FLAMMABILTY OF CABIN CREW UNIFORMS

UNSW AVIATION
AIR TRANSPORT SAFETY II
AVIA 3710

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16 November 2000

CONTENTS

1. Abstract

The requirements of cabin crew uniforms with respect to the flight attendants primary responsibilities is investigated. Flammability characteristics of various fabrics commonly used for cabin crew uniform are analysed and determined with respect to ignition temperatures, burning rates and products produced.

Various flammability test are critically analysed. The processes involved as well as the aims of the tests are evaluated. The validity of the tests with respect to cabin crew uniform requirements is examined.

The theories of Flame Retarding fabrics is investigated and evaluated. The various chemicals involved for flame retardancy are identified. The functions of the flame-retardants as well as their behaviour during combustion process is examined and discussed.

Finally, recommendation for further research in the testing methods is provided.

2. Hypothesis

What factors influence flammability of cabin crew uniforms and how can they be addressed.

3. Aims of This Report

This report renders to analyse the flammability of various textiles that may be used for cabin crew uniform. The primary aims of this report include:

- Analysing the flammability of several commonly used textiles
- Analyse ignition temperatures of natural fibre fabrics and man-made fabrics
- Analyse the combustible reaction of the various fabrics once the ignition source is removed
- Analyse flammability test methods with respect to aircraft conditions and the duties of Flight Attendants
- Analyse several Fire Retardant (FR) methods and chemicals which may be used on various textiles

The supplementary aims of this report include:

- Determine the factors requiring consideration when determining suitable materials for Cabin Crew uniforms
- Provide recommendations of the most suitable textiles to be used for Cabin Crew uniforms
- Recommend the most suitable Textiles Flammability Test method(s) with respect to Cabin Crew duties and aircraft environment
- Provide recommendations for the most appropriate Fire Retardant chemicals and/ or methods

4. Methodology

Research for this report will be conducted primarily through the analysis of secondary data sources. Experimental observations will be conducted to compare with the secondary data collected. Scientific methodology will be applied to collect relevant information. A review of various literatures as well as interviews with professionals within the Textiles Technology industry will be conducted. Qualitative methods are to be implored with respect to analysis of data collected. Narrative descriptions secondary data collected and of observations made through experimental means.

Newsletters published within the Cabin Crew Safety section of the Flight Safety Foundation website will be searched. In particular those regarding cabin fires, flammability, and cabin crew uniforms. References used for the reports will be further followed up.

Search links at the FAA website for reports concerning flammability of fabrics and cabin interiors. Use references from FSF newsletter to search for aircraft accident reports where the presence of fire caused significant injuries to passengers and crew members. Consult the US General Accounting website to retrieve and review statistical reports and analysis on aviation accidents involving fatalities cause by fires.

Professionals within the textile technology industry will be consulted and interview to gain an understanding of flammability and to be pointed in the right direction with reference to finding information and conducting research. The interviews will be conducted periodically to review new information found and how that information may be analysed and further researched.

Research materials and literature recommended will be analysed with the references of the literature sought to gain in-depth information Research material regarding the flammability of textiles, flame retardants and flammability tests will be searched at the University Library (UNSW) and the State Library of New South Wales. Research within the Textiles database of the UNSW Library shall be accessed.

Observations regarding the flammability of various textiles will be made through the conduction of several unofficial experiments. The experiments will be conducted without the control of variables as these will be done purely for the purposes of observation and not for the record of any measurement.

Conclusion and recommendation will be made with respect to the analysis of the data collected. Further research suggestions will made on the same grounds.

5. Literature Review

5.1 Flammability

Lewin (1985) explains flammability as the tendency of a material to burn with a flame. Indeed the flammability of textiles is a measurement of the ease with which fabric is able to be ignited and how effectively it burns. Kasem and Rouette (1972) profess that ignitability of the fabric as well as combustibility are the indicators of fabric flammability characteristics. The combustibility of the fabric is stated as the rate at which the flame (or the afterglow) is able to propagate. Ignition of the fabric is described as a more complex phenomenon by Tesoro et al (1976). Ignition involves the transfer of heat with 'thermal decomposition governed by fluid mechanics and chemical kinetics'. Exothermic reactions are triggered as the ignition temperature of the fabric is reached. The reactions accompanied by a flame or glowing of any sort is termed *ignition*.

The burning process of textiles as stated by Reeves, Drake and Perkins (1974) involves the release of heat, decomposition of the material, combustion and propagation of the flame. The decomposition of the material is explained as the breakdown of the hydrogen bonds that make up the composition of the fabric. Professor Pailthorpe in his report covering the Flameproofing of Textiles (2000) explains that the fabric is broken down into gaseous liquid and solid composites, which further fuel, the combustion process. His theory is in agreement with Lewin (1985) who provides a diagrammatical representation of the burning process, Diagram 1. When discussing the combustion process Perkins et al (1974) includes the notion of flaming, glowing and smouldering. Glowing is explained as the release of radiant heat and the existence of a luminescence without the flame. The reaction is exothermic and occurs in conditions of high oxygen levels. The slow suppressed exothermic reaction, termed smouldering, occurs beneath the surface of the fabric at low oxygen levels.

5.2 Factors Influencing Flammability Characteristics

In his report titled 'Flammability of Apparel', Bhatnagar (1975) uses the research of Richards (1969) to determine three principal properties of fabrics that dictate their flammability characteristics.

1. The Physical Properties
2. The Chemical Properties
3. The Thermal Properties

The **physical properties** of the fabric include its weight, construction and its configuration. As Kasem and Rouette (1972) also point out, the mass per unit area is directly proportional to the ease of ignition and the linear burning rate. That is the denser and hence heavier the fabric the longer it take to ignite and the longer it takes to burn. The construction of the fabric is referred to as the smoothness of the surface of the fabric. The notion regarding the configuration of the fabric is discussed by Saddler et al (1988) who go on to explain that a tightly configured fabric reduces the level of oxygen available to support combustion. A knitted textile is likely to be more porous than a woven fabric is.

Bhatnagar (1975) points out that fire is a chemical reaction, therefore the **chemical properties** of any fabric are able to influence its flammability characteristics. Chemical properties of the fabric are determined by the fibers used in the fabrication. Professor Pailthorpe (2000) noted in his report regarding the Flammability of Textiles that textiles with higher concentrations of carbon were less reactive to fire in comparison to those with a low concentration.

The **thermal properties** of fabric suggested by Reeves and Drake (1971) are the textile's ability to absorb heat. The ability of a textile to absorb heat can ordain its ignition temperature and burning rate.

Lastly, Reeves and Drake (1971) note that the conditions under which the fabric is tested is able to affect its flammability characteristics. The level of moisture present in the atmosphere and hence the ability of the fabric to absorb the moisture will deter its burning ability.

5.3 Theories of Flame Retardant Mechanisms

Lewin (1985) along with Reeves et al (1974) points out the various theories for flame retardant mechanisms. Four principal theories are discussed in most literatures, these include the coating theory; the thermal theory; the inert gas theory and the chemical theory

The **coating theory** according to Reeves and Drake (1971) is the where the retardant forms a glass fiber like coating on the surface of the textile. A barrier is hence formed between the fabric, the heat source and the oxygen present within the atmosphere. The coating of the fabric is also noted by Professor Pailthorpe (2000) to entrap any volatile substance of the fabric from being able to fuel combustion.

Little (1947) and Reeves et al (1974) both explain the two functions of the **thermal theory**. Firstly, where the 'caloric input from a source is dissipated by an endothermic change, such as fusion or sublimation of the flame retardant', which prevents the propagation of the combustion by absorbing considerable amounts of energy which otherwise would fuel the combustion. The second mechanism deters the heat supply away from the fabric at such a rapid rate that the textile is prevented from ever reaching ignition temperature. However Little (1947) as well as Reeves et al (1974 and 1971) along with Professor Pailthorpe (2000) and other literature reviewed state the inappropriateness of these two mechanisms with regard to clothing fabrics.

The **inert gas theory** is described by Lewin (1985) as the evolution to dilute fuel formed by pyrolysis. The inter gas theory is further explained by Drake et al (1974) as the process whereby the flame retardant is decomposed at ignition temperatures to release gases which are relatively unreactive and do not burn. The gases released tend to *dilute* the flammable gases that which would otherwise be produced to concentration levels below the flaming point. Effective gas include carbon dioxide (CO_2), hydrogen chloride (HCL^-), water (H_2O) and sulfur dioxide (SO_2)

The ‘Flameproofing of Textiles’ report complied by Professor Pailthorpe (2000) summarises the **chemical theory** as the introduction of certain chemical which alter the path of the decomposition of cellulose inducing the formation of non-volatile carbonaceous substances as opposed to flammable tars and gases. Professor Pailthorpe (2000) in agreement with Little (1947) and Perkins et al (1974) concluded that ammonium salts and metallic oxides increase the yield of char – an organic substance – from 20% to almost 50%; and decrease the formation tar – a flammable substance – from 60% to between 15 – 30%. This theory is referred to by Reeves et al (1971) as the ‘dehydration theory’ where the removal of the heat source ceases the combustion of the fabric.

Reeves and Drake (1971) deliberate a supplementary theory called the **hydrogen bonding theory**, which propounds that strong hydrogen bonding of flame retardants help to stabilise the bond between the cellulose fragments by reducing their volatility and hence their combustibility. The theory is later discarded as improbable as hydrogen bonds could not exist at 400°C – 500°C.

5.4 Concepts of Heat Transfer

Heat transfer has been defined by Sternheim (1988) as the process by which heat energy is exchanged between separate bodies or between regions of the same body at various temperatures. The rate of heat transfer according to Freeston (1970) depends on the form of heat and the heat source temperature as well as the thermal characteristics of the material in question.

Waldock (1999), in his contribution to the Cabin Crew Safety newsletter, claims that most burn injuries are caused by ambient and radiant heat. Ambient heat is broadly defined by Scott (1991) as atmospheric heat, where as radiant heat is that which is radiated from a specific heat source such as an open flame or an iron.

Backer (1976) et al identified three primary methods by which heat is transferred to the skin.

1. Convection of hot gases within the air-gap ‘towards cooler skin and conduction through a thin layer of stagnant air adjacent to the surface of the skin’.

2. Radiation from the production of solid particles (melted particles and glowing char) and gases from the combustion of the fabric.

3. Condensation of the products of pyrolysis (char and melted particles) as well as steam from the combust fabric ‘at sufficiently small spacing to cause flame quenching.

Alvares and Blackshear (1969) highlight the existence of a parallel problem regarding the process of heat transfer from burning fabrics to skin. It is recognised that 'thermal damage to skin and the ignition of cellulosic materials follow similar response parameters'. That is, critical rates of energy deposition need to exist before the skin will exhibit damage or before the cellulosic material will ignite.

Lewin (1985) proposes that heat transfer is related to the size of the burn and depth of burn injury.

5.5 Classification of Burn Injuries.

Moussa (1976) et al summarises the phenomenon of 'burn injury' as the variations that which occur in the human skin 'as a result of rapid heat transfer from the adjacent burning fabric'. Moussa (1976) goes on to explain that the skin functions thermally as a heat 'generator, conductor, transmitter, absorber, radiator and vaporiser'. The various thermal functions of the skin denote that it is highly prone to burn injuries. As can be noted from Table 1.1, developed by Stoll (1967), that skin has a pain threshold of 44°C, beyond that temperature skin tissues become incapacitated.

In his report to the Flight Safety Foundation Waldock (1999) discusses the need for cabin crew uniform that do not cause injuries to the flight attendant that would hinder their work capabilities. The classification of various burn injuries that would impede flight attendants from carrying out their duties are discussed by Bhatnagar (1975) as he explains the *degrees of burns*:

- **First Degree Burns** are those where the skin is not actually damaged. That is, no skin cells are damaged and hence nu scarring occurs. Sunburn is an example of such a burn. Burn injuries of this nature cause redness and pain but do not greatly prevent the flight attendant from carrying out their duties.

- **Second Degree Burns** are burns where the secondary skin appendages experience partial damage. Encyclopedia Britannica (1997) explains the secondary burn as those marked by blisters for example 'a scald caused by hot liquid'. Secondary injuries as suggested by Backer et al (1976), will reduce the cabin crew members' efficiency but should not disable them from preforming their duties to a certain extent. The size of the injury may however determine the level of disability of the flight attendant.

- **Third Degree Burns** occur when the secondary skin appendages are completely destroyed. As Moritz (1947) explained in a third degree burn both the epidermis and the dermis of the skin are destroyed and underlying tissues are also probable to be damaged. This level of injury will prevent the flight attendant from manoeuvring which in the event of an incident may be a hindrance to the rescue process.

Dissimilar to Bhatnagar's classification theory, Lewin (1985) annotates the burn injuries with respect to the depth of the burn injuries. First-degree burns are noted when the epidermis is affected up to a depth of 80μm. The entire epidermis plus segments of the dermis damaged to a depth exceeding 80µm is categorised as a second degree burn. A third degree burn includes the destruction of the epidermis the dermis plus subcutaneous tissue.

5.6 Considerations for Testing Flammability

Bhatnagar (1975) points out two classes of burning tests

1. Fire Retardant Test – those that which measure the inflammability characteristics of Fire Retardant (FR) treated fabrics. Little (1947) notes the property to be observed would be the burning rate of the fabric once ignition is propagated

2. Flammability Test – those that which determine the flammability characteristics of untreated fabrics.

As ascertained by Lewin (1985) most tests are designed to measure the ignition temperatures, ignition times, afterglow, flame times, length and area of char upon burning, mass loss, the flaming and frequency of melted drops and the rate of surface flame propagation.

Similar to Lewin's remarks, Little (1947) notes that observations of flame tests employed for the testing of flameproof textiles 'serve to estimate the degradation suffered by the specimen through three different mechanisms. The measurement of the area and length of char serves as an index of the damage induced by the sample whilst in contact with the flame. The extent of the decomposition caused by autocombustion after the flame has been extinguished may be noted from the time of the after-flaming. The duration of the afterglow is noted to represent an estimate of the damages suffered through oxidation of the charred residue at the desist of flaming

Little (1947) maintains that the selection of an appropriate flammability test procedure is imperative to ensure accurate results. The test procedure must be based upon the considerations of the types of fabric to be tested the type of flame to be used and the nature of the flame exposure to which it may be subjected. Little also stress the importance of selecting the appropriated apparatus with respect to the anticipated used of the fabric and 'the requirements to be satisfied'. A completely erroneous result of the relative efficiencies of flameproofing agents may be attained if the flame test is too severe or too mild.

RESEARCH ANALYSIS

DISCUSSION OF FINDINGS

6. Background

6.1 Cabin Crew Responsibilities:

Cabin Crew are employed within the aircraft for safety reasons. Their primary duty is the management of the safety of the passengers on board the aircraft and; secondly to provide in-flight customer service. With respect to their primary duties, flight attendants are expected to assist passengers evacuate a burning aircraft in the event of and emergency.

"…duty to assist the first person that couldn't help himself…" (FSF Vol.30 1995)

Injuries incurred in the course of performing core competencies may immobilise the flight attendant and/or restrict their ability to provide assistance to passengers.

6.2 Desired Factors of Cabin Crew Uniforms

Cabin crew require uniforms that would not hinder them from fulfilling their responsibilities in an emergency situation. Due to the varied duties and environments in which the duties are performed, several factors need to be considered when evaluating clothing fabric for Cabin Crew uniform(FSF Vol.33 1999). These are discussed below.

- Durability of the fabric in terms of its ability to withstand mechanical and environmental stresses.

- Launderability and Maintenance of the fabric. That is effort required to clean the fabric and how the cleaning deteriorates the fabric. Also the effects of the cleaning process on fire retardant materials.

- Reaction to Fire. That is the impact on the characteristics of the fabric when exposed to a heat source

- Level of Protection the fabric is able to provide the wearer when exposed to various conditions, especially heat sources. Measurement of how effectively the fabric conducts heat and the temperature at which its structure is deformed as well as the fabrics self-extinguishing abilities.

- Comfort Factor. The flexibility and breathability of the material along with its ability to absorb liquids and vapours and tendencies to irritate the skin.

Flight attendants need to be able to perform their duties with little concern for the appearance of their clothing. They are constantly juggling time and therefore require low maintenance outfits. The job also involves a degree of risk therefore the uniform needs to be appropriated to various environments and work conditions.

6.3 Types of Textiles

Fabrics are complied of two separate types of fibers. *natural fibers* and *man-made fibers*.

Natural fibers are those that which are naturally produced either from plants or on animals . These fibers are further categorised into *cellulose* or *protein*

Cellulosic Fibers

Cellulosic fibers are those which may be extracted from plants, the most common being cotton which may be further classified as a *seed hair* fiber. Cellulosic fibers are relatively economical and easy to separate from their plant.

Fabrics made from these fibers are generally good absorbers of liquids and vapours as well as being good conductors of heat (Textiles, 6^{th} Edition, 1988). The fiber becomes almost plastic like when it is wet increasing its durability. Their resiliency and flammability characteristics however are reasonably poor. Cellulosic fibers have a tendency to wrinkle easily. They are also able to be ignited quite easily and once ignited burn freely (Flammability of Apparel, Vol. 7.,1975) particularly if the garment is knitted and reasonably 'flimsy'. An afterglow is usually present once the heat source (the flame) is removed from cellulosic fabric decomposing into a feathery ash substance.

Protein Fibers

Including wool, silk and fur, protein fibers originate from animals, and are composed of amino acids. They contain portions of hydrogen, nitrogen, oxygen and carbon and are amphoteric, that is they contain both acidic and basic reactive groups (Textiles, 6^{th} Edition, 1988).

Protein fibers have moderate to high resiliency, that is, they do not wrinkle as easily as cellulosic fabrics and are able to maintain their shape. However unlike cellulosic fabrics, protein fabrics become weaker with excess moisture. Wool can lose up to 40% of its original strength where as silk loses up to 15% of its original strength. Fabrics made of protein fibers possess more favourable flammability characteristics than cellulosic fibers. The level of oxygen present within the composition of the fabric is reasonably low (Prof. Pailthorpe, 2000). The fabric does not burn readily and once the heat source is removed self extinguishes. Protein fibers tend to produce an odour when burnt and form black crushable ash (Flammability of Apparel, Vol. 7, 1975).

Man-made fibers such as synthetics are fabricated by compiling simple compounds (monomers) to produce more complex compounds (polymers). Man-made fibers are cheaper to produce than natural fibers and have higher levels of durability regardless of whether the fabric is wet or not.

Fabrics produced from man-made fibers are generally heat sensitive and are likely to soften and/ or melt at certain temperatures.

Natural fibers and man-made fibers are regularly combined to develop fabrics that which may contain the durability properties of man-made fibers and the flammability and comfort properties of natural fibers. These fabrics are referred to as *blends*. Blends represent a mixture of fibers of different compositions, lengths, diameter or colour. Blending of separate fibers is conducted obtain a more desirable appearance of the fabric. Also for economical reasons as man-made fibers are relatively inexpensive in comparison to natural fibers.

The resiliency and strength of the fabric depends upon the percentage of natural fibers present. A higher concentration of the man-made fiber improves the durability of the fabric however it remains highly sensitive to heat. The properties of the natural fiber become irrelevant due to the greater presence of man-made fibers. Table 1.2 summarises the comparisons between natural and man-made fibers.

The compilation of the fibers to construct fabrics can be achieved by two methods. *Weaving* and *knitting*.

Woven fabrics are produced by interlacing 2 systems of thread – warp and weft – lying in the same plane and at right angles to each other (Weaving: Control of Fabric Structure, 1975) as can be seen in Diagram 2. Woven fabrics are such as denim, are stronger than knitted fabrics. Because of their configuration woven fabrics can have only a relatively small level of oxygen present within the fabric.

Knitting involves the formation of a fabric by inter-looping one or more sets of yarn (Textiles, 6th Edition, 1988) refer to Diagram 3. The inter-looping composition of the fabric enables knitted fabrics to be reasonably flexible. Configuration of the fabric is classified as porous hence it enables a greater concentration of oxygen to be present.

7. Analysis

7.1 Flammability Characteristics of Various Fabrics

Of the fabrics developed from natural fibers, cellulosic are found to be the most flammable. The flammability of cotton is discussed below.

7.1.1 Cotton

Fabrics made of cotton are found to be the most flammable. With an ignition temperature of 400°C, cotton is able to be ignited in 2 second (Prof. Pailthorpe, 2000). Once ignited cotton burns quite readily, that is, it is able to support combustion. The removal of the ignition source produces an afterglow. The carbonaceous residue continues to combust the fabric until eventually it is decomposed entirely into a fluffy ash (Flame Resistant Cotton, 1971).

The burning characteristics of the cotton fabric were found to depend upon the configuration of the fabric, the strength of the configuration and the conditions under which the test is conducted. A knitted cotton fabric ignited and burned easily. The flame was able to propagate and spread in all direction quite rapidly (Experiment conducted 2000). A tightly woven heavy fabric, such as denim, tends to resist flaming. Once ignited, the fabric releases smoke particles, continues to glow and decompose however it does not catch on fire (Textile Fabric Flammability, 1976). The heavier fabric also produces a visible whitish smoke whereas the lighter fabric sample is found to release less visible smoke. The flammability of the fabric is found to increase once the cotton is washed with soap (Flammability of Apparel, Vol. 7, 1975). The material burned under hot flaming conditions, releases carbon dioxide (CO_2) gas which is relatively non-toxic (FSF, Cabin Crew Safety, Vol. 31, 1995).

7.1.2 Wool

Wool tends to burn slowly, that is the time of ignition and rate of propagation of the flame is gradual. With an ignition temperature of 590°C (Flameproofing of Textiles, Report 2000) wool is the least flammable of all natural fibers. It has a higher *limiting oxygen index* of 25% limiting its ability to support combustion. Its comparative flame resistance is due to the amino acids present. Amino acids, which make up the protein fibers, have organic (carbon) compounds (Chemistry: Basic Facts, 1991) which are fairly unreactive.

The fabric initially gives an impression of melting. Wool is found to self extinguish as soon as the ignition source is removed. Igniting the surface of the fabric saw the flame extinguish quickly without any afterglow. Ignition at the edge of the fabric at a 45° angle found the flame to propagate on a slow and steady trajectory path from where the flame initiated (Textile Fabric Flammability, 1976). The burning does not spread out in all directions.

7.1.3 Silk

As one of the strongest natural fibers, silk in its natural form displays similar flammability characteristics as wool (Textiles, 6th Edition, 1988). Being a protein fiber with amino acids the rate of propagation is slow. The combustion is not supported. The fabric self-extinguishes almost immediately with the removal of the flame.

Silk tends to form black coal like crushable ash. It also releases toxic carbon monoxide (CO) gas due to the concentration of carbon present within the amino acids (Textile Fabric Flammability, 1976).

Synthetic fiber textiles tend to soften and melt when in close proximity to a heat source.

7.1.4 Nylon

The ignition temperature is found to be at 530°C (Flammability and Flame Retardance of Fabrics, 1972). Nylon fibers are observed to shrivel away in all directions from the heat source at a rapid rate before they can ignite. Nylon is not able to support combustion. Combustion stops immediately aft of the removal of the heat source.

Nylon tends to melt and form hardened tan beads (black if the fabric is dyed) at the edges. Parts of the melted fabric drip, at times carrying the flame with them. Toxic hydrogen cyanide gas (HCN) is released during flaming of the textile (FSF, Cabin Crew Safety Vol. 31. 1995).

7.1.5 Polyester

Polyester fabrics, similar to Nylon, retract from the heat source before ignition is able to take place. Once inflamed polyester burns readily melting and shrinking in the process at relatively low radiant heat (Flammability and Flame Retardance of Fabrics, 1972). The *limiting oxygen index* was found to be approximately 20% and the ignition temperature at 510°C (Flameproofing of Textiles, Report, 2000). Once the flame is removed the combustion process is desisted. Flame initially propagates in all directions before following the general trajectory path from where the fabric was ignited.

The melted particles cool to form black hardened beads, which sometimes drip carrying the flame. During the burning process an aromatic odour is released with black smoke containing particles of soot. The heavier knitted fabric propagated a narrow irregular flaming path, other parts of the fabric are hence left unburnt (Textile Fabric Flammability, 1976). Melting regions of lighter structured fabrics tend to separate from the rest of the fabric leaving it unburnt. Combustion conducted at 280°C – 300°C in air (containing Oxygen and Nitrogen) sees the fabric slowly decompose to a gaseous evolution.

7.1.6 Acrylic

Igniting at 560°C Acrylic fabrics tend to take longer to ignite, once propagation is initiated however, the fiber burns quite readily. The fibers of the textile soften then burst into flames. The *limiting oxygen index* is found to be the same as that for cotton, 18%. Acrylic fabrics are hence able to support combustion similarly to cotton fabrics.

The textile is found to start melting ahead of the flame. At temperatures of approximately 232°C – 254°C the melting becomes sticky. Any fallen melting goblets tend to stick to most surfaces (including skin stimulant). The material sputters as it melts. Acrylic textiles decompose into a crumbly black residue whilst releasing cyanide gas (CN) when burnt (Prof. Pailthorpe, 2000). If inhaled cyanide gas prevents the flow of energy within the body, effective immediately aft of inhalation (Chemistry: Basic Facts, 1991).

7.1.6 Polyester/ Cotton Blends

Polyester/ Cotton blends tend to have an ignition point higher that that of cotton but less than that of polyester. The polyester properties of the fabric not only increase the ignition temperature it also induces shrinkage of the fabric and melting before the flame actually comes into contact with the fabric. Once ignited the flame propagates quickly. A sizzling liquid appearance is observed before the fabric inflames. The removal of the heat source results in the melted region hardening into a crispy rice paper like substance. The fabric tested at 45° angle results a reduction in the frequency of melt drops where as test samples at 90° angle are observed to produce hardly any melted drops at all (Textile Fabric Flammability, 1976). An ample amount of black smoke is produced as the fabric burns.

The heated fabric disseminating ahead of the flame has the effect of 'sagging' the fabric and hence inducing irregular burning. The flammability of the fabric is dictated by the percentage of cotton fibers present (Flammability of Fabrics, Vol. 9, 1974). A greater concentration of cotton will reduce the ignition temperature and increase the flammability.

Tables 1.3, 1.4 and 1.5 describe the various flammability properties of the material discussed

7.2 Flammability Tests

7.2.1 Limiting Oxygen Index (LOI)

As can be seen from Diagram 4, the LOI test is conducted by placing a sample vertically within a 'chimney'. A known mixture of varying ratios of oxygen (O_2) and nitrogen (N_2) is passed in an upward direction through the chimney (Flame Retardance of Fabrics, 1985). The fabric is ignited at the top of the sample. The aim of the test is to measure the amount of oxygen sufficient to sustain the flame. A 'volume fraction in the gas mixture of O2 and N2 is designated as the LOI' (Flame Retardance of Fabrics, 1985). The LOI test is sensitive, reproducible and independent of sample dimensions.

Measurements are able to be made with a degree of precision however the limitations of the test means that the accuracy of the results is questionable. Limitations of the test are:

- Influenced by the level of moisture content of the fabric, however the thickness of the sample and the velocity of the gas flow do not effect the value

- Results are influenced by the weight of the fabric

- It is unable to specify the degree of the afterglow or the rate of flame propagation (Flameproofing of Textiles, 2000)

- The gas flow is directed upwards whilst the burning of the fabric is propagates downwards. The gas flow dilutes the concentration of active halogen radicals in the flame perverting the accuracy of the results.

7.2.2 Vertical Tests

Designed specifically to measure the flame resistance abilities of Fire retardant (FR) fabrics (Flame Resistance of Cotton, 1971). The sample fabric is held vertically while the flame is positioned to ignite the fabric at the bottom edge. Diagram 5 illustrates the apparatus used for the conduction of the test. The flame is removed after a prescribed time and the flaming and the afterglow is recorded. Once the flame is extinguished the length of the char and the afterglow is measured from the edge of the sample.

Commonly used test is 'Flame Propagation Test' recommended in the Australian Standard AS1176.2. The fabric sample is marked at the top and the bottom two wires separated by approximately 500mm.The flame is positioned at the bottom of the sample. If the sample does not ignite or extinguishes before reaching the lower marker (placed at a distance of 100mm from the bottom edge of the sample) the result is recorded as 'flame not propagated (AS 1176.2, 1982). If the flame extinguishes before it is able to reach the upper marker is it observed to be 'self–extinguishing'. The test is used to measure the time of propagation of the flame. Refer to appendix 1.1 for a summary of the various vertical tests used.

7.2.3 Horizontal Test

The method is designed to be able to be used on all textile materials used for apparel. The fabric specimen is held wrinkle free between two plates in a horizontal position where the flame is positioned to ignite the surface of the fabric as opposed to the edge. The test is used to measure propagation of flame with reference to size the burning capacity of the sampled fabric. As opposed to the vertical test where the flame is removed after a set time period, the flame is not removed instead the sample is allowed to burn until the flame is extinguished and combustion ceases. Analysis is made by measuring the diameter of the hole produced by the burning (Flameproofing Textile Fabrics, 1947). The test is used to observe the melted particles that form and measure the frequency at which they drop from the sample to the simulant.

Horizontal test used in Australian Standard AS1176.1 (1982) to determine the ease of ignition of textiles in horizontal positions uses apparatus exhibited in Diagram 6. The fabric holder has several holes where the fabric tested. The flame burner is 'flicked' into position under the fabric and held for a set time period. Depending on whether the fabric is ignited the timer is adjusted by 0.2 sec and is 're-flicked' under another hole. The method is essentially 'trial and error' however the time of ignition is able to be determined in this manner.

A summary of the various horizontal tests may be analysed in appendix 1.2.

7.2.4 45° Angle Test

The 45° Angle test is similar to the vertical test with respect to what it aims to measure the difference being that the fabric sample is held at an angle of 45°. The flame is held at the bottom of the fabric and allowed to propagate in an upward direction. The burning rate is timed and recorded, as is the length of the charring (Flameproofing Textile fabrics, 1947). Refer to appendix 1.3.

7.2.5 Match Test

A qualitative test, this test method is not essentially recognised as an official test. The test is conducted by holding a small fabric sample in a vertical position from the bottom. The top of the sample is ignited and the sample is circulated. The test is used to determine the angular position at which the fabric must be held for the flame to extinguish (Flammability Measurements and Thermal Decomposition of Textiles, 1970). (Diagram 7)

A sample that which extinguishes at 0° is regarded to have passed the '0° flame test' which means that the fabric requires minium flame resistance. Generally flames that pass the 135° test will pass the vertical test.

7.3 Analysis of Flame Retardants

If the processes of fire can be summarised in a diagrammatical form it would resemble a triangle with fuel, ignition and oxygen positioned at the vortex as can be seen in Diagram 8

The Fire Triangle

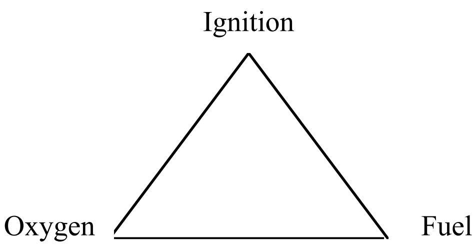

Diagram 8.

The aim of most flame retardants is to elimiate or block the function of one of the legs of the *'fire triangle'* (Textiles, 6^{th} Edition, 1988). For the flame retardant to be deemed appropriate it msut meet several requirements. These include:

- Minimal alteration to the physical properties of the fabric (texture of the fabric, smell, comfort, durability and strength)

- No afterglow and low levels of smoke toxicity

- Effective flame retardant with application of excessive reagent – the *add-on* should not be in excess of 20%

- Practical considerations – simple application process
  – conventional equipment for application
  – inexpensive

- Able to be combined with other finishes

- No impairment to dying or prints

- Stable to laundering and dry-cleaning

7.3.1 Non – Durable Flame Retardants

Non-durable treatments are most suited for use on cellulosic fabrics. Highly sensitive to weather conditions the treatment loses its effectiveness when exposed to weather, leached or laundered. The treatment requires reapplication after each laundering (Flame Resistant Cotton, 1971). Currently used non-durable retardants include:

1. *Borax – Boric Acid* – effective flame retardant, however an afterglow remains which can persist from 30 sec to several minutes

2. *Zinc Chloride* dissolved with *ammonia* – efficient flame retardant. $ZnCl_2$ alone is deliquescent, that is it absorbs moisture from the atmosphere (Flameproofing of Textiles, 2000)

3. *Borax – Diammonium Phosphate* – similar to Borax-Boric acid, however the presences of phosphate provides glow resistance (Flame Resistant Cotton, 1971)

Non-durable retardants are relatively inexpensive therefore are widely applied for commercial clothing flame proofing.

7.3.2 Semi-Durable Flame Retardants

Retardants are able to maintain their effectiveness for extended laundry cycles. Recommended for use on clothing which does not require frequent laundering. The oxides of zinc, tin, aluminium and antimony are most used along with insoluble salts comprising of zinc and stannic tungstate aluminium silicate and antimony oxychloride (Flameproofing of Textiles, 2000). Three different types of retardants are discussed below:

1. *Cellulose Phosphate* – a solution of diammonium phosphate and urea is attached to the cellulosic fabric. It is resistant to water but continuous laundering with soap or with water containing magnesium or calcium particles will gradually decrease the retarding ability.

2. *Phosphoryl Amides* – fabric is able to withstand launderings in de-ionised water or de-ionised water containing a detergent. Fabrics washed in solutions containing sodium, calcium or magnesium salts will lose their retardancy ability.

Diagram 9 is a flow-chart representation of the products of treated and untreated cellulose fabrics and the burning process that follows. It can be noted that treated fabrics perform better.

Durable Flame Retardants are used mostly on upholstery and other household apparel. Due to the irrelevance with respect to the research topic their flame retardancy characteristics have not been analysed in this report.

7.3.3 Flame Retardants for Wool and Silk.

Most commonly used flame retardants are Chrome treatments and Titanium treatments.

Chromium compounds are effective in increasing the natural flame resistant characteristics if 0.8% Cr_2O_3 (1.6% potassium bichromate) is 'exhausted onto the fiber by *reduced chrome* technique' (Fire Resistant Textiles Handbook, 1974). Treated fabrics are resilient to laundering and dry-cleaning.

Titanium compounds are applied in the form of organic and inorganic complexes. Citric, tartaric or oxalic acids are used as the complexing agents. The metal complexes are applied at $pH \leq 3$ to enable the negatively charged metal compounds to form complexes with the positively charged amino acids in wool and silk. The treated fabric is able to withstand 50 laundering cycles.

7.3.4 Retardants for Synthetic Fibers

Fabrics produced by synthetic fibers are inherently flame resistant. Chemicals are added to the melt of the fibers prior to the spinning process (manufacturing method for synthetics) that which ensure flame retardance of the fabric.

Phosphates are 'not too useful as flame retardants' for synthetic fabrics as fibers containing phosphorous compounds have poor spinning properties. Bromine derivatives of aromatic compounds are most effective, however their use is limited by their toxicity.

Polyester is difficult to treat. In most polyester/ cotton blends, the cotton is treated by a flame retardant. The amount of flame retardant used is dependent upon the percentage of polyester present within the blend.

% Polyester ∝ Amount of Flame Retardant Required

Note: refer to Appendix 2 for list and summary of various Flame Retardants

Afterglow Retardants include thermolabile compounds containing phosphorus and boron. Glow retardants divert carbon to the less exothermic carbon monoxide (CO) gas so that 'the heat of oxidation is insufficient to sustain further oxidation of carbon.

Chemicals used as flame-retardants may be represented in a diagrammatical format where the retardants are classified into three categories (Flame Retardance of fabrics 1985). Refer to Diagram 10

1. Primary – based on phosphorous and halogens in combination with each other. Phosphorous derivatives act in condensation phase in conjunction with nitrogen derivatives as synergists.

2. Flame Retardants based on halogen (chlorine and/ or bromine) are active in gaseous phase combined with antimony derivatives as synergists.

3. Alumina trihydrate, boron compounds, silicates and carbonates are classed adjunctive. Their activity is mostly physical.

7.4 The Analysis

Of the textiles made of natural fibers, cellulosic fabrics tend to ignite quickly and burn readily. An afterglow remains aft of the removal of the flame. Fabrics constructed from fibers originating from animals provide the most desirable result with respect to flammability. With a high ignition temperature, the flame takes longer to propagate due to the presence of amino acids. They are also self-extinguishing with the removal of the ignition sources.

Man-made fibers have inherent fire resisting properties and are cheaper to produce than natural fibers. Fabrics made of these fibers are likely to melt upon heating and stick to the adjacent surface whilst at times continuing to burn. Blends are constructed to improve the flammability aspects of cellulose fabrics as well as for economical reasons. Flammability characteristics of Polyester/ Cotton blends depends and on the percentage of cotton used to construct the textile.

Flammability tests are designed to measure and analyse the ignition time and temperature required to initiate the burning process; the rate of burning; the mass loss and the impacts from removal of flame. Used to test the flammability of both treated and untreated materials.

Flame Retardants are used mostly for cellulose and synthetic fibers. Wool and Silk are sufficiently fire resistant without the need for flame retardants. A relatively proportionate quantity (almost 10-30% of the of the weight of the fibers) of the treatments are incorporated into the textiles. Most treatments are either phosphorous based or contain halogens. Retardants containing phosphorus effect the pyrolysis of the polymers and act in the solid phase of the reaction. Halogens containing retardants affect the flaming reaction by behaving as ‘free radical scavengers’ act predominantly in the gas phase and also the solid phase of the reaction.

Melting of man-made fibers tend to cause more burn injuries – 2nd and 3rd degree burns. Cellulosic fabrics such as Cottons, have burning properties which can cause 2nd and 3rd degree burns. Afterglow causes as much damage as actual flame. The glowing phase yields almost 50%of the total thermal energy. In order to protect the skin the after glow should be removed as quickly as possible.

CONCLUSION

RECOMMENDATION
AND FURTHER RESEARCH

8. Conclusion and Recommendations

It would be recommended that natural protein fibers be used for uniform fabrics wherever possible. Tightly woven wool fabrics are recommended for jackets, skirts and trousers. The flammability characteristics, with respect to high ignition temperature and self-extinguishing ability, are deemed desirable. Wool is durable and easily maintained. Pure silk in the woven form is recommended for use on ties and scarves for similar reasons as wool.

Silk is not economically viable to be used for shirts and blouses. Treated Polyester/Cotton blends are suggested instead. The polyester content increases the ignition temperature, as well as increasing the durability and appearance retention properties of the fabric. The cotton content reduces the extent of melting. Fabric is recommended to be woven.

Nylon hosiery is recommended to be avoided as it shrinks and melts rapidly to adjacent surfaces.

It is recommended that adequate undergarments are worn with the uniform. This it to provide a barrier between the skin and the outer fabric. With respect to Polyester/ Cotton, the heated outer fabric will melt onto the undergarment protecting the skin from burn injuries.

The Vertical test methods are recommended with respect to cabin crew uniforms. The vertical test method is able to measure the ignition time as well as the rate of propagation. The extinguishing time and the afterglow time and length is also able to be determined. In short the Vertical flame tests are able to measure various parameters simultaneously. The vertical test is able to produce results for extreme case scenarios. The fabric sample ignited at the edge enables the flame to propagate on both sides at a rapid pace. It should be noted that ‘hot air rises’, the vertical positioning of the sample allows the flame to travel faster.

Semi-Durable Flame Retardants are recommended for use on Cotton fabrics. Polyester/ Cotton Blends should have inherent Flame Retardants in the polyester content of the fabric. Wool and silk fabrics are recommended to be treated with Titanium Compounds to increase their flame resistant properties. It is suggested that retardants selected also provide afterglow resistance

8.1. Further Research

Development of adequate test methods is an area which requires further research. Flight Attendants work in air-conditioned environments. The various test discussed do not simulate such atmospheric conditions and hence results recorded lack accuracy.

This report does not cover the aspects of smoke and toxic gas release with the burning of fabrics. Further research of the gases released by various treated and untreated fabrics is suggested. Certain flame retardants produce toxic gases as do various washing detergents. If the Flight attendant is relatively protected from fire they will be hindered by the smoke instead.

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APPENDICIES