning system in the narrow and airtight space and the
parameters of the ambient air vary indefinitely; (2) the slow replacement of the cabin air directly causes the poisonous and harmful substances in the air to stay in the confined space for a long time; (3) the dense personnel and long residence time. It is precisely because of the particularity of aircraft flight that most passengers and crew can easily feel uncomfortable during long-distance flight. In order to meet the requirements of air quality inspection and other green products in EU and other countries, civil aircraft manufacturing enterprises need to prepare well in advance, establish relevant enterprise standards, and actively reduce volatile organic compounds (VOCs) in the environment and the release standard of VOCs in the production process, which can also avoid huge losses caused by technical barriers to trade.

3.1 Introduction of harmful substances in the air of civil aircraft

Civil aircraft cabin air usually contains solid particles, volatile organic compounds (VOCs), carbon dioxide, carbon monoxide, ozone, bacteria and viruses. The odor in the cabin mainly comes from the cabin materials, such as the volatile organic compounds (VOCs) continuously emitted by cabin trim, paint, disinfectant and insecticide. In addition, carbon monoxide, exhaust gas, solid particles, hydraulic fluid, engine oil or other toxic compounds produced by combustion of extra cabin fuel will also enter the cabin with the exhaust gas from the engine. In general, the volatile harmful substances (including benzene, toluene, dimethylbenzene, formaldehyde, and etc.) contained in cabin components and interior materials, such as fabrics, plastic and rubber parts, paint, insulation materials, adhesives, sealants, and etc. are the main causes of VOCs pollution in the cabin.

3.2 Air quality control of civil aircraft

3.2.1 Air quality control status of foreign civil aircraft. With the increasingly strict regulations on air quality on a world-wide scale, it has become an inevitable trend for civil aircraft industry to strengthen the management of gaseous hazardous substances in space. As a pioneer in the field of environmental protection, the EU has been committed to the research and formulation of relevant environmental protection laws and regulations. In order to effectively control the harmful substances in aircraft components, the European Aeronautical Industry Association issued EN4618, i.e. Aerospace series-standards, conditions and determination methods of internal air quality of aircraft, for some common air pollutants in the cabin of civil aircraft. As shown in Table 1, the air quality of aircraft cabin is classified and managed according to the safety value, health value and comfort value. The American Society for testing and materials has issued ASTM D 6399, i.e. Standard Guide for instruments and methods for testing hollow air quality in aircraft cabin, which was shown in Table 2.

| Control project     | Safety value/ppm | Health value/ppm | Comfort value/ppm |
|---------------------|------------------|------------------|-------------------|
| formaldehyde        | 2 (15 min)       | 0.08 (30 min)    | /                 |
| acetaldehyde        | 25 (15 min)      | 1 (24 h)         | /                 |
| acrylaldehyde       | 0.3 (15 min)     | 0.02 (TWA 30 min)| /                 |
| acetone             | 1500 (STEL 15 min) | 750 (STEL 15 min) | 99               |
| butanone            | 500 (TWA 8h)     | 500 (TWA 8h)     | /                 |
| benzene             | 1 (TWA 8h)       | 4 (15 min)       | /                 |
| toluene             | 200 (15 min)     | 50 (8h)          | 40                |
| dichloromethane     | 0.86 (24 h)      | 0.86 (24 h)      | /                 |
| carbon dioxide      | 5000             | 20000 (15 min)   | 2000              |
| carbon monoxide     | 50               | 25 (TWA 1h)      | /                 |
| ozone               | /                | 0.25 (peak value, FARs) | /                 |
Control project | Safety value/ppm | Health value/ppm | Comfort value/ppm
--- | --- | --- | ---
| | 0.1 (TWA 3h, FARs) | < 0.06 (TWA 8h) | |
PM 2.5 | / | 100 (TWA 1h) | / |
PM 10 | / | 40 (continuously) | / |

* Time-weighted average;  
* Short Term Exposure Limit;  
* Federal Aviation Regulations.

Table 2 Air quality inspection standard for aircraft cabin of ASTM D 6399

| Parameters Measured | Level of Concern | Comment |
|---------------------|-----------------|---------|
| CO₂ | 7000 ppmv | upper |
| | 1000 ppmv | lower |
| CO | 35 ppmv | upper |
| | 9 ppmv | lower |
| O₂ | 20.9% at 7.6 km altitude or 8 kPa partial pressure | upper |
| | 20.9% at 2.4 km altitude or 6 kPa partial pressure | lower |
| O₃ | 0.25 ppmv | upper |
| | 0.08 ppmv | lower |
| PM 10 | 150 μg m⁻³ | upper |
| | 50 μg m⁻³ | lower |
| PM 2.5 | 65 μg m⁻³ | upper |
| | 15 μg m⁻³ | lower |
| Organic compounds | -100 ppmv | upper |
| | < 0.01 ppmv | lower |
| Cabin air pressure | 101.3 kPa | upper |
| | 37.6 kPa | lower |

3.2.2 Air quality control for domestic civil aircraft. Currently, China has only issued "public transport vehicle health standard" (GB 9673-1996) for aircraft cockpit air quality standard. Detection methods for aircraft cockpit and cabin, as workplace and public place, can only refer to “indoor air quality standard” (GB/T 18883-2002, see Table 3) and “public place health standard test method” (GB/T 18204-2000). Note that GB 9673-1996 is not suitable for the international standard due to its early establishment. Furthermore, though GB/T 18883-2002 standard standardizes the evaluation method of air quality inside residential and office buildings, some control items are not suitable for aircraft cabin environment. Thus, it is imperative to study the standards of aircraft cabin air quality detection methods and evaluation. With the purpose to respond to the call of national green manufacturing and improve consumers' use experience, the main manufacturers are supposed to pay attention to the air quality control in the aircraft cabin and all suppliers should cooperate them to implement the air quality standards and management in product design.

Table 3 Air quality control standards for workplaces and public places in China

| Standard number | Standard name | Scope of application | Control project | Limit (mg/m³) |
|-----------------|---------------|----------------------|----------------|--------------|
| GB/T 18883-2002 | Indoor air quality standard | Indoor air quality of residence, office building, and etc. | Formaldehyde benzene toluene dimethylbenzene TVOC | 0.1 (mean value per hour) 0.11 (mean value per hour) 0.2 (mean value per hour) 0.2 (mean value per hour) 0.6 (mean value within 8 hours) |
4. Assumptions on hazardous substances and air quality control of domestic civil aircraft components

In order to deal with the import requirements of EU and other countries calmly and avoid huge losses caused by technical barriers to trade, domestic aircraft manufacturers need to get prepared early, establish relevant enterprise standards, actively control the content of harmful substances in components and reduce the release of volatile organic compounds (VOCs). We need to carry out a series of work orderly, such as the source investigation of hazardous substances in civil aircraft, the establishment of the list and database of prohibited and restricted chemical substances, the establishment of technical specifications/industry standards for hazardous substances control, and the control of suppliers step by step. Only by establishing the standards suitable to the international community and strictly controlling the product quality, can China have the right to participate in the international competition of civil aircraft fairly.

4.1 Assumptions on control of hazardous substances in domestic civil aircraft components

4.1.1 Investigation on sources of harmful substances in civil aircraft components. Civil aircraft manufacturers are supposed to summarize and sort out the common materials of civil aircraft components, especially the new materials used in recent years. It is necessary to further study the raw materials and processes of the above materials so as to evaluate the current use of hazardous substances in materials and obtain the baseline of hazardous substances related to material performance, which may provide reference for later aviation products and their hazardous substances control.

4.1.2 Establishment of list and database of prohibited and restricted chemical substances. By screening out the chemical substances of common concern in the list of prohibited and restricted substances in foreign aviation industry, the list of prohibited and restricted chemical substances in accordance with China's national conditions can be established in combination with the actual situation of China's aviation industry materials and manufacturing technology. The establishment of high-risk materials database by means of chemical information transmission mechanism can not only conducive to the selection of later materials, but also can guide the improvement of design and manufacturing process of some temporarily irreplaceable materials.

4.1.3 Establishment of technical specifications/industry standards for hazardous substances control. Based on the establishment of the list and database of prohibited and restricted chemical substances in aviation products and through the preliminary investigation and testing of common materials and parts, the harmful substance content of common materials and parts can be preliminarily understood. Later, the technical specifications of hazardous substances control in aerospace products and the enterprise/industry control standards may be formed by taking its design, manufacturing process and substitutability into consideration. Note that the AD-DSL list of IAEG, HMTL list of AIA, reach regulations of EU, and etc. are supposed to be referred.

4.1.4 Manage the suppliers step by step. To implement the strict hierarchical management concept, it is required that full participation of the supply chain of “aerospace enterprises → suppliers at all levels from top to bottom → material suppliers”. We should establish the orderly management and control rules that the upper level suppliers establish strict acceptance standards for the lower level suppliers and the lower level suppliers are responsible for the upper level suppliers.

4.2 Assumptions on air quality control of domestic civil aircraft

The experience of automobile and rail transit industry can be learned to control the volatile organic compounds (VOCs) such as aldehydes and benzene in the cabin air. As shown in Figure 1, the total air index of the whole machine can be controlled and decomposed, and the parts suppliers should complete their respective performance and technical requirements. The specific control ideas are as follows:
(1) Domestic civil aircraft manufacturers can cooperate with experienced testing institutions to develop appropriate VOCs standards based on aircraft parts or materials (such as carpet, interior trim panel and sound insulation cotton) by fully testing and mastering the relevant data of existing aircraft components, drawing on relevant foreign standards and considering comprehensively;

(2) The main engine plant should establish the responsibility target through the total amount decomposition. These decomposed ones then can be transferred between the main engine plant, parts enterprises, and materials enterprises through the product VOCs performance technical requirements;

(3) Develop the VOCs test method of interior parts and materials which is unified with the test method of cabin air VOCs and establish a unified database. Parts and materials manufacturers can record, report and assess the test result through the database platform. Civil aircraft manufacturers can set reasonable VOCs limits for different parts and materials to make sure that the air quality in the cabin meet the control requirements.

Figure 1. The path of responsibility transfer between domestic civil aircraft manufacturers and parts enterprises.

5. Conclusion
There is still a big gap between China and the developed countries in the control of harmful substances and air quality of aircraft components. Only by establishing and strictly conducting the relevant industry standards as soon as possible, can we calmly cope with the high export requirements and fully grasp the new opportunities in the civil aircraft market. In today's highly integrated global economy, domestic civil aircraft manufacturer is supposed to promote the internationalization process of China's civil aircraft industry and its huge industrial chain by creating a safe and green new business card.

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