LUXURY FLAME RESISTANT FABRICS FOR EXECUTIVE JETS: Design Challenges

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INTRODUCTION

Textiles used inside commercial and, more recently, certain executive aircraft have to pass the stringent flammability requirements defined by the FAA specification FAR 25.853 Part IV Appendix F. For the executive market luxurious properties are of prime importance and this excludes many of the available flame resistant textiles such as those based on aramid fibres (eg Nomex ®, Du Pont) and their blends . This means that customers will demand the most exclusive of fabric qualities and designs and these usually comprise exotic animal hair fibres such as mohair, alpaca and cashmere as weft yarns on silk warp-containing woven fabrics. However, because of the stringent fire performance requirements, such fabrics will require flame retardant treatments, many of which may reduce the aesthetic quality [1].

Recently, a flame retardant system has been developed which enables examples of these fabrics to be both flame retarded effectively and pass the FAA specification FAR 25.853 Part IV. However, some fabrics pass marginally and may behave unpredictably during the test.
This paper describesa project funded by UK DTI (FLAREJET) that seeks to provide guidance for designing fabrics to pass the FAA specification. It uses a factorial analytical procedure to enable the optimization of the flame retardant formulation in the first instance. Fire performance is assessed using the Cone Calorimeter [2] which is considered to be a more scientifically-founded instrument compared to the OSU calorimeter defined in FAR 25.853 Part IV. Furthermore, it allows us to accommodate design variables and assess their affect on the final fire performance. An intended outcome of the research is to provide a means of assisting designers create fabric designs for exotic animal hair weft/ silk warp-containing woven fabrics, which in the presence of an optimized flame retardant system, will predictably pass the necessary aviation fire performance standards.

BURNING BEHAVIOUR OF EXOTIC ANIMAL HAIR-CONTAINING FABRICS

The use of wool and its flame retarded variants are well-established in the commercial aircraft field since the latter used alone or both forms blended with inherently fire resistant aramid and similar fibres will enable heat release peak and average values to be below the required 65/65 kWm^{-2} upper limits[3]. This is a consequence of the excellent low flammability of wool even when not flame retardant treated as shown by a relatively high LOI value of about 25 and a low flame temperature of about 680ºC. Its similarly high ignition temperature of 570-600ºC is a consequence of its higher moisture regain (8-16% depending upon relative humidity), high nitrogen (15-16%) and sulphur (3-4%) contents and low hydrogen (6-7%) content by weight [4]

The very similar, but aesthetically superior mohair fibres, while being produced from angora goats, might be expected to have similar flammability properties. The mohair fibre is typified by its high lustre, which coupled with its fineness and handle, provides fabrics having exceptional visual and physical aesthetics. The inherent flammability of all animal hair fibres is considered to be in part determined by their high nitrogen and sulphur contents as suggested above [5].

Alpaca fibres are produced from the species of llama, principally the llama, guanaco and vicuna. Fibres from the vicuna are the finest and because they have very smooth exterior surfaces, they are similar to the mohair fibre in terms of aesthetic properties. Similarly, cashmere fibres come from cashmere goats and are renowned for their extreme fineness and luxurious handle. Little, if any, data on the flammabilities of these fibres exist, however.

To date, mainly because of cost, exotic animal hair fibres like mohair, cashmere and alpaca have not found their way into aircraft fabrics although previous attempts to flame retard mohair have been as effective as for wool [5].

FIRE PERFORMANCE OF COMMERCIAL FABRICS

Previously reported experiments [6] have shown that when commercial 180 gsm (6oz/square yard) exotic animal hair weft – silk warp fabrics are mounted on representative wall-boards (eg S-SSCP from Schneller Inc) and treated with a proprietary flame retardant finish, OSU performance is marginal with some fabrics showing failures. Table 1 lists selected fabric performance from our previous study [6].

Table1: OSU heat release results according to FAA specification [6]

Sample	**Mass, g**	**Thickness, mm**	**Peak heat release rate, kW m^{-2}**	**2 minute average HRR, kWm^{-2} min^{-1}**	**Time to PHR, s**	**Pass/fail**
Mohair(61%)-silk(39% as warp):plain weave						
MS3*	-	-	86	55	23	Fail
MS5	58.5	8.7	58	41	39	**Pass**
Mohair(61%)-silk(39% as warp): fleur-de-lys motif						
MSF3*	-	-	58	52	23	**Pass**
Mohair-polyester(warp)						
MP2*	32	3	67	65	20	Fail
Alpaca(60%)-silk(40% as warp)						
AS2*	34	5	77	60	25	Fail
Schneller S-SSCP*	26	3	55	41		**Pass**
Airbus board		7.2	21	17	-	**Pass**

Note: * refers to samples mounted on S-SSCP (Schneller Inc.) board as opposed to Airbus board

These results show that for very similar fabrics, whether a pass or fail is gained following the FAR 25.853 Part IV Appendix F OSU test, is impossible to predict. It was considered at the time that whether or not a fabric/board combination passed or failed depended upon fabric design variables or error within the OSU test protocol. As a consequence and in order to be able to create ranges of fabrics that will have predictable passes when mounted up on a typical board, a research programme was initiated to understand the importance of the following variables:

- Fabric composition
- Fabric area density or weight
- Fabric design
- Flame retardant treatment
- Means of adhering fabrics to wall board materials
- Wall board materials

In practice, a given fabric requires a flame retardant (FR) treatment, the application of a back-coated resin to act as a base for an adhesive and an adhesive to fix it to a wall board. The project is divided into three parts:

1. **Part 1**: Establishment of an optimum fabric/FR/back-coating/adhesive combination for a given fabric
2. **Part 2**: Testing the optimum combination on a range of fabrics
3. **Part 3**: Quantifying the effect of design on fire performance
4. **Part 4**: Development of a design tool that predicts whether a given fabric will pass or fail FAR 25.853 Part IV Appendix F

This paper will consider the first two parts of the overall project objectives.
Based on these requirements, a factorial analysis approach was adopted with regard to the following selected variables identified in Table 2.

Table 2: Factorial analysis variables

Variable	Number	Level/type
Fabric	6	Plain weave; 180 gsm; 60% weft, 40% warp (w/w)
Flame retardant	2	2 concentrations, L1 & L2
Back-coating	1	None or 1
Adhesive	2	2 application levels, l1 & l2

The six 180 gsm fabrics selected comprised a variety of exotic animal hair fibres (mohair, alpaca and cashmere) and Sea Island cotton as weft yarns and silk or polyester warps:

- Mohair weft/ silk warp (MS)
- Mohair weft/polyester warp (MP)
- Cashmere weft/silk warp (CS)
- Alpaca weft/silk warp (AS)
- Alpaca weft/polyester warp (AP)
- Sea Island weft/silk warp (SS)

Part 1: Table 2 for one selected fabric (MS) suggests that a maximum of 32 experimental fabric combinations are to be produced and tested although only 25 were in fact selected (see Table 3). Because the FAR 25.853 Part IV Appendix F OSU protocol is time consuming and expensive, it was decided to use the more recently developed cone calorimeter to assess the heat release behaviour of the prepared fabrics according to ISO 5660 [2]. A heat flux of 35 kW m^{-2} was used to mirror that in the FAR method. Since the failures on our previously reported work [6] occurred mainly as an excessive peak heat release rate (PHRR) value, then the main emphasis would be on monitoring the effect of variables on this parameter. Table 3 summarises the results.

Table 3: Peak heat release rates at 35 kW m^{-2} for mohair/silk (MS) fabric combinations

Flame Retardant	**FR level**	**Back-coating: None or BC1**					
		None	**BC1 Adhesive (levels L1 & L2)**				
			None	**AD1**		**AD2**	
				l1	**l2**	**l1**	**l2**
MS Control		80					
FR1	L1	37	11	46	80	11	34
	L2	31	13	18	60	18	**10**
FR2	L1	58	13	12	47	24	17
	L2	41	15	14	108	27	19

A number of conclusions may be drawn from this experimental matrix:

- The most effective FR is FR1 applied at the higher level L2 giving a reduction in PHRR from 80 to 31 kW m^{-2} at 35 kW m^{-2}
- The addition of a back-coating BC1 without adhesive can further reduce PHRR values to a range 11-15 kW m^{-2} at 35 kW m^{-2}
- The addition of an adhesive significantly increases heat release
- The best combination for the MS fabric is FR1 at level L2, back-coating BC1 and adhesive AD2 at level l2 (emboldened in Table 4).

Part 2: The optimized formulation from Part 1 was then applied to all six fabrics above which were adhered to Schneller S-SSCP board and tested to both FAR 25.853 Part IV Appendix F (OSU calorimetry) and ISO 5660 (cone calorimetry). However, before actual testing could occur, there was concern regarding the exact heat flux to use with the cone calorimeter given that it has an electrical spark ignition system in contrast to the gas flame on the OSU calorimeter. Table 4 shows the results for a short comparative study for mohair/silk fabrics prepared using the optimized treatment and adhered to S-SSCP board.

For board only, in the cone calorimeter 45 kW m^{-2} flux yields similar results to 35 kW m^{-2} in the OSU instrument; however, when fabric was present, in the cone calorimeter 50 kW m^{-2} flux was the minimum level required to produce specimen ignition. Based on these results, it was considered that the OSU calorimeter at 35 kW m^{-2} heat flux produces comparable PHRR values from samples exposed to the cone calorimeter at 50 kW m^{-2} incident flux.

Table 5 shows the peak heat release rate and average heat release rate (AvHRR)results for the six fabrics prepared with the optimum treatment and mounted on S-SSCP boards exposed to both OSU and cone calorimetric procedures.

Of particular interest, is that now all six fabrics, when given the optimized treatment, pass the "65/65" FAR 25.853 Part IV Appendix F requirement whereas these same fabric composites previously performed in a less predictable manner (see Table 1).

Table 4: OSU versus cone calorimetry results for S-SSCP board and MS/S-SSCP fabric/board composites

Calorimetry technique	**Heat flux, kW m^{-2}**	**PHRR, kW m^{-2}**	
		S-SSPC Board	***MS fabric/S-SSPC composite***
OSU	**35**	**55**	**58**
Cone calorimetry	35	10	14
	40	30	22
	45	***58***	15
	50	78	***60***
	60	-	74

Table 5: PHRRand AvHRR values for fabric/board composites tested to FAR 25.853 Part IV Appendix F and cone calorimetry

Fabric	**OSU at 35 kW m^{-2}**		**PHRR (Cone at 50 kW m^{-2}), kW m^{-2}**	
	PHRR, kW m^{-2}	**AvHRR, kW m^{-2}min^{-1}**	**PHRR, kW m^{-2}**	**AvHRR, kW m^{-2}min^{-1}**
Mohair/silk (MS)	58	54	48	25
Mohair/polyester (MP)	62	63	62	32
Cashmere/silk (CS)	61	55	56	26
Alpaca/silk (AS)	58	53	46	22
Alpaca/polyester (AP)	61	63	65	28
Sea Island/silk (SS)	41	54	46	26

The cone calorimetric results are similarly consistent within themselves and relate to respective OSU results.

CONCLUSIONS

The major conclusions from this work to date are that a range of exotic animal hair, luxury fabrics for internal decoration of executive jets can give predictable passes to the stringent requirements of FAR 25.853 Part IV Appendix F if their flame retardant and associated treatments including choice and level of adhesive are carefully chosen and optimized. The use of factorial analysis as an experimental tool has been validated and this has demonstrated also that the use of cone calorimetry offers an alternative to OSU calorimetry in studying and predicting resulting fabric fire performance.

Current and future work will focus on the incorporation of fabric weight and fabric design variables into the experimental matrix and hence the fulfilling of Parts 3 and 4 of this project.

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