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Honeywell

EFFECT OF UV-C ON AIRCRAFT INTERIOR MATERIALS

Version 2, September 25, 2020

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Effect of UV-C on Aircraft Interior Materials (Honeywell, September 2020)

Executive Summary

The purpose of this paper is to provide data on the effects of ultraviolet (UV-C) light, generated by the Honeywell UV Cabin System, on materials inside an aircraft cabin. The Honeywell system uses 253.7 nanometers (nm) UV-C light. To support introduction of this new system, Honeywell has exposed aircraft materials including seat coverings, carpet, seat belts and plastics in the laboratory. Materials exposed to the UV light were tested for three categories of impact:

(1) Flame retardancy
(2) Strength
(3) Appearance

As more specifically detailed below, test results on identified materials indicate no significant impact for flame retardancy or strength. Changes in appearance depended on the accumulated level of UV dose over time. In most cases, the materials showed no appearance changes over a significant number of treatments. In some cases, color changes such as yellowing or darkening have been observed. These appearance changes occurred after cumulative doses corresponding to multiple years of daily cleaning.

Introduction

Surfaces, fabrics, carpets and other materials used in aircraft cabin interiors are exposed to a measurable amount of UV-C light during each cleaning using the Honeywell UV Cabin System. Honeywell has tested the effect of UV-C light on key characteristics including flame retardancy, strength and appearance. The testing approach compares material samples from the same roll or lot that have been exposed to increasing doses of UV-C light to control samples with no UV exposure.

Effect of UV-C light on materials

Testing indicated that in order for UV-C light to affect the properties of a material, two things must happen[1]: (1) absorption of the light, and (2) chemical reaction. Many materials that are transparent to visible light are opaque to UV light, limiting penetration of the light deep into the material. Other materials, like the leather or other fabric materials commonly used for aircraft seating, are opaque because they scatter the light or because of materials blended into the polymers from which they are made. For these materials, the effect of UV-C light will be only on the exposed surface. Once light absorption has occurred, surfaces exposed to air can oxidize, with possible impact on their strength or other properties. In the absence of oxygen from the air, other chemical reactions can occur which may result in color changes to the material.

[1] R.E. Kauffman "Study the Degradation of Typical HVAC Materials, Filters and Components Irradiated by UVC Energy" ASHRAE Research Project Report RP-1509, April 2011.

Honeywell UV Cabin System and Applied Dose

Figure 1: Honeywell UV Cabin System

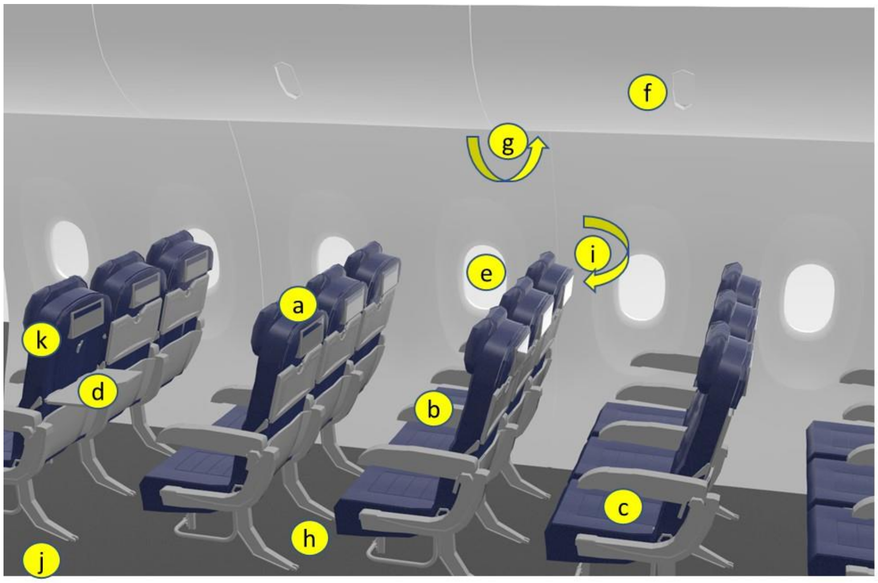
The Honeywell UV Cabin System (Figure 1) is equipped with UV-C lamps and is wheeled through an aircraft cabin by an operator at a speed controlled by the operator with input from a speedometer to control level of dose. UV lights are mounted on two wings that extend over the seats of the aircraft and expose both the seats beneath the wings and the overhead compartment above them. Additional smaller UV lights are mounted on the wingtips for better exposure of the aircraft walls, on the body of the cart to expose the sides of the aisle, and near the crown of the cart to expose the overhead compartment doors. Since the incident angle for the UV light on a surface changes as the cart is moved, locations that are in shadow are reduced. The lights turn on only when an operator has his/her hands on the controls, and the operator is shielded from the UV light by clear shields tested for UV safety. The relationship between the UV dose provided by this system and UV doses required to inactivate tested pathogens are described in a related white paper.[2]

The Honeywell UV Cabin system employs 253.7nm UV-C light and exposes materials in the cabin of an aircraft to UV-C light during use at doses which depend on the location and proximity to the material being treated and the time of treatment. All UV-C effects on materials are dose-dependent. Dose can be generally measured by the light intensity and time, so the same effect can be observed with low intensity over a long period of time or high intensity for a short time. Since the intensity of the light on a surface will depend on the distance between the surface and the light source, and the angle between the plane of the surface and the incident light, it will be different for different positions in the aircraft. The cumulative dose experienced by materials in the cabin can be estimated by multiplying the single treatment dose by the number of treatments per day, and the number of treatment days.

Dose measurements have been taken using the Honeywell UV Cabin System at positions corresponding to many locations in a typical narrow body aircraft. The measurements were made by placing an ILT800-CUV radiometer in each location and moving the UV system through the test area at the indicated speed. Figure 2 shows the measurement locations, and Table 1 shows the measured single treatment doses. Note that, except as indicated, the dose corresponds to two passes (forward and back) down the aircraft cabin aisle. The table also shows the number of treatments required to reach the doses used in color evaluation studies, and the number of years of use required to reach this number of treatments. Dose measurements for 10 rows/minute are provided to show dose examples for speed which can be used to treat areas of higher risk.

[2] "Aircraft Bacteria & Virus Reduction Using UVC Lighting", white paper issued May 2020, Honeywell International.

Effect of UV-C on Aircraft Interior Materials (Honeywell, September 2020)



Location	Description
a	Top of Aisle headrest
b	Top of Armrest
c	Seat Cushion Aisle
d	Top of Tray table (1 pass)
e	Aircraft Window
f	Overhead luggage handle
g	Passenger service unit
h	Floor in front of aisle seat
i	IFE screen
j	Cabin Aisle Floor
k	Side of Aisle headrest

Figure 2: Dose Measurement Locations in Aircraft

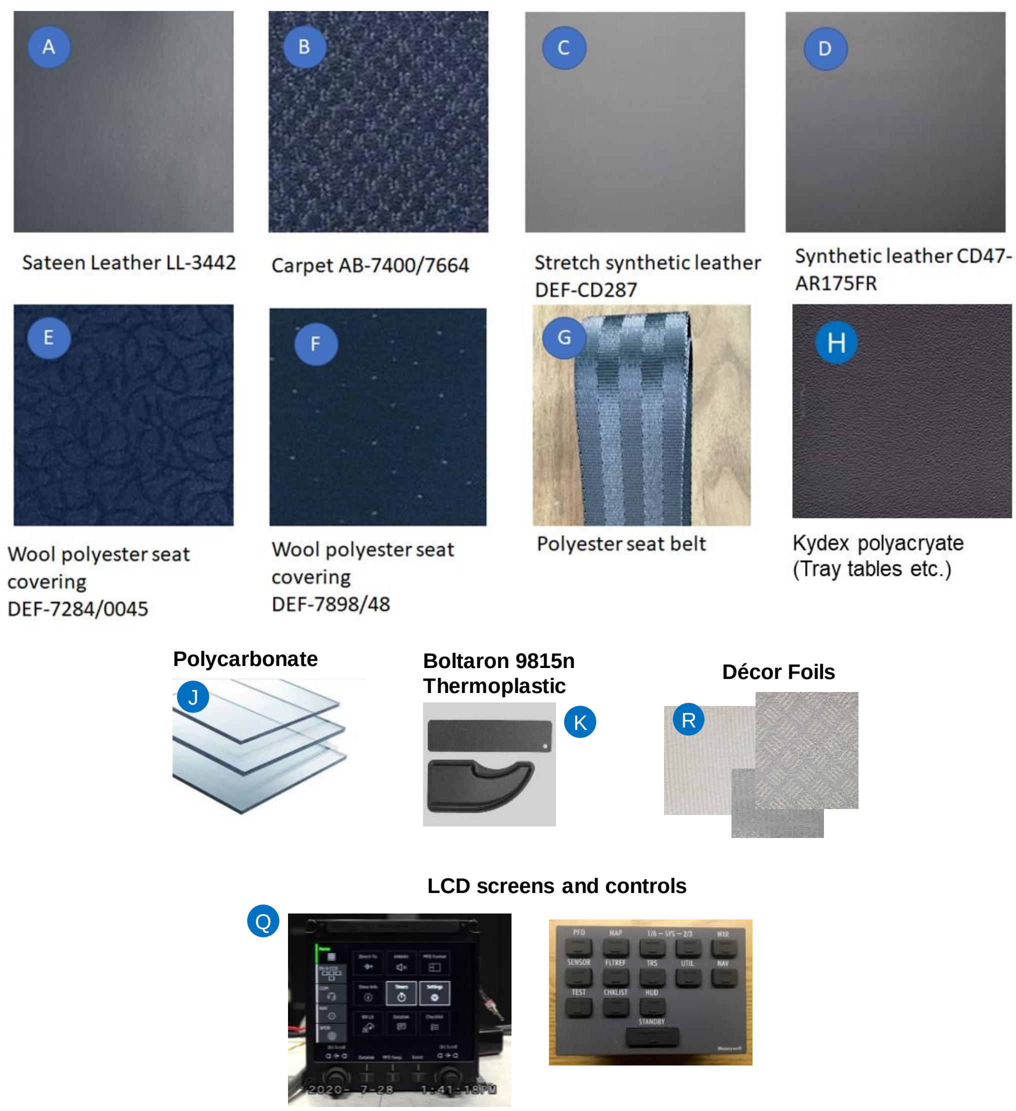
Table 1: Measured treatment doses in aircraft, and number of treatments corresponding to cumulative doses used in progressive color studies

	Description	Treatment dose (mJ/cm2)		Number of treatments to reach cumulative dose (30 rows/min treatment)			Years of use at 1 treatment/day (30 rows/min treatment)		
		10 rows/ min	30 rows/ min	17 J/cm^2	34 J/cm^2	51 J/cm^2	17 J/cm^2	34 J/cm^2	51 J/cm^2
a	Top of Aisle headrest	39.0	13.0	1,311	2,622	3,933	3.6	7.2	10.8
b	Top of Armrest	28.2	9.4	1,806	3,613	5,419	4.9	9.9	14.8
c	Seat Cushion Aisle	21.3	7.1	2,387	4,774	7,161	6.5	13.1	19.6
d	Top of Tray table (1 pass)	15.9	5.3	3,235	6,469	9,704	8.9	17.7	26.6
e	Aircraft Window	10.2	3.4	5,055	10,109	15,164	13.8	27.7	41.5
f	Overhead luggage handle	10.5	3.5	4,902	9,805	14,707	13.4	26.9	40.3
g	Passenger service unit	9.6	3.2	5,238	10,476	15,714	14.4	28.7	43.1
h	Floor in front of aisle seat	18.3	6.1	2,777	5,554	8,330	7.6	15.2	22.8
i	IFE screen	21.0	7.0	2,429	4,857	7,286	6.7	13.3	20.0
j	Cabin Aisle Floor	15.3	5.1	3,305	6,609	9,914	9.1	18.1	27.2
k	Side of Aisle headrest	27.3	9.1	1,861	3,723	5,584	5.1	10.2	15.3

Materials Testing Methods

Materials testing was completed in June - September 2020 at the Honeywell Aerospace Advanced Technology lab in Des Plaines, IL. Samples of materials used in the referenced testing are shown in Figure 3 and include fabrics for seats and carpets, seat belts and plastics typically used in tray tables, etc. Testing for each material was completed with a single batch or roll of material. Samples were exposed to UV-C light in a Rayonet reactor (Figure 4) equipped with 16 mercury vapor UV-C lamps arranged around the circumference of a cylinder of UV-reflective material. For soft materials like fabrics, samples were cut into the sizes appropriate for the analysis and wrapped around a length of PVC pipe. This pipe was centered in the center of our reactor and rotated slowly during the UV exposure (Figure 5). Rigid materials were suspended on a wire in the center of the reactor. A fan in the base of the reactor kept the temperature during exposure within 10°C of room temperature.

Figure 3: Samples used in materials study



The UV-C dose applied to the samples was determined by the following process:

1. Using a UV-C radiometer, the UV intensity was measured at intervals around the reactor, with the radiometer positioned at the same distance from the surrounding ring of lamps as the samples. These measurements were averaged to provide a single intensity.
2. A programmable timer was used to supply the AC power to the reactor. Various times were used to provide the doses shown in the tables below. Intensity multiplied by (x) time provided the dose.

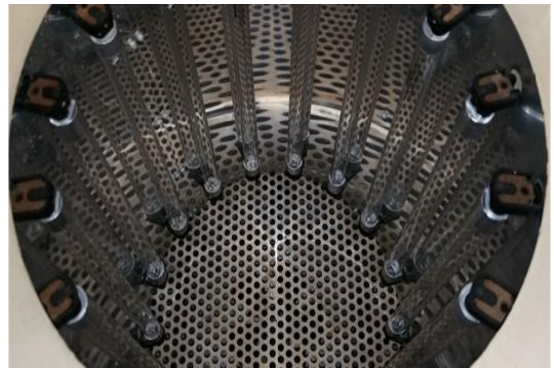


Figure 4: Reactor used for UV-C materials stability exposures

Samples for flame retardancy testing were cut into 3" by 12" strips prior to UV-C exposure, and five samples at each level of UV-C dose (including the control with no UV-C exposure) were obtained. The samples were analyzed for flame retardancy according to FAA protocols by AeroBlaze Inc. Fabrics were tested using a 12 second vertical burn measurement[3], and seat belts and carpet were tested using a 15 second horizontal burn measurement[4]. For fabrics and carpet, the impact of UV-C on strength was measured by two techniques, tensile strength (ASTM method D5035) and tear strength (ASTM method D5587/2261). These measurements were made at the Honeywell Fibers Technology Center in Colonial Heights, Virginia (U.S.). Seat belt strength was measured by Element Los Angeles, according to SAE standard[5]. In all cases, the approach was to compare the performance of control samples that were not exposed to UV-C to samples at various UV-C doses, including those much higher than would be expected in normal use. The highest dose used in the flame retardancy studies (269 J/cm^2) would correspond to 20,692 treatments (30 rows/minute treatment rate) and at 1 treatment per day, would correspond to 56.7 years of use (for the top pf the aisle headrest, the surface receiving the maximum exposure. All other surfaces would see a lower exposure or, equivalently, more than 20,692 treatments or 56.7 years of use would be needed to reach this high dose).

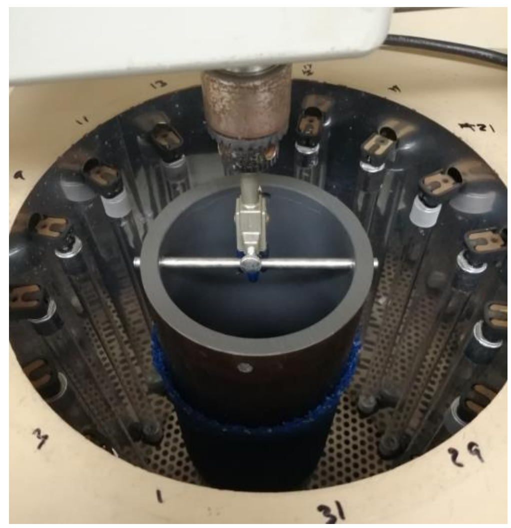


Figure 5: Reactor with material stand and motor

To facilitate evaluation of the effect of UV-C exposure on the appearance of materials, a sample was masked in sections with masking tape, leaving one section unmasked. This sample was exposed to UV-C and then one additional section was unmasked. This procedure was repeated to obtain a sample with

[3] 12 seconds vertical burn per 14 CFR 23, Appendix F, Part I(d), 14 CFR 25, Appendix F, Part I(b)(4), FAA Fire Test Handbook, Chapter 1, BSS 7230-F1/F2, RTCA DO-160G, Section 26.

[4] 15 seconds horizontal burn per 14 CFR 23, Appendix F, Part I(e), 14 CFR 25, Appendix F, Part I(b)(5), FAA Fire Test Handbook, Chapter 3, AC 23-2A, BSS 7230-F3/F4, RTCA DO-160G, Section 26

[5] SAE International standard AS8043 "Torso Restraint Systems" Issued 1986-03-01.

sections reflecting different exposure doses. The doses used in this study correspond to those in Table 1.

The following panel summarizes the materials, or material categories, that were tested and the results for flame retardancy, strength, and appearance. Detailed results for each of the materials are presented in the following sections.

Material	Flame Retardancy	Strength	Appearance
Sateen leather	● No significant change	● No significant change	● Slight change
Nylon carpet	● No significant change	● No significant change	● Slight change
Columbia synthetic leather	● No significant change	● No significant change	● Slight change
Luxair synthetic leather	● No significant change	● No significant change	● Slight change
Wool-polyester blend (EU)	● No significant change	● No significant change	● Slight change
Polyester-wool blend (US)	● No significant change	● No significant change	● No significant change
Polyester seat belts	● No significant change	● No significant change	● No significant change
Kydex (tray tables etc.)	---	---	● Slight / Significant change
Boltaron	● No significant change	---	● Slight / Significant change
IFE screens	---	---	● No significant change
Polycarbonate window covers	● No significant change	● No significant change	● Slight change
Décor foils	---	---	● Slight / Significant change

● No significant change ● Significant change ○ In progress

● Slight change ● Fails to meet requirements --- Not Required

Results of Materials Compatibility Studies

Sateen Leather (Douglass Interior Products, Moon Grey, LL-3442)

Summary: As indicated in Table 2 and 3 below, UV-C exposure testing resulted in no significant effect on tensile strength, tear strength or flame retardancy of the sateen leather. At higher doses, a slight change in color was observed. According to the dose table, and using the most heavily exposed part of the seat (top of aisle headrest), the highest dose corresponds to 10.8 years of use (30 rows/min, 365 treatments/year).

Table 2: Strength for Sateen Leather (No significant effect)

Exposure (J/cm^2)	Tensile Strength (lbf)	Trapezoid Tear Strength (lbf)
0	61.5	17.6
76	54.4	18.9
191	54.1	17.9

Table 3: Flame Retardancy for Sateen Leather (Passes Test)

Exposure (J/cm^2)	Flame Time (sec)	Drip Time (sec)	Burn Length (in)
0	0	0	1.3
27	0	0	1.0
54	0	0	0.5
134	0	0	0.9
269	0	0	0.6
Success Criteria:	**Must not exceed 15 sec.**	**Must not exceed 5 sec.**	**Must not exceed 8 in.**

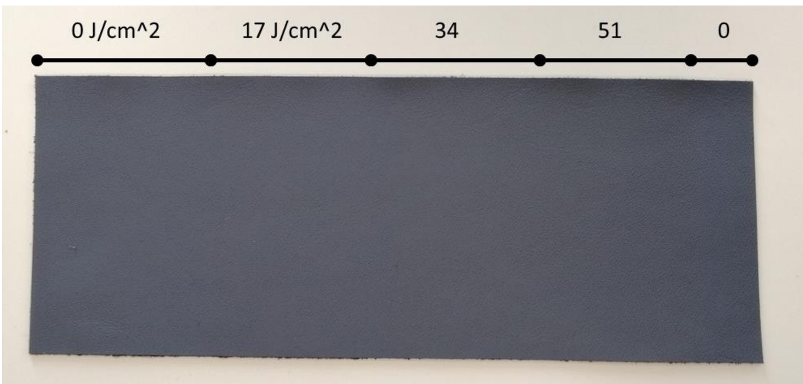


Figure 6: Progressive UV-C Exposure for Sateen Leather

Nylon Carpet (Douglass Interior Products, Humility First, AB-7400/7664)

Summary: As indicated in Tables 4 and 5 UV-C exposure testing resulted in no significant change in tensile strength, tear strength or flame retardancy of the nylon carpet. Fading in carpet color is first visible at 34 J/cm^2 dose. Using the dose information above, this would correspond to 15-18 years of use (30 rows/min, 365 treatments/year).

Table 4: Strength of Nylon Carpet (No Significant Effect)

Exposure (J/cm^2)	Tensile Strength Warp (lbf)	Tensile Strength Weft (lbf)	Trapezoid Tear Strength Warp (lbf)	Trapezoid Tear Strength Weft (lbf)
0	168.3	102.8	72.8	66.0
76	169.4	102.1	76.3	70.8
191	163.8	99.5	76.3	65.5

Table 5: Flame Retardancy of Nylon Carpet (Passes Test)

Exposure (J/cm^2)	Burn Rate (in/min)
0	0.58
27	0.57
54	0.54
134	0.56
269	0.50

Success Criteria: Average shall not exceed 2.5 in/min

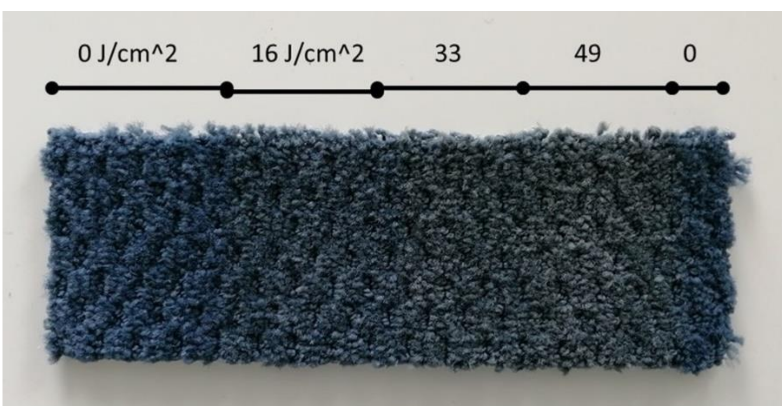


Figure 7: Progressive UV-C Exposure for Nylon Carpet

Columbia Synthetic Leather (Douglass Interior Products, Glacier, DEF-CD287)

Summary: As is indicated in Tables 6 and 7, UV-C exposure testing resulted in no significant effect on tensile strength, tear strength or flame retardancy of the synthetic leather. Yellowing of the material was first observed after doses of 17-34 J/cm^2, corresponding to 4-7 years of daily use at the most exposed location (aisle headrest, 30 rows/min, 365 treatments/year).

Table 6: Strength of Columbia Synthetic Leather (No significant effect)

Exposure J/cm^2	Tensile Strength Warp (lbf)	Tensile Strength Weft (lbf)	Trapezoid Tear Strength Warp (lbf)	Trapezoid Tear Strength Weft (lbf)
0	62.0	64.2	8.7	14.9
76	61.8	65.8	9.1	14.7
191	60.7	61.9	9.2	14.9

Table 7: Flame Retardancy of Columbia Synthetic Leather (Passes Test)

Exposure (J/cm^2)	Flame Time (sec)	Drip Time (sec)	Burn Length (in)
0	0	0	2.2
27	0	0	2.5
54	0	0	2.5
134	1.2	0	2.5
269	0.8	0	2.3
Success Criteria:	**Must not exceed 15 sec.**	**Must not exceed 5 sec.**	**Must not exceed 8 in.**

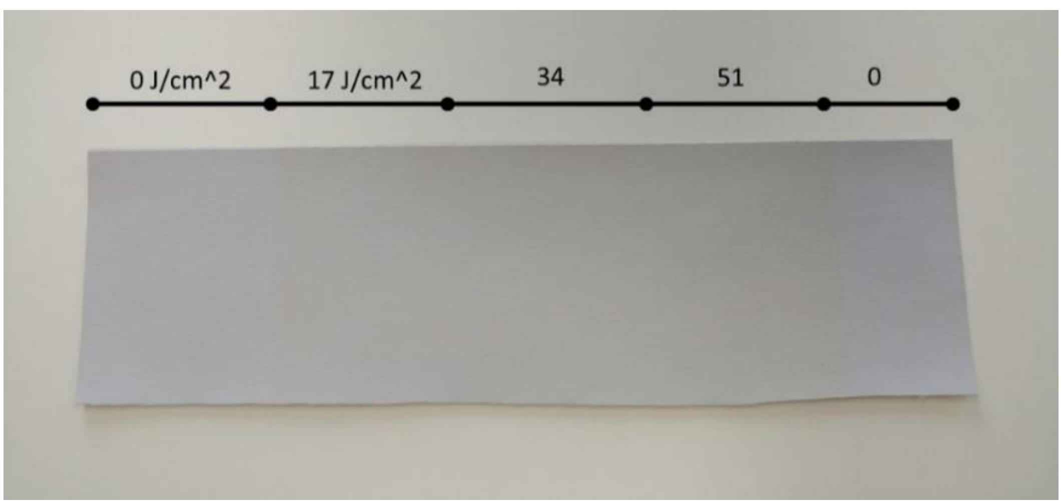


Figure 8: Progressive UV-C Exposure for Columbia Synthetic Leather

Luxaire Synthetic Leather (Douglass Interior Products, Nickel, CD47-A175FR)

Summary: As indicated in Tables 8 and 9, UV-C exposure testing resulted in no significant impact on tensile strength, tear strength or fire retardancy of this synthetic leather. It darkened slightly at the highest UVC dose (51 J/cm^2, corresponding to 10.8 years using 30 rows/min treatment rate and 365 treatments/year).

Table 8: Strength of Luxaire Synthetic Leather (No significant effect)

Exposure J/cm^2	Tensile Strength Warp (lbf)	Tensile Strength Weft (lbf)	Trapezoid Tear Strength Warp (lbf)	Trapezoid Tear Strength Weft (lbf)
0	69.5	37.7	8.6	6.1
76	67.2	38.9	8.7	6.0
191	69.4	38.1	8.8	5.8

Table 9: Flame Retardancy of Luxaire Synthetic Leather (Passes Test)

Exposure (J/cm^2)	Flame Time (sec)	Drip Time (sec)	Burn Length (in)
0	0	0	2.2
27	0	0	2.2
54	0	0	2.1
134	0	0	1.7
269	0	0	1.6
Success Criteria:	**Must not exceed 15 sec.**	**Must not exceed 5 sec.**	**Must not exceed 8 in.**

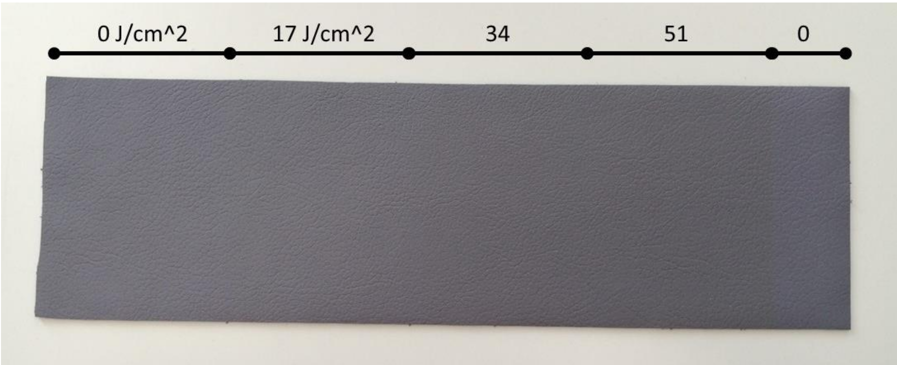


Figure 9: Progressive UV-C Exposure for Luxaire Synthetic Leather

Heavy duty wool-polyester blend (Douglass Interior Products, DEF-7284/0045)

Summary: As indicated in Table 10 and 11, UV-C exposure testing resulted in no significant effect on tensile strength, tear strength, or fire retardancy of this wool-polyester blend. It also showed no visible effect of UV-C on color or appearance.

Table 10: Strength of Wool Polyester Blend (No significant effect)

Exposure J/cm^2	Tensile Strength Warp (lbf)	Tensile Strength Weft (lbf)	Trapezoid Tear Strength Warp (lbf)	Trapezoid Tear Strength Weft (lbf)
0	89.2	88.2	53.6	68.3
76	84.0	82.9	53.4	65.1
191	92.0	84.4	52.1	68.3

Table 11: Flame Retardancy of Wool Polyester Blend (Passes Test)

Exposure (J/cm^2)	Flame Time (sec)	Drip Time (sec)	Burn Length (in)
0	0	0	1.8
27	0	0	1.8
54	0.7	0	1.7
134	0	0	1.5
269	0	0	1.5
Success Criteria:	**Must not exceed 15 sec.**	**Must not exceed 5 sec.**	**Must not exceed 8 in.**

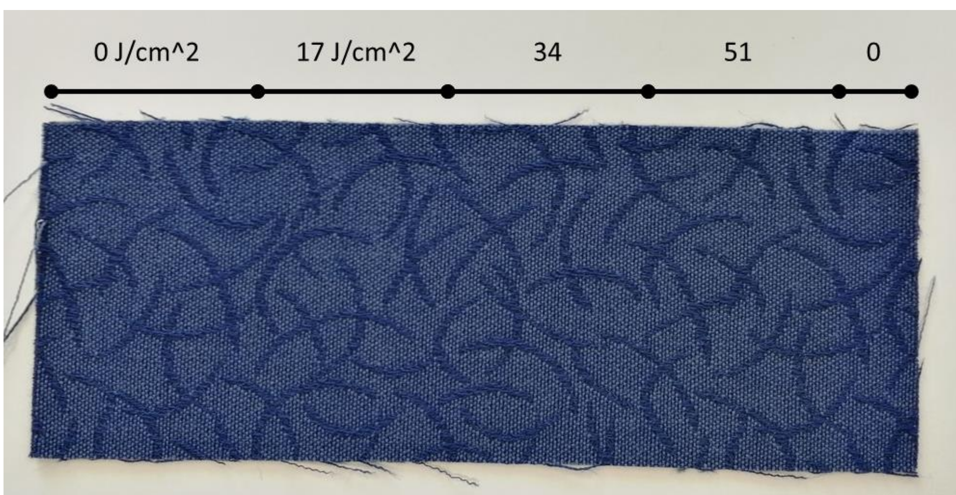


Figure 10: Progressive UV-C Exposure for Wool-Polyester

Heavy duty wool-polyester blend (Douglass interior Products, DEF-7898/48)

Summary: As indicated in Tables 12 and 13, UV-C exposure testing resulted in no significant effect on tensile strength, tear strength, or fire retardancy of this wool-polyester blend. It also showed no visible effect of UV-C on color or appearance.

Table 12: Strength of Wool Polyester Blend (No significant effect)

Exposure J/cm^2	Tensile Strength Warp (lbf)	Tensile Strength Weft (lbf)	Trapezoid Tear Strength Warp (lbf)	Trapezoid Tear Strength Weft (lbf)
0	214.7	162.4	70.7	47.5
76	212.4	161.7	71.8	48.8
191	219.8	153.3	69.6	48.0

Table 13: Flame Retardancy of Wool Polyester Blend (Passes Test)

Exposure (J/cm^2)	Flame Time (sec)	Drip Time (sec)	Burn Length (in)
0	0	0	2.6
27	0	0	2.4
54	0.0	0	2.5
134	0	0	2.8
269	0	0	3.4
Success Criteria:	**Must not exceed 15 sec.**	**Must not exceed 5 sec.**	**Must not exceed 8 in.**

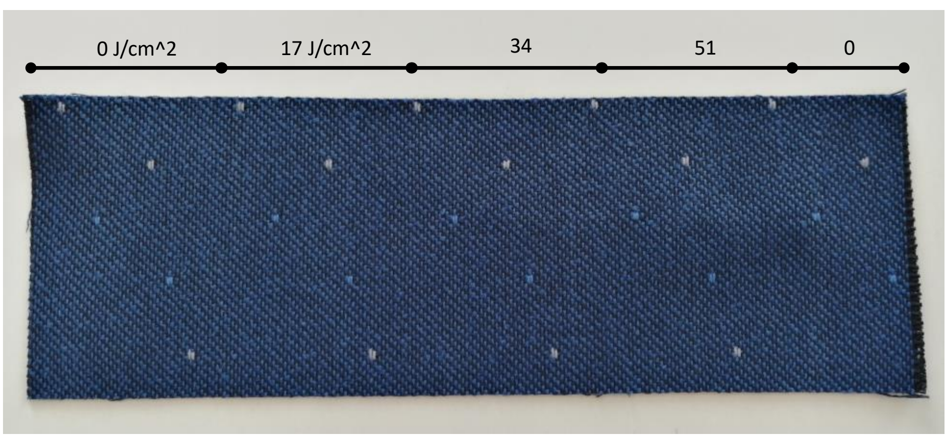


Figure 11: Progressive UV-C Exposure for Wool-Polyester

Effect of UV-C on Aircraft Interior Materials (Honeywell, September 2020)

Polyester seat belt webbing (Aircraft Belts Inc., standard)

Summary: Seat belt samples were exposed to UVC to the indicated dose twice (once on each side). As indicated in Tables 14 and 15, UV-C exposure testing resulted in no significant impact on flame retardancy or strength, and the material was unchanged in color or appearance.

Table 14: Breaking Strength and Elongation for Seat Belt (Method AS8043, Passes Test)

Exposure (J/cm^2)	Breaking strength (lbf)	% Elongation
0	5945	16.6%
54	6615	13.3%
153	6939	16.6%
307	7125	13.3%
Success Criteria:	**Minimum 5000 lbf.**	**Must not exceed 20% at 2500 lbf.**

Table 15: Flame Retardancy of Polyester Seat Belt Webbing (Passes Test)

Exposure (J/cm^2)	Burn Rate (in/min)
0	0.94
27	0.88
54	1.01
134	0.77
269	0.85

Success Criteria: Average shall not exceed 2.5 in/min

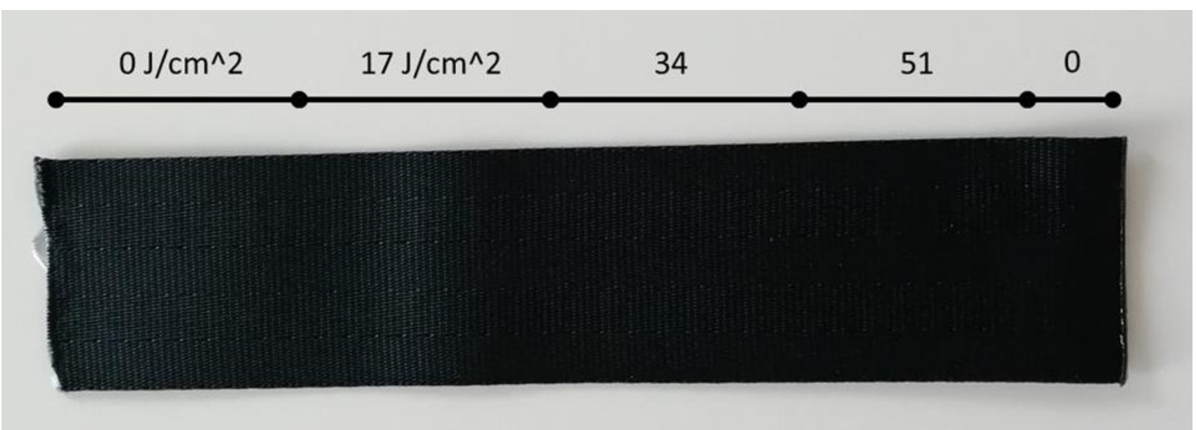


Figure 12: Progressive UV-C Exposure for Polyester Seat Belt Webbing

Effect of UV-C on Aircraft Interior Materials (Honeywell, September 2020)

Kydex polyacrylate (Sekisui, 7200ST)

Summary: This polyacrylate material is frequently used as the surface for plastic cabin materials including tray tables and other surfaces. The exposure testing showed no detectable change in color on UV exposure.

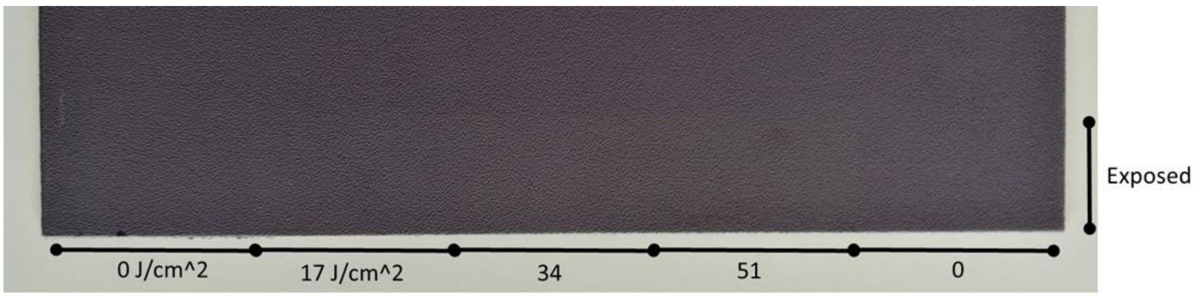


Figure 13: Progressive UV-C Exposure for Kydex

Boltaron 9815N

Summary: According to the manufacturer, Boltaron 9815N is used for tray tables, aircraft seat shells and other applications. As Table 16 shows, UV-C had no effect on flame retardancy. Some color change was observed with this material after UV exposure. If this material were used for a tray table, with a single treatment dose of 5.3 mJ/cm^2, then the 34 J/cm^2 cumulative dose shown in Figure 14 would correspond to 6469 treatments.

Table 16: Flame Retardancy of Boltaron 9815N (Passes Test)

Exposure (J/cm^2)	Flame Time (sec)	Drip Time (sec)	Burn Length (in)
0	0.0	0	0.4
76	0.0	0	0.4
382	0.0	0	0.4
Success Criteria:	**Must not exceed 15 sec.**	**Must not exceed 5 sec.**	**Must not exceed 8 in.**

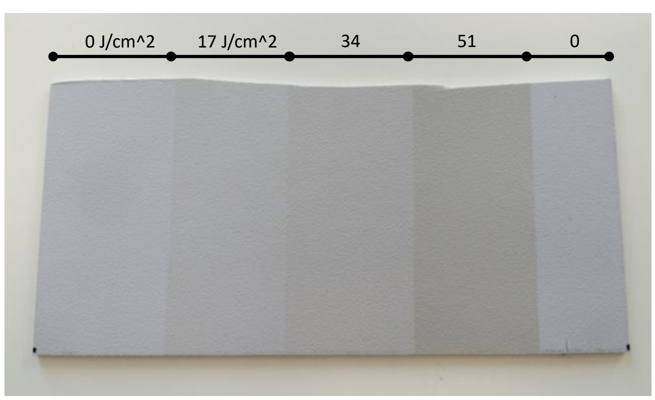


Figure 14: Progressive UV-C Exposure for Boltaron 9815N

Tray Tables

Two samples of tray tables were supplied by an airline for evaluation. The tray tables were cut into smaller pieces suitable for UV-C exposure in the Honeywell test chamber and were exposed using the progressive masking technique. Honeywell's recommended approach is to make one pass with the tray tables down and a second with them up to expose the seat cushions and the back of the tables instead. Using this approach, a single treatment would give a dose of 5.3 mJ/cm^2. With this assumed cumulative dose increment of 17 J/cm^2 would correspond to 3207 treatments (8.8 years at 1 treatment/day). We observed different UV sensitivity for the small blue tray table compared with the larger gray one. As Figure 15 below shows, yellowing was observed for the blue tray tables beginning at 34 J/cm^2 and becoming more extreme at 51 J/cm^2. 34 J/cm^2 is equivalent to 17.7 years of treatments at one treatment/day and 51 J/cm^2 is equivalent to 26.6 years of treatments at one treatment/day. If this tray table were exposed at these doses an average of four times/day, the color change occurring at 51 J/cm^2 would occur after 6.5 years and the color change at 34 J/cm^2 would occur at 4.5 years. In contrast, the larger tray tables did not show discoloration with UV-C light.

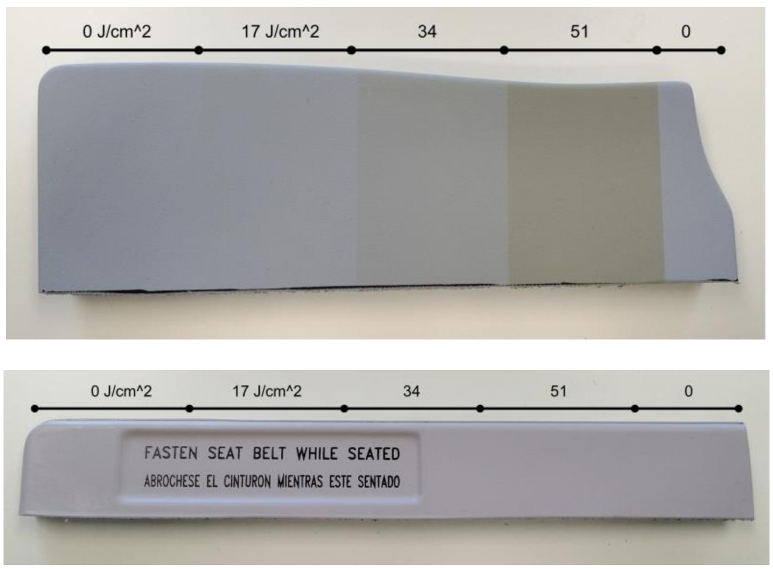


Figure 15: Tray tables after progressive UV-C exposure. Top: Small blue tray table, Bottom: Larger gray tray table.

Window shade

A window shade was cut into sections, and one such section was used for a progressive color evaluation, using the same approach and the same intervals as for the tray tables. Since window shades receive less UV-C light from the Honeywell UV-C system (3.4 mJ/cm^2 for a two exposure treatment) the 17 J/cm^2 increment corresponds to an increment of 5,000 treatments (13.7 years at 1 treatment/year). Figure 16 below shows the results from this study. We observed initial yellowing at 34 J/cm^2, and a bit more intense yellowing at 51 J/cm^2. 34 J/cm^2 is equivalent to 27.7 years of treatments at one treatment/day and 51 J/cm^2 is equivalent to 41.5 years of treatments at one treatment/day. If this window shade were exposed at these doses an average of four times/day, the color change occurring at 34 J/cm^2 would occur after 6.9 years and the color change at 51 J/cm^2 would occur at 10.4 years.

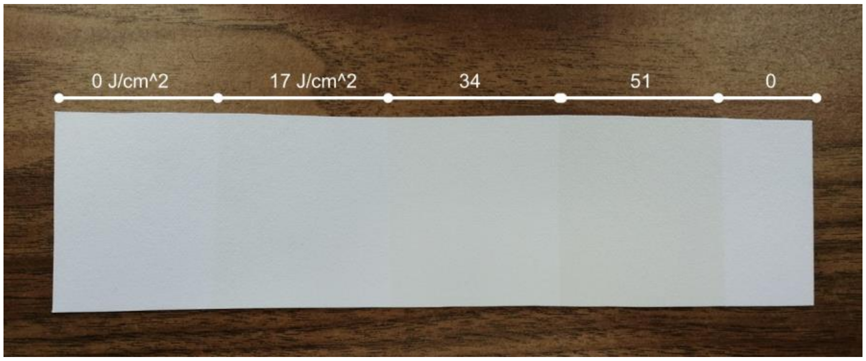


Figure 16: Window shade after progressive UV-C exposure

Effect of UV-C on Aircraft Interior Materials (Honeywell, September 2020)

Prolens aircraft grade polycarbonate

Summary: Transparent polycarbonate is used for the window dust covers for aircraft windows. Samples were irradiated on a single side. As Table 17 shows, UVC had no effect on flame retardancy, and as Table 18 shows, there was no effect on tensile strength. Figure 17 shows progressive UV-C exposure for a sheet of polycarbonate, which has been taped to a white illuminated panel for greater clarity. A trace of yellowing can be seen at the highest dose (51 J/cm^2). Referring to Table 1, this dose would correspond to 15,164 treatments (30 rows/min rate), and 41.5 years of use at one treatment per day.

Table 17: Flame Retardancy of Prolens polycarbonate (Passes Test)

Exposure (J/cm^2)	Flame Time (sec)	Drip Time (sec)	Burn Length (in)
0	2.2	0	0.6
76	0.5	0	0.6
382	1.96	0	0.5
Success Criteria:	**Must not exceed 15 sec.**	**Must not exceed 5 sec.**	**Must not exceed 8 in.**

Table 18: Tensile Strength for Prolens polycarbonate

Exposure (J/cm^2)	Peak Load (lbf)	Peak Stress (psi)	Modulus (Mpsi)	Elongation (%)
0	362.8	9482	0.3688	17.49
76	365.2	9476	0.3524	15.47
382	365.4	9476	0.3614	19.6

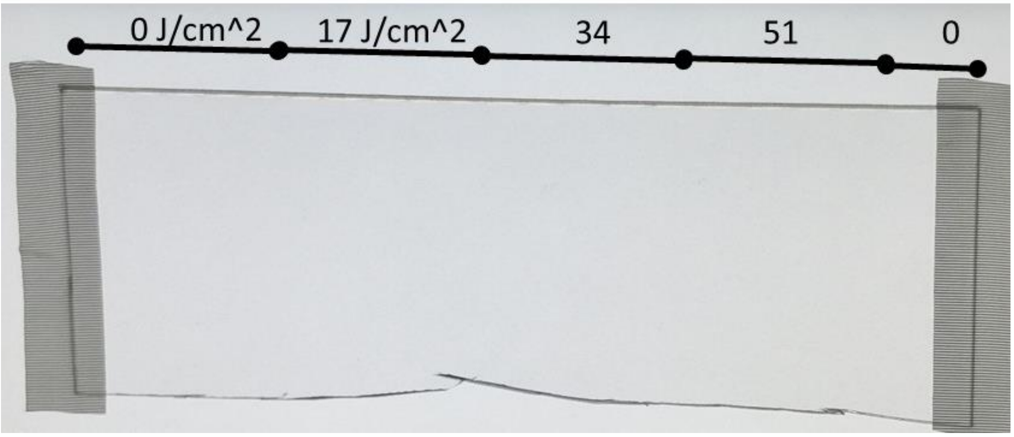


Figure 17: Prolens polycarbonate after progressive UV-C exposure

Schneller aircraft interior decorative laminate

Summary: Three samples of aircraft interior decorative laminate were received. Each was exposed to UV-C using the progressive exposure approach. All three showed yellowing at higher UV-C doses. Samples P/N S016329 and P/N S05051-011-H5 were marked as containing a heat-activated adhesive. Further experimentation will be required to understand whether the observed color changes resulted, in part or completely, from this adhesive. Referring to Table 1, a dose of 17 J/cm2 would correspond to 5055 treatments at the 30 rows/minute treatment rate.

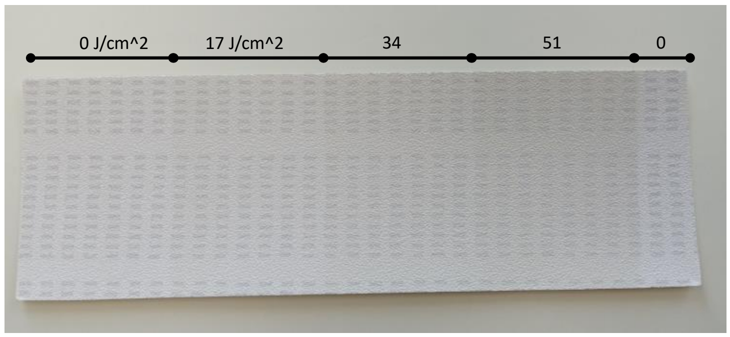


Figure 18: Schneller decorative foil laminate (P/N S3863)

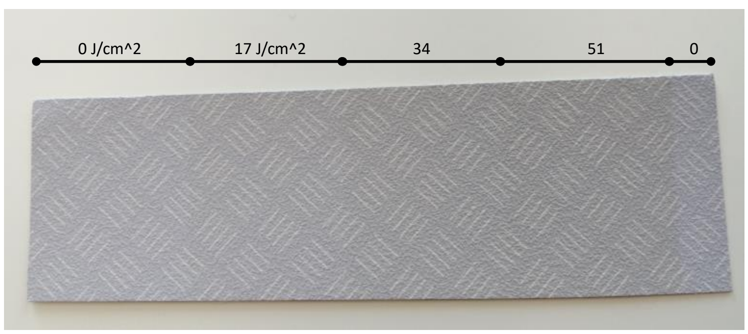


**Figure 19: Schneller decorative foil laminate (P/N S016329)
(Includes heat activated adhesive)**

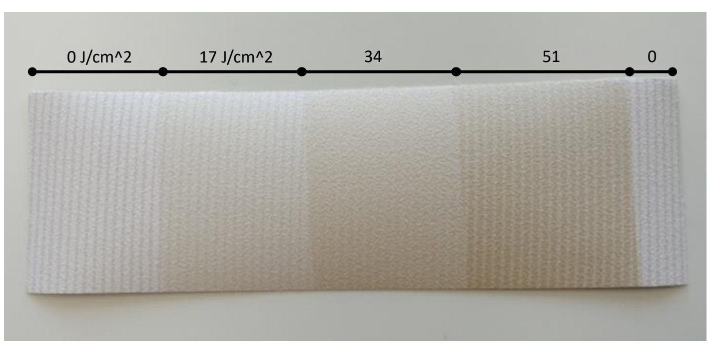


**Figure 20: Schneller decorative foil laminate (P/N S05051-011-H5)
(Includes heat activated adhesive)**

Additional Decorative Foil Laminates

Summary: Referring to the photographs, we could discern no change in color in response to UV-C light for samples A and D. Samples B and C did experience progressive yellowing, first detectable at 13 J/cm^2 for Sample B and at 27 J/cm^2 for Sample C. Based on our radiometry and using a typical treatment rate of 30 rows/minute for the Honeywell unit, these cumulative doses would correspond to 3993 or 7986 treatments, or, assuming one treatment per day, 10.9 or 21.9 years of use. Honeywell is not aware of the provenance of these samples, and particularly whether they contain heat-activated or pressure sensitive adhesives. If these are present, they would contribute to color generation in a way that would not be faithful to how the same laminates would react after use in an aircraft.

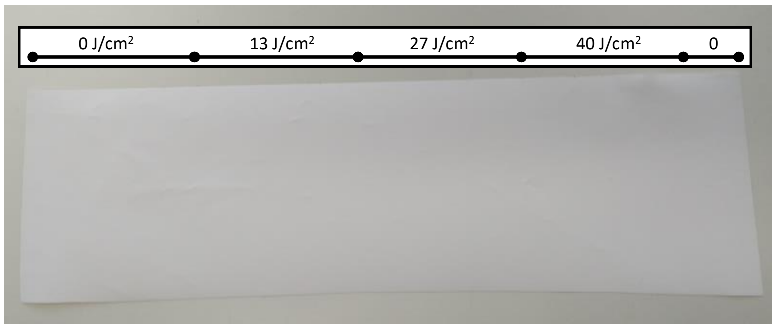


Figure 21: Sample A

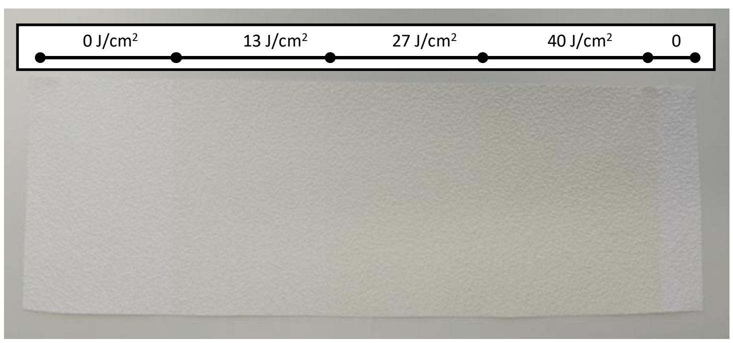


Figure 22: Sample B

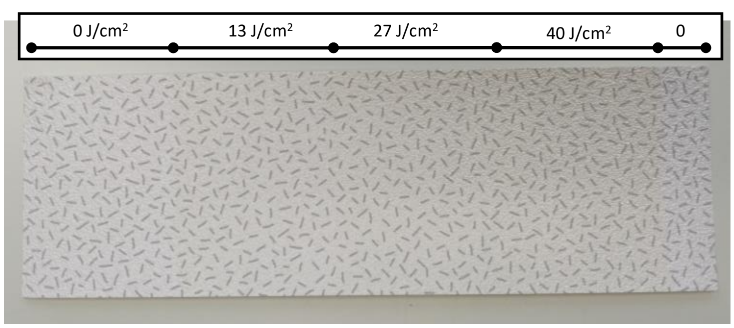


Figure 23: Sample C

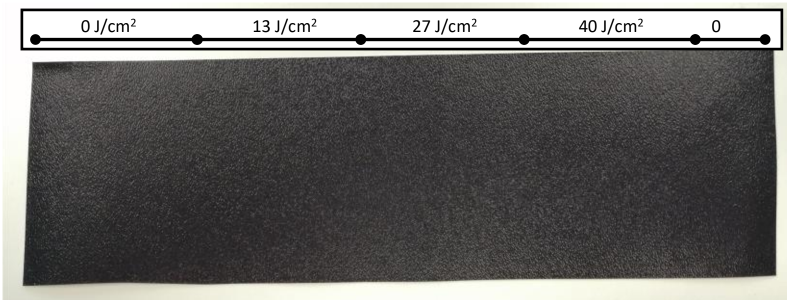


Figure 24: Sample D

Honeywell TSC 2.0 Cockpit Touch Screen Display

The TSC 2.0 is a Honeywell cockpit touchscreen display common product currently fielded for the Pilatus PC-12 and PC-24 aircrafts. UV-C exposure testing was completed on the TSC 2.0 to validate lifetime exposure limits of the unit. Exposure on the unit varied from 0 J/cm^2 to 20 J/cm^2. Measurements and pictures were taken pre and post exposure. A visual inspection shows no detectable changes to the display, bezel, or buttons. Quantitative luminance and chromaticity measurements of the display were taken at screen center in the 10 J/cm^2 exposure area of the LCD, these measurements can be seen in the table below. These measurements show negligible change pre to post UV-C exposure. The small amount of change in luminance and chromaticity can be accounted for by test setup and measurement equipment normal variations.

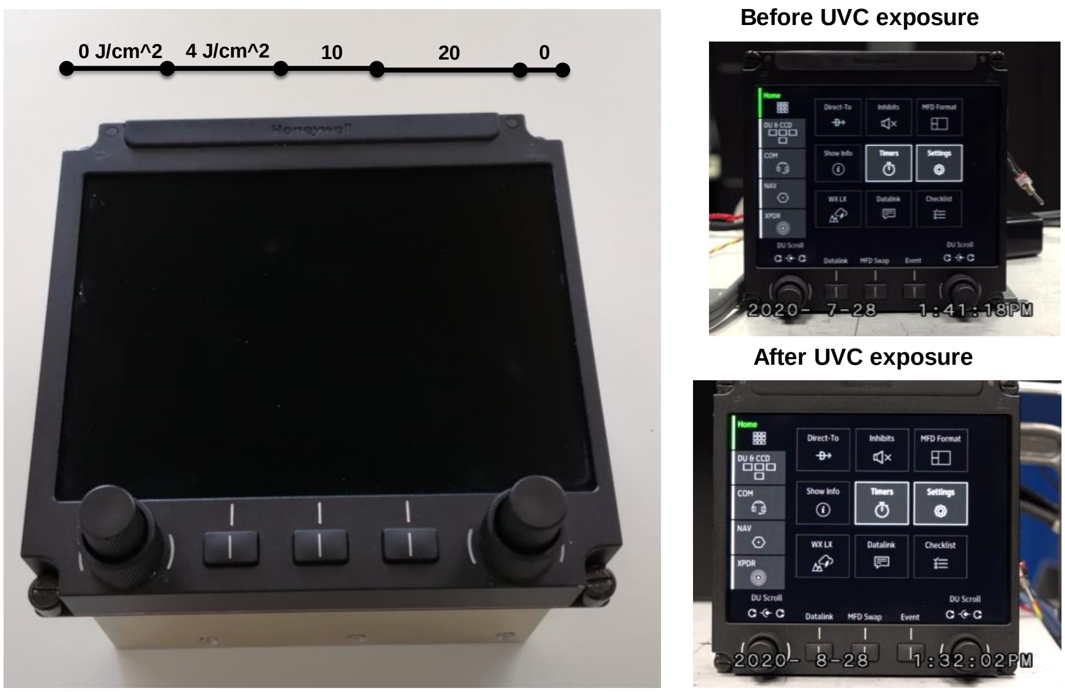


Figure 25: Honeywell TSC 2.0 cockpit touchscreen display. Left: UV progressive doses; Right: Before and after display.

Table 19: Colorimetric analysis of display before and after UV exposure

	Center Measurement (0,0) (H,V)					
	Post UV Exposure			Pre UV-Exposure		
	L	u'	v'	L	u'	v'
White Full Bright	183.2	0.2097	0.4905	182.2	0.2087	0.492
Green	39.03	0.1336	0.5734	40.11	0.1324	0.5734
Blue	8.275	0.1438	0.2859	8.672	0.1459	0.2849

Honeywell cockpit instrument panels

Summary: Assorted small instrument panels used in the cockpit were exposed to UV using the progressive approach. No change in appearance was noted with increasing UV exposure, and the buttons appeared to remain functional.

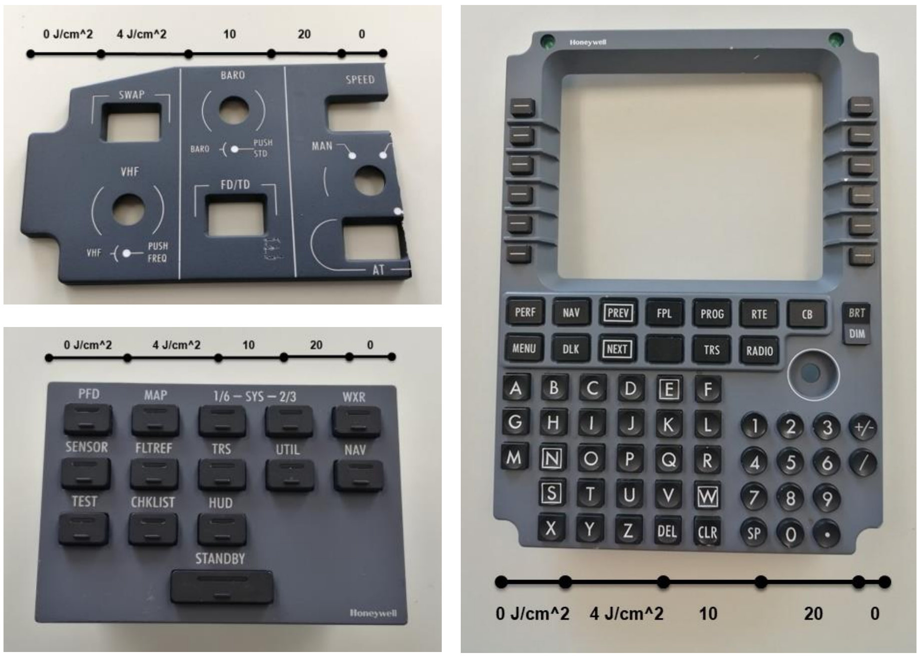


Figure 26: Honeywell TSC 2.0 cockpit touchscreen display.
Left: UV progressive doses; Right: Before and after display.

Appendix 1: Additional Leather Test
Leather seat coverings

The leather seat coverings were cut into 3 x 12" sections for flame retardancy studies. Three control samples received no UV-C exposure, while other sections received doses of 185 and 365 J/cm^2. Using a single treatment dose of 13 mJ/cm^2 as measured for the most exposed section of a typical airline seat (aisle headrest, 30 rows/min exposure speed, 2 exposures/treatment), a cumulative dose of 185 J/cm^2 would correspond to 14,230 treatments (39 years at 1 treatment/day). Leather has been, in our experience, one of the most resistant materials to UV-C light, and we observed no color difference between the control and exposed samples in Figure 27. The samples were sent to AeroBlaze for the FAA vertical burn measurement, and, as the results in Table 20 show, there was no significant effect of UV-C light on flame retardancy.

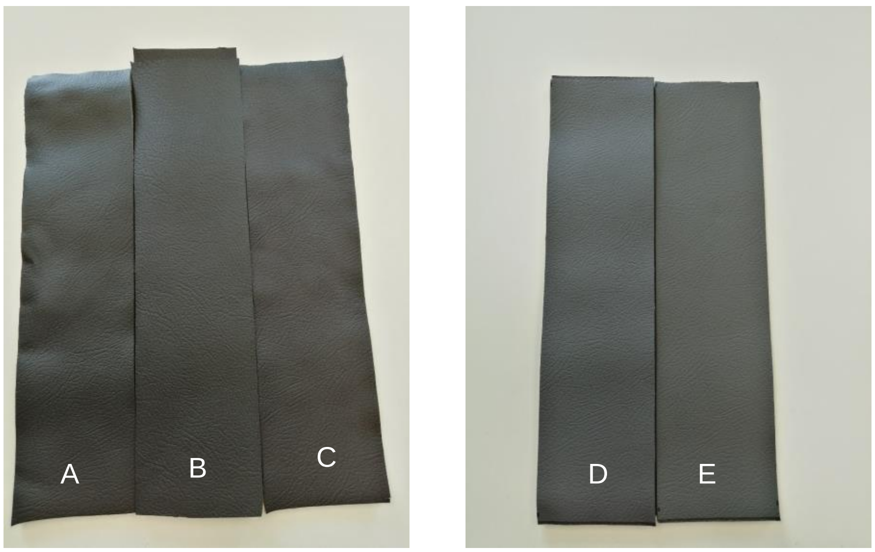


Figure 27: Leather Seat Coverings. Group 1: A No UV-C exposure, B 185 J/cm^2, C 365 J/cm^2; Group 2: D No UV-C exposure, E 365 J/cm^2

Table 20: Flame retardancy results for leather seat coverings

Group	Exposure (J/cm^2)	Flame Time (sec)	Drip Time (sec)	Burn Length (in)
Leather 1	0	1.95	0	1.75
	365	4.7	0	1.70
Leather 2	0	0	0	2.5
	185	4.1	0	1.9
	365	1.6	0	1.5
	Success Criteria:	**Must not exceed 15 sec.**	**Must not exceed 5 sec.**	**Must not exceed 8 in.**

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Leather Armrest

The leather armrest provided appears to be the same leather as that used for the seat covering. It was used for a progressive color test by masking the sample with tape, and progressively unmasking it after incremental exposures to UV-C light. Each incremental dose was 19 J/cm^2. Using our measured UV-C dose of 9.4 mJ/cm^2 (one treatment equals two exposures at 30 rows/min treatment speed), a cumulative dose of 19 J/cm^2 would correspond to 2021 treatments (5.5 years at 1 treatment/day). Figure 28 below shows the complete armrest, which received 10 incremental doses, and an expanded view on the upper portion spanning doses between 0 and 76 J/cm^2. No detectable change in color is apparent.

Figure 28: Leather armrest after progressive UV-C exposure. Photo on right is close up of the upper portion of the left photo, with UV-C dose marked.

Leather Headrest

A leather headrest was similarly exposed using the progressive approach at Dimer LLC. The Figure below shows this sample, with the exposure “stripes” indicated by the applied tape. For this sample the increment between doses was 38 J/cm^2. As with the seat covering and the armrest, we do not see any change in appearance for this material.

Figure 29: Leather armrest after progressive UV-C exposure. Photo on right is close up of the upper portion of the left photo, with UV-C dose marked.

Appendix 2: Other Test Results: Gerber Technology Colored Labels, Ultrafabrics Synthetic Leathers, Schroth Seatbelts

Gerber Technology Colored Labels

Colored labels from Gerber Technology (Tolland, CT USA) were exposed to UV-C by Dimer to test effect on appearance and color.

Gerber supplied a 6”x 4.5” LexEdge FR65-10mil label for testing. The sample had a white background with black, red, yellow and blue colors. A strip of white foam tape was placed across the sample to partially cover each color (see photo, Figure 30).

Figure 30. Colored Label Sample, Before Exposure

The sample was then exposed to a total dose of 48.5 J/cm^2, corresponding to more than twenty years of use (with a daily cleaning) for most locations (refer to Table 1 to determine years of exposure for labels in specific areas of the aircraft cabin).

At the conclusion of the test, we did not detect any visual or tactical differences between the exposed and unexposed portions of the label (Figure 31).

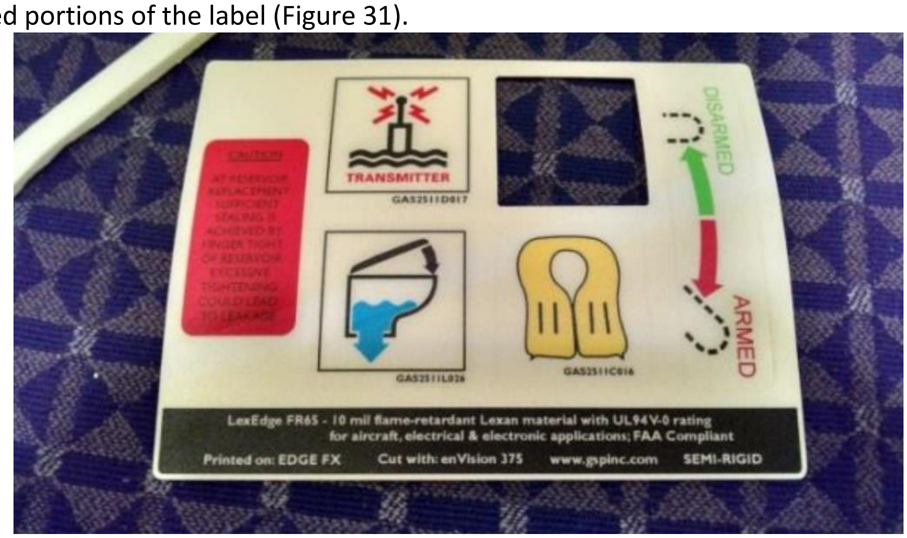

Figure 31. Colored Label Sample, After Exposure

Ultrafabrics Synthetic Leathers

Ultrafabrics (Uf) provided a set of fourteen 12” x 12” samples of aircraft polyurethane synthetic leathers of various colors. These were tested at Dimer LLC with a progressive exposure protocol that exposed each band at multiples of 4 J/cm^2:

Band 0: 0 J/ J/cm^2, original, no exposure
Band 1: 4 J/cm^2
Band 2: 8 J/cm^2
…
Band 10: 40 J/cm^2

After the exposure, all fourteen Ultrafabrics samples tested revealed no detectable color change at any exposure levels. For all samples tested, the tactile “feel” as well as bending properties appeared unchanged, with no cracking visible under magnification. No formal material testing pre and post exposure was performed. The following figures show the samples tested with the progressive exposure bands marked to the right hand side of each picture (0: no exposure, 10: 40 J/cm^2, with 4 J/cm^2 increment at each progressive band).

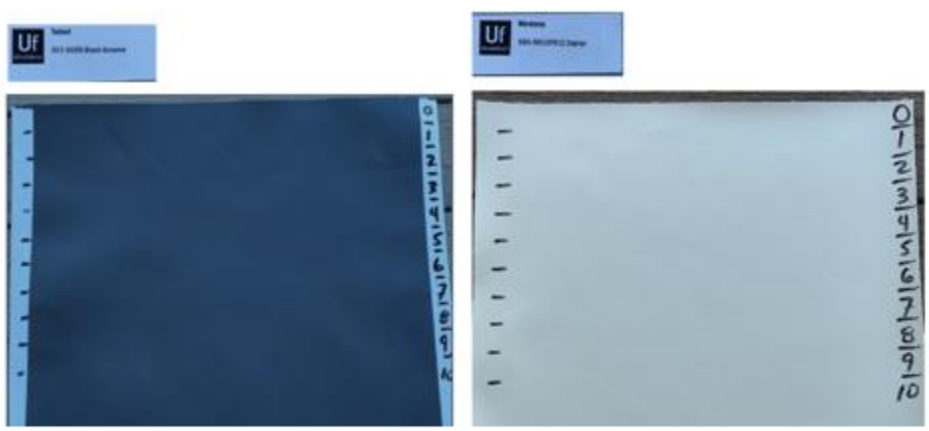

Figure 32. Ultrafabrics Samples, Progressive Exposure to 40 J/cm^2

Figure 33. Ultrafabrics Samples, Progressive Exposure to 40 J/cm^2

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Two additional colors samples were tested for progressive exposure, and effect on flame retardancy and fabric strength. As indicated in Tables 21 and 22, UV-C exposure testing resulted in no significant effect on tensile strength, tear strength, or fire retardancy of this synthetic leather fabric. It also showed no visible effect of UV-C on color or appearance.

Table 21: Strength Test Results

Ultrafabrics 492-6022FR12 Hydra

Exposure J/cm^2	Tensile Strength Warp (lbf)	Tensile Strength Weft (lbf)	Trapezoid Tear Strength Warp (lbf)	Trapezoid Tear Strength Weft (lbf)
0	175.9	88.2	30.8	25.8
60	179.1	96.5	30.6	23.7
151	176.6	89.4	31.6	24.1

Ultrafabrics 590-5012FR12 Zephyr

Exposure J/cm^2	Tensile Strength Warp (lbf)	Tensile Strength Weft (lbf)	Trapezoid Tear Strength Warp (lbf)	Trapezoid Tear Strength Weft (lbf)
0	178.5	79.9	34.0	20.7
60	184.1	75.2	34.9	20.4
151	185.3	76.8	34.1	20.8

Table 22: Flame Retardancy Test Results (Ultrafabrics 492-6022FR12 Hydra)

Exposure (J/cm^2)	Flame Time (sec)	Drip Time (sec)	Burn Length (in)
0	0	0	2.2
27	0	0	2.3
54	0	0	2.6
134	0	0	2.7
269	0	0	2.6
Success Criteria:	**Must not exceed 15 sec.**	**Must not exceed 5 sec.**	**Must not exceed 8 in.**

Figure 34. Ultrafabrics 492-6022FR12 Hydra (Gray), Progressive Exposure

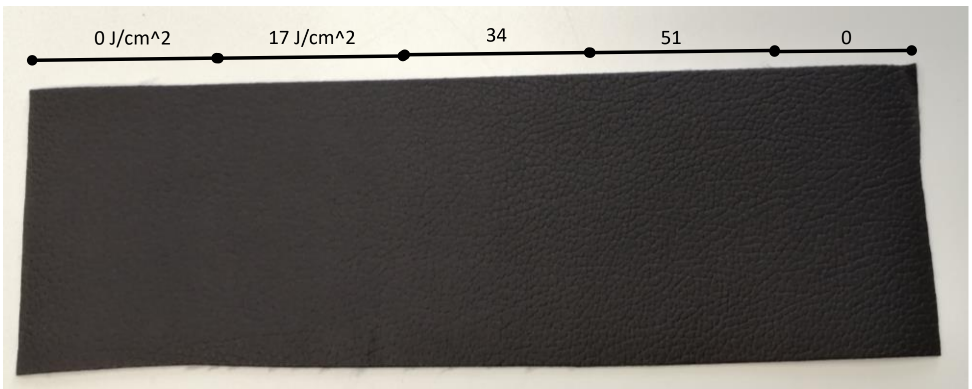

Figure 35. Ultrafabrics 590-5012FR12 Zephyr (Black), Progressive Exposure

Schroth Seatbelts

Schroth seatbelts are commonly used on a large variety of commercial air transport aircraft and business aviation aircraft.

Figure 36. Airlines with Schroth Seatbelts (list provided by Schroth)

Schroth 2-Point Lap Belts (P/N: 19-3500B0B-D7) were exposed by Dimer to UV-C and the returned to the manufacturer for additional breaking strength and flame resistance testing, as listed in the following table.

Table 23: 2 Point Lap Belt Test Matrix & UV-C Exposure Levels

Test No.	Sample Identific.	DOM Serial No.	Serial No.	UV-C Simulated Duration	UV-C Exposure	Tests
001	72	06/20	ABL757-1-003	0.5 years	2250 $[\frac{mJ}{cm^2}]$	Breaking Strength in accordance to SAE AS 8043 para. 9.2
002	71	06/20	ABL757-1-001			
003	73	06/20	ABL757-1-002			
004	74	06/20	ABL757-1-006	1 year	4500 $[\frac{mJ}{cm^2}]$	
005	75	06/20	ABL757-1-005			
006	76	06/20	ABL757-1-004			
007	77	06/20	ABL757-1-009	2 years	9000 $[\frac{mJ}{cm^2}]$	
008	78	06/20	ABL757-1-008			
009	79	06/20	ABL757-1-007			
010	710	06/20	ABL757-1-010	5 years	22,500 $[\frac{mJ}{cm^2}]$	
011	711	06/20	ABL757-1-011			
012	712	06/20	ABL757-1-012			
013	713	06/20	ABL757-1-015	10 years	45,000 $[\frac{mJ}{cm^2}]$	
014	714	06/20	ABL757-1-014			
015	715	06/20	ABL757-1-013			
016	N/A	06/20	ABL753-1-008	2 years	9000 $[\frac{mJ}{cm^2}]$	Flammability Resistance in accordance to SAE AS 8043 para. 10
017	N/A	06/20	ABL753-1-009			
018	N/A	06/20	ABL753-1-007			
019	N/A	06/20	ABL753-1-014	10 years	45,000 $[\frac{mJ}{cm^2}]$	
020	N/A	06/20	ABL753-1-015			
021	N/A	06/20	ABL753-1-013			

No effect was observed on material appearance or color.

Breaking strength was assessed using the method described in SAE AS 8043 para 9.2. Three tests were conducted for each UV-C exposure level. Results are shown in the following table: all tests exceed the minimum required strength and no statistically significant dependency on UV-C exposure was observed.

Table 24: 2 Point Lap Belt Test Matrix & UV-C Exposure Levels

Test No.	Exposure [years]	Average Breaking Strength [kN]	Pass/Fail	Limits
001	0.5	28.052	Pass	Breaking Strength of not less than 26.6 kN is in accordance to SAE AS 8043 para. 9.2
002				
003				
004	1	26.826	Pass	
005				
006				
007	2	27.406	Pass	
008				
009				
010	5	27.845	Pass	
011				
012				
013	10	27.692	Pass	
014				
015				

Flame resistance was tested in accordance to SAE AS 8043 Para. 10 on samples with simulated UV-C exposure of 2 years and 10 years (3 samples each). Per specification, the flame is applied to the specimen for 15 seconds and then removed. The time is recorded when the marking of the timing zone is reached by the flames. If the flames do not reach the marking “end timing zone” within 4 minutes, the flames are extinguished, and the burning length is recorded (Figure 37). Per AS 8043 para. 3.10, for parts tested in accordance with the procedure of Section 10, where the specimen is tested horizontally, the average burn rate shall not exceed 63.5 mm per minute. A slightly decrease of the flammability resistance was determined comparing the flammability results of the samples simulated UV-C exposure of 2 years and 10 years, however all test samples passed the required values.

Results are shown in the following tables for 9 J/cm^2 and 45 9 J/cm^2 UV-C exposures.

Table 25: Schroth Seat Belt Flame Resistance – 9 J/cm^2 Exposure

Sample	Burning Length [mm]	Burning Time [s]	Burning rate $[\frac{mm}{min}]$	Pass/Fail
016	0	0	Self extinguished	Pass
017	0	0	Self extinguished	Pass
018	33	60	33	Pass
Ø			11	

Table 26: Schroth Seat Belt Flame Resistance – 45 J/cm² Exposure

Sample	Burning Length [mm]	Burning Time [s]	Burning rate $[\frac{mm}{min}]$	Pass/Fail
019	44	60	44	Pass
020	31	60	31	Pass
021	22	60	22	Pass
Ø			32.3	

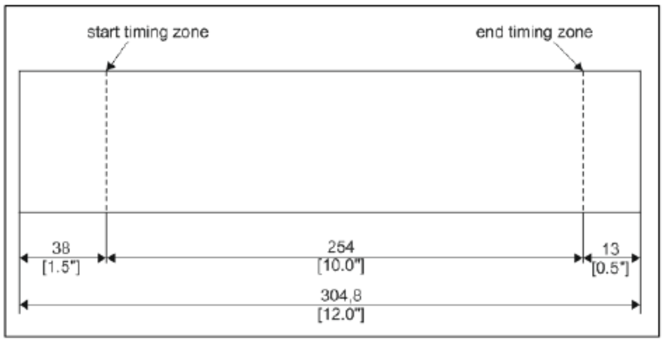

Figure 37. Seat Belt Flame Resistance, Test Set-up