Flammability on textile of flight crew professional clothing

M C Silva-Santos1, M S Oliveira2,3, A M Giacomin1, M C Laktim1 and J Baruque-Ramos1

1University of Sao Paulo, School of Arts, Sciences and Humanities, Av. Arlindo Bettio, 1000, Sao Paulo – SP – Brazil.
2University of Sao Paulo, Faculty of Architecture and Urbanism - FAUUSP, Rua Maranhaeo, 88, Sao Paulo, Brazil.
3Mackenzie Presbyterian University, R. Consolação, 930, Sao Paulo - SP - Brazil
Email: marcia3.silva@usp.br

Abstract. The issue about flammability of textile materials employed in passenger cabins of commercial aircrafts is an important part of safety routines planning. Once an in-flight emergency initiated with fire or smoke aboard, time becomes critical and the entire crew must be involved in the solution. It is part of the crew functions, notably the attendants, the in-flight firefighting. This study compares the values of textile material of flight attendant working cloths and galley curtain fabric with regard to flammability and Limiting Oxygen Index (LOI). Values to the professional clothing material indicate that they are flammable and the curtains, self-extinguishing. Thus, despite of the occurrences of fire outbreaks in aircrafts are unexceptional, the use of other materials and technologies for uniforms, such as alternative textile fibers and flame retardant finishes should be considered as well as the establishment of performance limits regarding flame and fire exposing.

1. Introduction
Professional uniforms, including those ones of aeronauts, provide information about the company's status, hierarchical position, homogenize the group and giving to the worker a sense of responsibility and team participation [1]. Flight attendants are trained, among other activities, to in-flight firefighting. Their function can be defined as: "... to perform safety duties in the passenger cabin in accordance with the requirements of the operator and the Authority; qualified to perform cabin functions in emergency situations and enact procedures to ensure a safe and orderly evacuation of passengers when necessary" [2].

The worldwide air traffic is about 3,5 billion of passengers and 34 millions of departures per year [3]. Accidents in the aviation are extremely seldom and even more seldom are fatal accidents. The involvement of human lives and the impossibility to get zero air crashes lead airlines to work hard on their operating routines. Furthermore, commercial aviation security depends on partnerships, information exchange and global standards [4].
2. **Worldwide civil aviation**

2.1. **Continuing Airworthiness**

Continuing airworthiness consists of a systematic arrangement of actions to maintain the safety levels obtained during the aeronautical product certification process. The process flow of the Continuing Airworthiness starts on initial type certification, then go on through maintenance and operational regulatory and authority approval. In the other words, it means keep the aircraft according its approved design and been in a condition for safe operation [5].

2.2. **Air Accidents**

The collection of information during the analysis of accidents, contribute to the development of preventive routines. It is about the identification of risks and occurrences through the collection of data and its analysis [6].

Due to the greatness and scope of the air transport industry, safety is characterized as a key element and in the search for improvement, aeronautical companies are going through the proactive approach, which uses daily flight monitoring, thus identifying the risks involved and anticipating security actions [7].

The impact of security approaches is reflected in the Global Accident Rate. This index shows the number of accidents in 2015 was 2.8 accidents per million departures. This is a slightly lower index than in 2014 (3.0), which in that year interrupted the index's downward trend since 2011. The significant reduction was observed in the number of fatalities that in 2014 registered 904 falling to 474 in 2015 [3].

2.3. **Textile Materials in Commercial Aviation**

Civil aviation is a sector highly regulated by laws, standards, procedures, among others and local and international issues. For the safety of the aviation system, regulations are critical elements that bring benefits to the company and its customers as they promote clarity and certainty for all [8].

Aligned to regulatory compliance, the flammability characteristics of textile materials employed in the aircraft passenger cabin are well defined in CFR 14 standard and rigid tests are conducted to evaluate the flame propagation time. The materials, which compose the passenger compartment of an aircraft seeking compliance with the "§ 25.853 – Compartment Interior" of CFR 14 - Part 25, shall present at least the following requirements: (i) materials shall be at least spark resistant (static discharge); (ii) walls, ceiling linings, upholstery coverings, floors and furniture shall be at least flame-resistant; (iii) each receptacle for towels, paper or waste should be at least fire resistant and must restrict fire. However, such regulations do not cite the textile materials of crew uniforms [9].

On other hand, professional clothing are commonly made from polyester and its blends with cotton, since they are relatively cheap materials for the textile apparel industry and provide the comfort and breathability of the cotton with the strength and durability of the polyester [10]. However these fibers and blends present low thermal stability and high flammability [11].

2.4. **Flight attendants and their functions**

Airmen are called those workers who work in terrestrial services to support the aeronautic activity. The technicians working on board the aircraft in operation are called aeronauts, being divided into technical crew composed by pilot and co-pilot and service crew composed by the flight attendants [12].

The presence of flight attendants goes far beyond their duties of caring for and serving passengers. They are flight safety professionals and often the only physical interaction between the customer and the airline [13]. Also, the aeronauts have the particularity in their function that is the training of combat to the emergencies of fire on board [9], in a restricted environment in which the action must be very fast and assertive. In this way, crew members including flight attendants must undergo a qualification process to obtain a specific license to practice the profession [2].
3. Textile Flammability

Materials are flammable when easily ignite and the flames propagate rapidly. Textile materials are intensely used in daily routines and are often exposed to fire. The most common natural fibers are separated into two categories: ligno-cellulosic fibers like cotton and flax, which are easy to ignite and flammable and protein fibers such as wool and silk that are harder to start the flame [14].

In this way flammability, or the ability of a fabric to ignite and maintain flame, becomes a constant concern for safety, to the point that some countries issue laws to reduce the risk of injury from highly flammable fabrics [15].

One of the measures of flammability is the Limiting Oxygen Index (LOI), which represents the percentage of oxygen required to sustain the flame. As lower the LOI, as easier the fiber can burn [16].

Natural fibers such as cotton and some synthetic fibers such as polyester and nylon have relatively low LOI (between 18 and 21), while other natural fibers such as wool or synthetic fibers such as aramids are more flame resistant (with LOI between 25 and 30) [17].

3.1. Uniforms

The use of uniforms by employees of a company is a common fact, aiming at organizing the work, presentation of the company to the public, corporate image and commercial objectives [18]. The uniform becomes an indicator of the set of rules of appropriate conduct and its internalization by the employee [19].

Airlines from all over the world adopt the uniforms for the personal presentation of their crew. Wearing the uniform according to the standards established by the company is the responsibility of each flight attendant, but the final compliance direction is verified by in-flight service leadership [20].

3.2. Evolution of materials used in uniforms

An example of a uniform's evolution is the flight suit. The aviation was developed with open cockpit and caused the pilots a great discomfort with its noise, speckled oil, cold wind and possibility of rain and snow. During World War I, a set of two pieces of leather is adopted by the pilots. It is the preferred material because it was durable and offered protection against impact with insects, debris or drops of oil during the take-off and landing procedures [21].

In the period of World War II, pilots needed a functional uniform in the reduced space of the cockpit. The materials used were wool and a heavy twill cotton to resist wind and fire. During the 1960s with Project SR-71 - Blackbird, the need arises for protection at high temperatures generated by friction with the layers of the upper atmosphere. New Technologies have been developed and applied in aircraft materials and in uniforms, helmets, visors, masks, gloves and shoes [22].

With the arrival of jet airplanes, it was necessary to develop a clothing that protected the pilot from physical stress from acceleration by the compression of the body. The first goal was to avoid the accumulation of blood in the lower extremities of the body, maintaining blood circulation, thus avoiding the lack of oxygen in the brain and consequent fainting. It also provides a firm abdominal support to compensate the effort used by pilots during their maneuvers [23]. The suit pressurizing technology was adopted by the aerospace industry. The one-piece costume used in the Mercury Program (1958 - 1963) was an adaptation of the pressurized clothing of jet pilots and there was no provision for external missions [21].

Materials with flammability potential were replaced by lower risk other ones. In this scenario, meta-aramid fiber fabrics were the current material for flight military clothing, rescue and police air services under requirements from military standards [24, 25]. The most known brand of meta-aramid fiber is Nomex® (DuPont™).

On the other hand, the civil aviation aeronauts nowadays are still using majority polyester fiber in their uniforms. Taking in account a simple potential failure analysis (considering factors such as severity, frequency of the occurrence and the way of detecting the failure), a plausible hypothesis could be related to the rarity of accidents enrolling the issue of flammability of their uniforms, implying in a very low risk.
However, considering the differences of flammability criteria between fabrics of aeronauts and the coating materials inside the civil airplanes, this study aimed to compare the values of textile material of flight attendant working cloths and galley curtain fabric with regard to flammability and Limiting Oxygen Index (LOI).

4. Material and Methods
This research has started with the collection of qualitative data in the scientific literature on the professional uniforms, the textile materials and the methods to increase the flame resistance. In addition, vertical flame tests were carried out and the obtained results were analyzed with LOI values of usually employed textile materials.

The textile material from a female blazer, worn by flight attendants of a Brazilian airline, was analyzed and the material identified as canvas 100% polyester (warp - 23 yarns/cm; fill – 20 yarns/cm) and 272 g/m² weight.

This material was submitted to the Vertical Flammability Test according to FAR 25.853 at SENAI CETIQT (Rio de Janeiro-Brazil). In parallel, the galley curtain material of an aircraft owned by a Brazilian airline presents jacquard structure and 417 g/m² made with Trevira CS® polyester, which is certified as M1 by the NFP 92-507 standard for non-flame-propagating fabric.

The data on its flammability were collected from report 7878/8 M110557-04-04 (Lantal, Swiss), evaluating the products manufactured with Trevira CS® [26]. For both materials, the Limiting Oxygen Index (LOI) values - which indicates the oxygen concentration of each material to sustain the flame - were analyzed.

5. Results
From obtained literature information, fire in the galley curtain material (Trevira CS®) extinguishes immediately upon removal of the flame, whereas in the blazer polyester fabric it continues for an average of 25 seconds (warp direction) and 22 seconds (weft direction). These values represent the times in which the textile continues burning after 12 seconds of flame exposition. The post-flame limit time specified by test standard is up to 15 seconds. The LOI data (Table 1) present a great difference in the values to the professional clothing material (20.6 - flammable) and the curtains (29.0 - 30.0 - self-extinguishing) [27].

| Ref. | Fiber       | LOI  | Classification               |
|------|-------------|------|------------------------------|
| [14] | Flax        | 17.4 | LOI < 20.95 - Flammable      |
| [17] | Cotton      | 18.4 | LOI < 20.95 - Flammable      |
| [17] | Polyester   | 20.6 | LOI < 20.95 - Flammable      |
| [28] | Silk        | 23.0 | 21< LOI < 28 - Slow burning  |
| [28] | Wool        | 25.2 | 21< LOI < 28 - Slow burning  |
| [26] | Trevira CS® | 29.0-30.0 | 28 < LOI < 100 - Self extinguishing |
| [17] | Para-Aramid | 29.0 | 28 < LOI < 100 - Self extinguishing |
| [17] | Meta-Aramid | 30.0 | 28 < LOI < 100 - Self extinguishing |

Source: Compiled from references indicated in Table.

6. Conclusion
Despite the difference in characteristics and end-use of the analyzed textiles, it is evident that there is not the same degree of concern about the flammability of textiles of flight attendant working cloths (flammable) than lining textiles inside the aircraft (self-extinguishing). Despite of the occurrences of fire outbreaks in aircrafts are unexceptional, the safety must be ensured. In an aboard fire situation, if the uniform is flammable, this fact could make impossible to keep the appropriate firefighting actions and limit the attendants’ acting as flight safety agents. Thus, the use of other materials and
technologies for uniforms, such as alternative textile fibers and flame retardant finishes should be considered as well as the establishment of performance limits regarding flame and fire exposing.

Acknowledgements
Financial support from grant 2016/01331-9, São Paulo Research Foundation (FAPESP) and CAPES (Brazilian Coordination for the Improvement of Higher Level Personnel) are gratefully acknowledged.

References
[1] Farias R 2010 Entre a igualdade e a distinção: A trama social de uma grande empresa corporificada no uniforme (Between equality and distinction: The social intrig of a large corporation embodied in uniform) (Campinas: Thesis bank University of Campinas)
[2] IATA 2015 Cabin Operations Safety - Best Practices Guide 2015 (Montreal) p182
[3] ICAO 2015 Annual Reports of Council.Available from http://www.icao.int/annual-report-2015/Pages/the-world-of-air-transport-in-2015.aspx
[4] Tyler T 2014 Strong partnerships, strongs business Annual Review 2014 1–32.
[5] Possi R, Passos RC, Oliveira O 2010 Um novo modelo para submissão de ocorrências aeronáuticas (A new model for submission of aeronautical occurrences) Conexão SIPAER (São Paulo) Nov 163-80
[6] Wilke S, Majumdar A and Ochieng WY 2014 Saf Sci (Elsevier Ltd) 63:18–33.
[7] Li L, Hansman RJ, Palacios R and Welsch R 2016 Transp Research (Elsevier Ltd) 64:45-57
[8] International Air Transport Association (IATA) 2015 IATA Annual Review 2015
[9] FAA 2016 Part 25- Airworthiness standards: transport category airplanes
[10] Leistner M, Abu-Odeh AA, Rohmer SC, Grunlan JC 2015 Carbohydr Polym (Elsevier Ltd); 130:227–32.
[11] Attia NF, Morsy MS 2016 Mater Chem Phys. (Elsevier B.V); 180:364–72.
[12] Mistura GV, Silva Filho AI 2010 Custo Humano, Prazer e Sofrimento no trabalho:Um estudo com aeronautas (Human cost, pleasure and suffering at work: one study with aeronauts). Revista Conexão SIPAER Jul;69–99.
[13] Nery MLC 2009 Freqüência e prevalência de diagnóstico psiquiátrico determinante do afastamento de comissários de bordo da atividade aérea (Frequency and prevalence of psychiatric diagnosis determining absence from work of flight attendant from aerial activity) (Sao Paulo: Universidade de Sao Paulo)
[14] Kozłowski RM, Muzycecz M 2012 Handbook of Natural fibres Volume 2: Processing and applications, Kozłowski RM, editor. (Cambridge: Woodhead Publishing Limited Abington Hall) p. 516.
[15] Fan J, Lau L 2009 Engineering apparel fabrics and garments Fan J, Hunter L, editors. (Cambridge: Woodhead Publishing Limited Abington Hall) p. 413.
[16] Horrocks AR 2014 High Performance Textile and Their application Laurence CA, editor. (Cambridge: Woodhead Publishing Limited Abington Hall) p. 451.
[17] Sinclair R 2015 Textile and Fashion: Materials, Design and Technology (Cambridge: Woodhead Publishing Limited Abington Hall) p. 845.
[18] B-Fonseca PF 2014 Disciplina juridica da utilizacao de indumentaria no ambiente de trabalho.(Legal discipline of the use of clothing in the work environment) Direito UNIFACS–Debate Virtual;164.
[19] Craik J 2007 Uniformierungen in Bewegung vestimentare praktiken zwischen Vereinheitlichung, Kostümierung and makerade Mentges G, Neuland-Kitzerow D, Richard B, editors. (Munster: Waxmann Verlog) p. 37–55.
[20] United 2013 Your image is the United brand: Flight Attendant Uniform Appearance Standards from:https://unitedafa.org/docs/uniforms/appearance_standards.pdf
[21] Sweeting CG 2015 United States Army Aviator’s clothing, 1997 -1945. 2nd ed.(Jefferson North Caroline:McFarland & Company)181 p.
[22] O’Lary M, Schulzinger E 1989 *Black Magic: America’s Spyplanes SR-71 and U-2.* (Motorbooks International) 144 p.

[23] Jenkins DR 2012 *Dressing for Altitude: U.S. Aviation Pressure Suits - Wiley Post to Space Shuttle.* (Washington: National Aeronautics and Space Administration - NASA) 526 p

[24] Standard MIL-C-81814C : Military Specification : Cloth, twill, aramid, high temperature resistance, 1990 Washington.

[25] Standard MIL-J-83388E: Flyer’s Jacket, cold weather, 1992 STANAG 4671 (Edition 1) Unmanned Aerial Vehicle Systems Airworthiness Requirements (UASAR).

[26] Bajaj P 2000 *Handbook of Technical Textile* Harrocks AR, Anand SC, editors. (Cambridge: Woodhead Publishing Limited Abington Hall) p. 559.

[27] Younis AA 2016 *Egypt J Pet* 25(2):161–9.

[28] Bourbigot S 2008 *Advances in fire retardant materials.* Horrocks A. R, Price D, editors. (Cambridge: Woodhead Publishing Limited Abington Hall) p. 625.